A Conceptual Model for Quality 4.0 Deployment in U.S. Based Manufacturing Firms

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A CONCEPTUAL MODEL FOR QUALITY 4.0 DEPLOYMENT IN US BASED MANUFACTURING FIRMS

by

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A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Industrial Engineering and Management Systems
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Spring Term
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Major Professor: Ahmad K. Elshennawy
ABSTRACT

Manufacturing is currently undergoing a fourth industrial revolution, referred to as Industry 4.0, enabled by digital technologies and advances in our ability to collect and use data. Quality 4.0 is the application of Industry 4.0 to enhance the quality function within an organization. Quality practitioners are uniquely positioned within organizations and already possess data application skillsets. Despite a perception that Quality 4.0 will be critical to future success shared by a majority of industry, most companies have not attempted to implement Quality 4.0 strategy, and those that have report very low rates of success. The goal of this study was to understand the challenges and key factors behind implementation of a Quality 4.0 system and develop a model for implementation, highlighting those key factors. The model was developed through literature review, case study analysis, and expert interviews. The model indicated that four main constructs exist in Quality 4.0 deployment, digital strategy, enabling factors, methodologies, and technology. A top-level strategy should be developed to address key technology development themes as well as nontechnical business process themes. Strategy should then be executed in the domain of enabling factors and methodologies with a clear technology application serving as the output. A successful Quality 4.0 implementation will use the technology application to drive tangible quality improvement activities which add value to the business.
ACKNOWLEDGMENTS

I am incredibly grateful to have Dr. Ahmad Elshennawy as my PhD advisor. I have nurtured a passion for quality which has been able to flourish under his guidance, and I am tremendously blessed to have been able to learn from him. Dr. E, I appreciate you supporting my career goals while developing my research ideas, and for always working with me and accommodating my busy schedule balancing career and PhD. I appreciate your guidance and look forward to our future conversations and collaborations.

I also want to thank my committee members, Dr. Luis Rabelo, Dr. Gamal Weheba, and Dr. Thomas O’Neal. I was utterly stuck on how to execute a survey with a legitimate sample size when the sample space doesn’t yet exist. Your challenging questions, insights and experience, and guidance on shaping my study has been very helpful, thank you all.

I am also very grateful to everyone who participated in this research. All of my interview candidates developed expertise over years of dedicated careers and their knowledge is what made this research possible in addition to taking the time to sit down and share that knowledge with me so a special appreciation to all of them. Dr. Hayder Zghair, Chris Koch, Kevin Donaldson, Dr. Alaa Elwany, Seshu Akella, Dr. Tahany El-Wardany, Rick Burke, and Dr. Elizabeth Cudney, without you this research doesn’t exist. I hope that the model we developed manages to serve you all in your careers.

For helping me identify these experts I would like to show my appreciation for Dr. Gamal Weheba and through him Emily Orwaru at the Smart Factory @ Wichita, Dr. Ahmad Elshennawy,
and Dr. Hayder Zghair. I wouldn’t have known where to start in looking for people with this specific knowledge, so finding them for me was tremendous.

I would like to thank my family for challenging me and helping me grow into who I am, without all of that I would never have been able to complete this dissertation. More than anyone, my grandparents helped me learn what I was capable of through teaching me work ethic and being supportive enough for me to learn to trust myself and take on bold challenges. My parents for showing me the value of pursuing education, and demonstrating the tenacity required to balance schooling with everything life demands. My siblings for listening to my stresses and challenges during this process. A special thanks to Danielle for being my most reliable dog sitter and to Tamara for listening and bringing the perspective I’ve needed during the dissertation process.

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LIST OF ACRONYMS

5g  5\textsuperscript{th} Generation Wireless Communication Systems
AI  Artificial Intelligence
ANOVA Analysis of Variance
ANSI American National Standards Institute
ASQ American Society for Quality
AR Augmented Reality
BCG Boston Consulting Group
BI Business Intelligence
BoK Body of Knowledge
CPS Cyber-Physical Systems
DGQ Deutsche Gesellschaft für Qualität
DL Deep Learning
ERP Enterprise Resource Planning
IaaS Infrastructure as a Service
IIoT Industrial Internet of Things
IoT Internet of Things
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>IPv6</td>
<td>Internet Protocol Version 6</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>LiDAR</td>
<td>Light Detection and Ranging</td>
</tr>
<tr>
<td>LSS</td>
<td>Lean Six Sigma</td>
</tr>
<tr>
<td>ML</td>
<td>Machine Learning</td>
</tr>
<tr>
<td>MRP</td>
<td>Manufacturing Resource Planning</td>
</tr>
<tr>
<td>NN</td>
<td>Neural Networks</td>
</tr>
<tr>
<td>PaaS</td>
<td>Platform as a Service</td>
</tr>
<tr>
<td>PCA</td>
<td>Principal Component Analysis</td>
</tr>
<tr>
<td>QMS</td>
<td>Quality Management System</td>
</tr>
<tr>
<td>RFID</td>
<td>Radio-Frequency Identification</td>
</tr>
<tr>
<td>SaaS</td>
<td>Software as a Service</td>
</tr>
<tr>
<td>SME</td>
<td>Small and Medium Sized Enterprise</td>
</tr>
<tr>
<td>SPC</td>
<td>Statistical Process Control</td>
</tr>
<tr>
<td>TPM</td>
<td>Total Productive Maintenance</td>
</tr>
<tr>
<td>TQM</td>
<td>Total Quality Management</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>VoC</td>
<td>Voice of the Customer</td>
</tr>
<tr>
<td>VSM</td>
<td>Value Stream Mapping</td>
</tr>
<tr>
<td>WIP</td>
<td>Work in Progress</td>
</tr>
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CHAPTER ONE: INTRODUCTION

1.1 Overview

1.1.1 Industry 4.0

Global manufacturing is in the midst of the fourth industrial revolution. This fourth industrial revolution is driven by the digital technologies of the 21st century, and is specifically defined by access to the internet, advancements in sensor technology and availability, and also by advanced analytics capabilities such as artificial intelligence (AI) and machine learning (ML) (Schwab, 2017, p. 7). This evolution is often characterized as a digital transformation for an organization and it has also been called Industry 4.0 or Smart Manufacturing (Savastano, Amendola, Bellini, & D’Ascenzo, 2019). The trend towards transforming business operations is well established in industry, in a 2018 survey over 80% of responding companies had already invested in digital transformation strategies (De la Boutetière, Montagner, & Reich, 2018, p. 2). In this text the term Industry 4.0 will be used to describe all digital transformation and smart manufacturing technologies.

1.1.2 Quality 4.0

Quality 4.0 is the application of Industry 4.0 technologies to improve the flow and use of data to allow organizations to better utilize resources, both people and equipment, in the pursuit of improved performance (N. M. Radziwill, 2020, p. 19). New technologies do not change the definition of quality or the quality goals of an organization, in a Quality 4.0 environment quality departments utilize Industry 4.0 technologies to achieve organizational quality goals. Quality 4.0 may be used to enhance an organization’s ability to improve quality. Quality 4.0 is recognized as
a critical element to success in manufacturing, according to a 2019 survey 74% of quality leaders recognize Quality 4.0 efforts as being either very important or extremely important in the manufacturing stage of the value chain (Daniel Kupper, 2019, p. 5). The future of quality management in manufacturing will be heavily influenced by new technologies and understanding the role they will play. Successful implementation and application of these technologies will be critical success factors in manufacturing quality moving forward.

1.1.3 Current State of Industry

While a majority of companies surveyed see Quality 4.0 as being on the five year horizon, only 16% of such companies have initiated any effort towards implementation (Daniel Kupper, 2019, p. 7). Interestingly, Industry 4.0 and the philosophy of Total Quality Management (TQM) have significant overlap in their application (Babatunde, 2020). This overlap may provide opportunities for successful organization wide Industry 4.0 implementations to begin with more focused Quality 4.0 implementations. Industry quality leaders may have an advantage when implementing an Industry 4.0 strategy.

Despite many companies attempting to implement Industry 4.0 technologies, success rates are currently low. As recently as 2018 only 16% of these implementations was reported as successful (De la Boutetière et al., 2018, p. 2). Changing the way in which an organization utilizes technology is a challenging prospect. While the success of Industry 4.0 implementation is not high today, there exists significant opportunity to develop a path forward for manufacturing organizations.
1.2 Research Idea

Quality 4.0 applications have the potential to greatly improve performance for many organizations. Quality has been a focus in manufacturing since the early 1900s with developments such as Ford creating “total quality practices”, Western Electric developing its quality department, and methods such as statistical process control (SPC) being developed (Evans & Lindsay, 2013, p. 12). In both 2017 and 2020, 84% of business and quality leaders agreed that quality directly impacted their organizations ability to compete (McKendrick, 2020, p. 4), so the focus on quality is still reflected today. Quality 4.0 presents an opportunity for the next advancement in quality focus.

Searching for publications on Quality 4.0 provides very little literature in the form of established methods and case studies. There is a significant gap in existing literature and bridging the research gaps to develop the body of knowledge around Quality 4.0 for future researchers and practitioners is a meaningful and valuable endeavor. Researching factors required for organizations to succeed with Quality 4.0, as well as key barriers, is important research for the future of quality management.

1.3 Research Problem Statement

The low success rate of Industry 4.0 implementations indicates an opportunity to identify key factors for successful implementation. Currently there is a lack of sufficient case study data by which to identify these key factors. Expert judgement highlights company strategy, management, expertise, management structure, data collection, IT technologies, leadership, communication, and organizational skills are all key factors to small and mid-size companies (Moeuf et al., 2020). Systematic literature review has identified factors for success such as strategy
alignment, leadership, employee engagement, and change management (Sony & Naik, 2020). These works are developed through literature review and expert judgement. Boston Consulting Group partnered with the American Society for Quality and the Deutsche Gesellschaft für Qualität (DGQ) on a survey and developed a similar list focused on the implementation of Quality 4.0, encompassing strategy, skills, culture, and leadership (Daniel Kupper, 2019).

The literature indicates that technology skills alone may not be sufficient for successful implementation of these changes with factors such as leadership, lean management, and planning may also be significant to the successful implementation of Quality 4.0 (Pozzi, Rossi, & Secchi, 2021). The presence of leadership, culture, and strategy as significant factors mirrors industry quality standards, such as the Malcom Baldrige Award (National Institute of Standards and Technology, 2021). The current body of knowledge supporting Quality 4.0 is limited by the available research and case study publication on the topic (Raut, Gotmare, Narkhede, Govindarajan, & Bokade). More research is needed in areas such as implementation, impact of leadership, and organizational culture (Sony, Antony, & Douglas, 2020).

Research on Quality 4.0 is limited in part due to how new the topic is. The term “Quality 4.0” originated from LNS Research (Johnson, 2019). LNS published their initial guide to Quality 4.0 in 2017 (Jacob, 2017a). Due to the relatively short time during which research has been pursued there are many gaps in the BoK today.

There is a lack of clarity in the literature on how to successfully deploy a Quality 4.0 system, which presents a research opportunity to develop a model for successful Quality 4.0 implementation.
1.4 Research Question

To develop an adequate model for Quality 4.0 deployment it is necessary to identify what success looks like and how it has been achieved so far. The following research questions are presented in this study:

- What key factors are significant for manufacturing firms in achieving success with Quality 4.0 implementation?
  - What key factors are influencing Quality 4.0 outcomes in manufacturing firms already attempting any level of Quality 4.0?

1.5 Relevance of the Research

This study serves the purpose of developing the BoK of Quality 4.0 for both academia and industry. The academic goal of this study is to provide a path forward for future research into Quality 4.0 success, laying a potential research foundation for further development of roadmaps for implementation and prioritization of resources and effort for companies. The industrial goal of this study is to provide actionable focus areas for companies to use as a starting point for Quality 4.0 implementation, as well as insight into how a Quality 4.0 strategy may provide a tangible structure to follow to achieve Industry 4.0 aspirations. To achieve this a conceptual model for Quality 4.0 deployment will be developed.

1.6 Conceptual Model and Constructs

This research examines the existing knowledge of Quality 4.0 to the extent which it is available to model key factors for success. Understanding what success looks like in the current
state of the art as well as identifying enabling factors as well as barriers is critical. The conceptual model highlights the following constructs as enablers in Quality 4.0 deployment:

- Strategy
- Culture
- Organizational Resources
- Management Tools

### 1.7 High Level Research Methodology

In order to develop an adequate conceptual model that captures the full breadth of the current BoK of Quality 4.0 expert input is needed. The conceptual model was initially developed through a systematic literature review to capture constructs available through academic and industry publications. The model is then refined based on expert testimony, achieved through semi-structured interviews with Quality 4.0 experts from industry and academia.

The literature review will follow a PRISMA protocol to identify the key constructs from the available body of publication. Case studies will also be analyzed to develop a benchmark of what successful Quality 4.0 deployment looks like today where they are available.

To allow for flexibility in expert testimony, semi-standardized interview methods will be employed, and qualitative data analysis methods will be used to capture relevant themes (Ryan, Coughlan, & Cronin, 2009). These themes and their prevalence will be utilized to revise the initial conceptual model.

The key steps in the research methodology are as follows:
1. Perform a systematic literature review in order to understand the depth and breadth of the existing BoK including:
   a. Quality 4.0 technologies and case studies
   b. Industry 4.0 technologies
   c. Quality success factors
   d. Relationships between Quality 4.0 and legacy methods

2. Develop an initial conceptual model for successful Quality 4.0 implementation from the initial literature review.
   a. Develop initial interview based on the conceptual model.
   b. Baseline success factors from existing case studies to define successful Quality 4.0. The case studies should be analyzed in the context of the existing framework.

3. Execute expert interviews and revise the conceptual model.

4. Summarize findings and draw conclusions from the analysis.

5. Propose final conceptual model for Quality 4.0 deployment in manufacturing.

1.8 Research Limitations

This research has two significant limitations. First, expert interview is rooted in qualitative analysis over quantitative. This leaves the opportunity for subjectivity to influence the output of the study. In this case the relatively small BoK presents a risk of subjectivity in general. The second limitation of this study is the lack of available case study data with which to baseline what Quality 4.0 success looks like. This work is pioneering in nature in its goal of developing a model for success with Quality 4.0 implementation and as such it is important to recognize limitations.
and utilize the results of this study as a foundation for further study. The intent is to grow the field with the long-term goal of thoroughly understanding Quality 4.0 success.
CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The available literature is useful in developing the preliminary model for Quality 4.0 success. The systematic literature review process is used to identify key themes and build specific constructs into a preliminary conceptual model. There are three high level constructs highlighted by the literature review:

1. Technology
2. Methodology
3. Implementation Enablers

2.2 Systematic Literature Review Method

In order to be exhaustive, the review of the literature should be broad enough to cover digital transformation topics in general related to both Quality 4.0, including Industry 4.0 relevant technologies. The systematic literature review process follows the PRISMA checklist with the goal of identifying, screening, determining eligibility, and finally including papers only relevant to this work (Moher, Liberati, Tetzlaff, Altman, & Group, 2009).

The goal of this literature review is to explore the current state of Quality 4.0 in manufacturing. It includes review of the current state of Industry 4.0 technologies, how Industry 4.0 technologies are applied to quality in Quality 4.0, overlap between Quality 4.0 and other methods, success factors for implementation of Quality 4.0, and Quality 4.0 case studies. To be eligible a study must have appeared in an academic journal and be published in English. Journal searches were performed in academic databases including Compendex, IEEE Xplore, and Web of
Science. The search strategy included restricting searches to journal articles only, restricting searches to everywhere except full text, restricting search results to only articles with full article access, and setting the language to only English. Keywords and search results are summarized in Table 1:

<table>
<thead>
<tr>
<th>Database</th>
<th>Keywords</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web of Science</td>
<td>Quality 4.0, Industry 4.0, TQM and Quality 4.0, Quality 4.0 Success Factors, Digital Transformation, Industry 4.0 Technologies, Manufacturing Quality Success Factors, Quality 4.0 Case Study, Quality 4.0 Implementation, Industry 4.0 Implementation, Smart Factory, Smart Factory Success Factors, Manufacturing Digital Transformation</td>
<td>219</td>
</tr>
<tr>
<td>Compendex</td>
<td></td>
<td>349</td>
</tr>
<tr>
<td>IEEE Xplore</td>
<td></td>
<td>154</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>722</td>
</tr>
</tbody>
</table>

The literature review results are further detailed in figure 2, the PRISMA protocol flow diagram:
Figure 1 - PRISMA Diagram
Technology and technical competency are major themes in the available literature. Technology improvements are foundational to an industrial revolution. Industry 4.0 has been described as feasible due to the blend between improved information technologies and advances in operational technology applied on shop floors (Bloem et al., 2014). Technology has been addressed by multiple authors with varying frameworks. Industry 4.0 technology applications are comprised of physical components which serve to collect data, network components which serve to connect data sources, and a data application layer in which automation and analysis occurs (B. Chen et al., 2017). Raut et al identified five key technologies: radio-frequency identification (RFID), internet of things (IoT), cloud computing, big data analytics, and blockchain (Raut et al., 2020). Various frameworks and technologies have been explored as centerpieces to Industry 4.0, and the literature lends itself to the following three core technology constructs:

1. Data Collection and Management
2. Data Analytics
3. Automation

Many challenges have been identified in implementation of Industry 4.0 technologies, such as resistance to change, lack of capital investment, and lack of employee skill (Bajic, Rikalovic, Suzic, & Piuri, 2021). The literature on barriers and enablers provides a baseline for the development of the initial conceptual model. Additionally, the literature overlaps between Industry 4.0 and sustainability, the link between Industry 4.0 and Lean Manufacturing, and the overlap with Quality 4.0 and TQM are explored.
2.3 Industry 4.0 Technologies

2.3.1 Data Management

The technologies presented in Industry 4.0 literature can be fit into the categories of data collection, data analytics, and automation. All of the technologies are only as viable as the data which supports them. Successful applications require there must be sufficient volume of data to feed the tools that use it, the data must move with sufficient velocity to support real time or near real time applications, and it must appear in the right formats to be usable, which can be described as the correct variety of data (Gaurav, Yadav, Kaliyar, & Goyal, 2018). Additionally a fourth V, veracity, is often used to describe the necessary quality and consistency of data to feed Industry 4.0 technologies (Saha & Srivastava, 2014).

2.3.1.1 Data Security

The connections and networks which are leveraged to connect data through a Quality 4.0 system are also vulnerable to attack from their own connection to the internet (Mullet, Sondi, & Ramat, 2021). This threat has led to growth in the education sector for cyber security, with companies also investing in cyber security skill development (Lewis, 2021). Guidelines and technologies are being applied to the issue of cyber security, with blockchain being a prominent Industry 4.0 technology utilized to protect data (Fernández-Caramés & Fraga-Lamas, 2019).

2.3.1.2 Data Connectivity

A key development in data connectivity has been internet protocol version 6 (IPv6) which enables the use of enough unique addresses for all of the new devices becoming connected (Nicole M Radziwill, 2018, p. 4). Another technological advance is 5th generation wireless communication systems (5g). In order to achieve data volume and velocity for real time analytics applications,
wired connections have often been needed, however this is not optimal for many applications such as with mobile robots or autonomous drones. 5G has enabled wireless applications for many of these technologies (Gundall et al., 2021). Data connectivity is necessary for handling the velocity and volume needs of managing data in an Industry 4.0 application, and it is necessary to have satisfactory data connectivity and information technology in place before undertaking an Industry 4.0 deployment (Arcidiacono, Ancarani, Mauro, & Schupp, 2019).

2.3.2 Data Collection

The technologies empowering data collection for Industry 4.0 are a central development in the fourth industrial revolution. The literature references IoT, RFID, advanced sensors (Raut et al., 2020) (B. Chen et al., 2017), and the industrial internet of things (IIoT) which is similar to IoT (Abuhasel & Khan, 2020). As IoT is usually used to describe the principle of connected devices on a consumer level and IIoT is applied to an industrial scale, IIoT will be utilized in this paper for describing such factory devices (Jaidka, Sharma, & Singh, 2020). In the context of Quality 4.0 data collection extends beyond the factory floor to harvest the voice of the customer (VoC) as sensors and data collection built into consumer goods and software continually utilize data on product usage (Freeman & Radziwill, 2018).

2.3.2.1 RFID

RFID is a technology that is deployed to wirelessly track or trace the location of an RFID tag. It is often utilized in manufacturing firms to improve operational efficiency, improve visibility, and manage inventory among other benefits (Bhattacharya, Chu, & Mullen, 2008). RFID systems enable machine to machine communication which can result in real time inventory
location tracking, compiled within a manufacturing resource planning (MRP) system (C. Wang, Chen, Soliman, & Zhu, 2018).

2.3.2.2 Advanced Sensors

Sensor technology takes on many forms. Three ways in which sensors may play a role in manufacturing advancements include (Indri, Lachello, Lazzero, Sibona, & Trapani, 2019):

1. Sensors are utilized to support automation working concurrently with human operators
2. Sensors are deployed to monitor human operations and assist in error prevention
3. Sensors are utilized with a fleet of automation to automate entire production areas

These proposals involve using sensors to detect several data points, such as position or images. Sensors can be utilized to track data points such as temperature, vibration, or deformation (Borghetti, Cantu, Sardini, & Serpelloni, 2020). Sensors are critical for most data collection applications, and advances in sensor technology have reduced the barrier to their use by lowering costs and implementation complexity in recent years (Kalsoon, Ramzan, Ahmed, & Ur-Rehman, 2020).

2.3.2.3 IIoT

The IIoT is a concept in which devices in a manufacturing area are equipped with an array of sensors in order to monitor performance while connected to a network in order to aggregate data (Abuhasel & Khan, 2020). With an IIoT application the integration of the system provides value beyond singular sensor applications, as the breadth of data collected can be utilized for much deeper comprehensive analytics if integrated correctly. Integrating the system is critical to develop a relevant data pipeline which can support business success (Illa & Padhi, 2018). An IIoT system
has the data capacity to empower large scale analytics algorithms, such as ML models, which can detect manufacturing faults, empowering quality improvement of the system (Marino et al., 2021).

2.3.3 Data Analytics

Data Analytics describes how data is used after it is collected and connected. While data itself is at the heart of the emergence of new practices in industry, analytics is what makes data useful and actionable.

“Data is not equal to value. To create value with data needs analytics. Analytics facilitates data reduction to actionable items thus creates value.” (D. Wang, 2018)

Data analytics methodologies range from simple and advanced analytics to newer methods (D. Wang, 2018). The primary new drivers of being AI, ML, Deep Learning (DL), and Neural Networks (NN). All of these methods are enabled by advancements in data and computing technologies and the infrastructure needed for AI deployment must facilitate data flow and security (Peres et al., 2020). Other technological enablers for advancement of data analytics include edge computing, cloud computing, and advanced simulation techniques.

2.3.3.1 Simple and Advanced Analytics

One application of analytics is Business Intelligence (BI). BI applications involve developing performance measurement systems in order to monitor and improve business operations. Key elements to BI success in application include managerial alignment with IT, technical skills and competency, and a good infrastructure for data management (Bordeleau, Mosconi, & de Santa-Eulalia, 2020). Analyzing customer data, operations data, equipment data, and logistics data are all useful endeavors for improving manufacturing performance, however
data collection and infrastructure remains critical to all applications (Lazarova-Molnar, Mohamed, & Al-Jaroodi, 2019). Overall, traditional analysis of manufacturing processes may be more streamlined and effective when automated through Industry 4.0 technologies (Lopes & Martins, 2021).

2.3.3.2 AI

AI is an umbrella term which is often utilized to describe AI, ML, DL, and NN. The relationship between these techniques is that ML is a type of AI, NN is a type of ML algorithm, and DL is the application of NN with many layers to the algorithm (N. M. Radziwill, 2020, p. 53), this relationship is demonstrated in figure 3:

![Figure 2 - Relationship Between AI, ML, NN, and DL](image)

All of these analytical methods apply learning and cognition, while other statistical methods can fit into the data analysis sphere of Industry 4.0, but do not constitute AI applications.
“Any machine or program that demonstrates cognitive capabilities that are usually attributed to humans can be considered AI. Examples include vision, perception, interpreting spoken language, understanding the meaning of spoken language, reasoning, problem solving, creativity, insight, or pattern recognition.” (N. M. Radziwill, 2020, p. 56)

The data collection network is the device layer in an Industry 4.0 application, and further specifies that the devices on the floor must be embedded with communication technologies to facilitate the flow of data (Patel, Ali, & Sheth, 2018). Industry 4.0 type AI applications must have infrastructure to support real time data processing with high reliability, connectivity, and security while adding that the data itself must be of sufficient volume, velocity, and variety to be useful (Peres et al., 2020).

Much of the available literature details case study examples of how AI functions. A common application of AI is classification, which can be used to classify the status of a product or process, examples from the literature include:

- Ultrasonic sensor data used to classify if a solution is mixed or not (Bowler, Bakalis, & Watson, 2020)
- Vision systems to classify cylinders into defective or non-defective while categorizing defects (Villalba-Diez et al., 2019)
- Classification of a conveyor system to determine if the system is in need of maintenance or not based on time series data of multiple data points (Kiagala & Wang, 2020)
2.3.3.3 ML

ML is a specific type of AI which is common in the literature of industrial applications, and NN as well as DL are both specific types of ML. ML algorithms may be used to predict outcomes, learn series of actions, detect patterns, or classify inputs based on data (Angelopoulos et al., 2020). ML models must be fed training data in order to learn and insufficient training data is a potential roadblock to the implementation of useful ML (Rueden et al., 2021). Four types of training are described for ML models: supervised learning, unsupervised learning, deep learning, and reinforcement learning (Angelopoulos et al., 2020; Gong, Zhong, & Hu, 2019).

Applications for ML focus on pattern recognition in areas including images, audio inputs such as speech, text comprehension, and even gameplay (Rueden et al., 2021).

“It is evident that as the Industry 4.0 era is upon us, there exists an ever increasing adoption level of ML algorithms to satisfy the needs of different aspects of industrial settings. These include process monitoring and quality control, fault detection and diagnosis, as well as machine health and monitoring.” (Angelopoulos et al., 2020, p. 3)

ML based vision systems have been shown to identify components for automated material handling with accuracies in excess of 95% (T. Wang et al., 2018). Fault detection is another example of ML, with algorithms capable of detecting process faults through monitoring variables such as currents and vibrations in electromechanical systems exhibiting accuracies over 90% (Arellano-Espitia, Delgado-Prieto, Martinez-Viol, Saucedo-Dorantes, & Osornio-Rios, 2020).
2.3.3.4 Learning Types

One factor that differentiates ML from other analysis methods is the learning step of the process. ML learns through utilizing training data sets in order to learn patterns and relationships in the data, and one of the most significant challenges in training a ML model is having adequate data (Roh, Heo, & Whang, 2021). Not all training utilizes data the same way.

2.3.3.4.1 Supervised Learning

Supervised learning involves utilizing training data with a known status. Input data for the training set should include the same data points which will be utilized when the ML model is live, and the training data should include known results. This allows the model to map input patterns to outputs. This type of training is common when classification or regression are the desired outputs (Angelopoulos et al., 2020). In supervised learning the data must be pre-processed, as the model will only operate at a quality level which is enabled by the quality of data used to train it (Gong et al., 2019).

2.3.3.4.2 Unsupervised Learning

Unsupervised learning utilizes a data set which does not have known outputs to train a model (Gong et al., 2019). Unsupervised learning enables models to identify patterns in data, which is useful for applications such as clustering and associating factors with one another (Angelopoulos et al., 2020).

2.3.3.4.3 Reinforcement Learning

Reinforcement learning utilizes a decision and reward system in which the model learns actively by monitoring the outcome of actions that the model selects. This method does not depend
on large historical training data sets but learns as it is applied (Angelopoulos et al., 2020). For reinforcement learning to train a model it must receive adequate feedback for its reward system. Reinforcement learning is often used for sequential actions.

2.3.3.4.4 Deep Learning

Deep learning involves training through supervised and unsupervised means but is used to train models with several layers of complexity. This type of learning enables more complex models to handle larger, more complex datasets and still perform at high levels (Angelopoulos et al., 2020).

2.3.3.5 Computing Technologies

Cloud computing is a key technology enabling access to technology, edge computing has enabled less cumbersome movement of data, cyber-physical systems (CPS) serve as integration mechanisms connecting digital and physical equipment, digital twins provide a platform for advanced simulation and predictive modeling, and they all increase usability of data (Basir et al., 2019; Y. Chen, 2017; J. Lee, Azamfar, & Bagheri, 2021; Sinha & Roy, 2020). These enabling computing technologies are necessary to leverage the data now being collected to an actionable level. Recent advances allowing these technologies to be more feasible to implement have been a key driver in Industry 4.0’s recent advancements (N. M. Radziwill, 2020, p. 7).

2.3.3.5.1 Cloud Computing

Cloud computing is an umbrella term that captures many types of services which are now available. The commonality between the different applications available with cloud computing is
that they involve varying aspects of information technology (IT). Different outsourcing options include (N. M. Radziwill, 2020, pp. 29-30):

- Infrastructure as a Service (IaaS)
- Software as a Service (SaaS)
- Platform as a Service (PaaS)

The differences between the different service levels are based on how much a company is willing to outsource. The advantage of cloud computing is that software or IT applications are not required to be deployed locally, reducing the technical competency demanded for their use (Y. Chen, 2017).

Cloud computing may also facilitate deployment of integration of shopfloor technologies due to a company only needing to physically deploy the data collection technologies and not the data analysis components (Frank, Dalenogare, & Ayala, 2019). Cloud computing may be a means to drive intelligent operations in manufacturing (Raptis, Passarella, & Conti, 2019). Cloud computing is also useful in the organization aspect of integrating applications and operations (Manuel Sanchez, Ernesto Exposito, & Jose Aguilar, 2020).

2.3.3.5.2 Edge Computing

Edge computing is a method employed to reduce the time required to transfer large amounts of data, which enables more real time data usage applications. Edge computing works by performing data processing locally where data is collected, either partially processing data and sending smaller amounts of data to a non-local application, or totally processing data at the source and driving action locally. This both reduces delays in data processing and improves data security.
with less network usage (Aazam, Zeadally, & Harras, 2018). Edge computing may also be called fog computing, as cloud computing happens in a different location and fog computing is local.

IIoT can benefit from edge computing applications, however challenges exist in deployment. To capitalize on edge computing with IIoT it may be necessary to efficiently allocate data storage locally, local devices will increase electrical loads and demands, and bandwidth must be managed appropriately (Basir et al., 2019). When planning an edge computing IIoT system the context of data size and speed are important factors (Mahmud, Toosi, Ramamohanarao, & Buyya, 2020). Capitalizing on the benefits of local security also requires effective asset management at the local level and should be planned for accordingly (Sengupta, Ruj, & Bit, 2021).

2.3.3.5.3 CPS

CPS are the linked systems involving both physical equipment on the manufacturing floor as well as IT. The literature describes the 3C’s of CPS as computing, communication, and control as a high-level description of the system view (Sinha & Roy, 2020; Tao, Qi, Wang, & Nee, 2019). Other Industry 4.0 technologies build into a CPS structure when the overall application strategy is realized, and well executed CPS increases flexibility within a manufacturing system to recover to disturbances (Tran, Park, Nguyen, & Hoang, 2019).

2.3.3.5.4 Digital Twins

Digital twins are utilized to create virtual simulations of the physical equipment within a manufacturing operation in order to perform simulation. These simulations may serve several purposes such as assembly line design, equipment management, and process optimization among others (Tao et al., 2019). Digital twins require integration of the data collections and networks.
Data collection and analysis must be effective in for a successful digital twin application (Jay Lee, Azamfar, Singh, & Siahpour, 2020), and in addition digital twin success depends on planning and integration into the system (Moyne et al., 2020).

2.3.4 Automation

In order to extract value from data it must be converted into information which can drive or inform action, and when utilized correctly this information can help drive improved business operations (Gaurav et al., 2018). Automation is part of the value proposition of Quality 4.0 as the autonomy for these technologies to execute analyses and create information is key to their success (M. Sanchez, E. Exposito, & J. Aguilar, 2020).

There are many forms of automation enabled through the use of Industry 4.0 technologies. Autonomous decision making is possible due to AI, logistics processes may be supported through autonomous material movement in the form of robots or vehicles, and autonomous product inspection has tremendous potential in quality improvement (Barbosa et al., 2020; Leng et al., 2021; Sell, Rassolkin, Wang, & Otto, 2019; Villalba-Diez et al., 2019).

Several levels of automation also exist as defined by Radziwill (N. M. Radziwill, 2020, pp. 13-14):

1. Computer follows instruction set by human
2. Computer proposes options, human selects
3. Computer proposes options and suggests a best option, human selects
4. Computer proposes options and selects, human may reject selection
5. Computer executes option with human approval
1. Computer executes option but human can stop process
2. Computer executes option and reports results
3. Computer executes option and reports summary results
4. Computer executes option and reports summary results if asked
5. Computer executes option and nothing is reported, but logs are kept

2.3.4.1 Information Automation

The capabilities of AI are very broad in the context of the nature and scope of information which may be autonomously generated. Vision systems are a common method of feeding AI models data, as AI excels at image classification. Well trained models are capable of accurately distinguishing parts for sorting with over 90% success rates, and this may even be paired with robotics applications to create an intelligent sorting operation with no human involvement needed (T. Wang et al., 2018). Vision systems are also effective tools where continuous visual inspection is beneficial. In a 100% inspection quality control application Villalba-Diez et al observed success rates for defect classification of 98.4%. In that study the operator was informed of the likelihood of a defect and was able to provide feedback to the model to support the learning process (Villalba-Diez et al., 2019). In cases such as these AI supports decision processes through providing information which guides proper choices, or through outright making the choices on its own.

Models are also capable of diagnosing equipment needs. Typical maintenance programs depend on a maintenance interval, such as performing maintenance tasks on a monthly basis. Effective maintenance practices also include incorporating operators into equipment maintenance, as the operator is most likely to notice when a machine is acting differently than normal and this operator inclusion is a key factor in total productive maintenance (TPM) (Manos & Vincent, 2012,
Machine learning is another application of the same principle, with a good data framework a ML model can learn equipment performance patterns and predict when maintenance will be needed (Kiangala & Wang, 2020; Wan, Yang, Wang, & Hua, 2018; Xu & Hua, 2017).

Augmenting human intelligence, speeding up decision making processes, selecting superior alternatives to make better decisions, and improved adaptability to new circumstances are benefits that may be realized from Quality 4.0 applications (Nicole M Radziwill, 2018). Collaboration has been identified as a key element of Quality 4.0 and that collaboration is largely driven by linking information across businesses and value streams in order for decision makers and processes to utilize the most current and accurate information (Jacob, 2017a).

2.3.4.2 Mechanical Automation

Autonomous vehicles (AVs) are one application of logistics automation with several organizations currently pursuing such applications. AVs may utilize data collection technologies such as light detection and ranging (LiDAR), ultrasonic sensors, radar, cameras, or satellites to generate position and movement data. When combined with AI platforms to intelligently manage the system, degrees of autonomy in moving material with AVs become possible (Sell et al., 2019). AV applications demonstrate the benefit of modern data collection and processing. Detecting potential collisions and appropriate interventions for an AV may require real time data collection combined with edge computing locally on the AV platform, combined with autonomous decision making to execute the intervention and prevent the collision (Indri et al., 2019). Barriers to deployment of AVs include data collection challenges, such as laser navigation systems, advanced sensor applications, and RFID, guidance system challenges which involves application of the data
being captured, and wireless sensor applications as AVs are mobile and may require wireless designs to be functional (Oyekanlu et al., 2020).

Robotics are also applied to logistics, often being used to pick-and-place, sort, or stage parts as needed within the production process. These robot applications extend beyond just logistics, with additive manufacturing and welding applications as examples of other applications (Barbosa et al., 2020). Robotics applications combined with Industry 4.0 analytics empowers smart applications, such as robotic sorting of parts on a line (T. Wang et al., 2018). Robotic applications are utilized to automate repetitive tasks, which has been practiced since before Industry 4.0 technologies, and with the improved flexibility of intelligent applications robotics may now be utilized in more complex manufacturing systems (Wu, C.-Y, H.-W, & P.T, 2020).

2.3.4.3 Augmented Reality

Augmented reality (AR) involves adding computer generated stimulus to the actual world. This may be achieved with wearable technology such as glasses (Angrisani, Arpaia, Esposito, & Moccaldi, 2020). This automates information which is delivered to human operators in real time. The purpose of the supplemental stimulus is to enhance the information being perceived by human operators, which may increase decision making speed or accuracy. AR is utilized to improve performance through the display of relevant instructions when work is being done. In this way, standard work may be built directly into the task level of work for the operators (Fraga-Lamas, FernáNdez-CaraméS, Ó, & Vilar-Montesinos, 2018). Digitally integrated instructions demonstrate improved performance when training new employees (Hořejší, Novíkov, & Šimon, 2020).
2.3.5 Technology Constructs

The literature highlights data and information technology as a core construct for Quality 4.0 applications. Technology can be broken down into three more specific constructs within the initial conceptual model:

1. Data Collection and Management Construct
2. Data Analytics Construct
3. Data Automation Construct

Each of these constructs serves as part of the technology deployment portion of Quality 4.0 implementation.

2.4 Quality 4.0

2.4.1 Quality 4.0 Literature

Dan Jacob of LNS research originally published the term “Quality 4.0”. Jacob describes Quality 4.0 (Jacob, 2017b):

“Quality 4.0 blends new technologies with traditional quality methods to arrive at new optimums in Operational Excellence, performance, and innovation. The new technologies include Machine Learning/artificial intelligence, connected devices and operations, new forms of collaboration like social media and blockchain, Big Data, Cloud computing, and new apps like AR/VR and mashups.”

The technologies which have enabled Quality 4.0 are those which improve data, analytics, connectivity, scalability, and collaboration (Jacob, 2017a, p. 6). All of these competencies are
framed into the scope of improving quality and pursuing an organizations overarching quality strategy in the described Quality 4.0 applications.

Radziwill poses the question of how to leverage new technologies to improve performance, and defines Quality 4.0 (N. M. Radziwill, 2020, p. 7):

“That’s the domain of Quality 4.0, the pursuit of performance excellence during this disruptive era of physical, digital, and social transformation.”

The quality function of an organization is highlighted as being uniquely positioned to drive digital transformations, while also having the data driven mindsets and skills to be central in architecting these changes (Jacob, 2017a, p. 4; N. M. Radziwill, 2020, pp. 17-18).

Quality 4.0 is increasingly recognized as an important pursuit in industry. A Boston Consulting Group (BCG) survey identified Quality 4.0 as being important throughout the value chain of a company. They define Quality 4.0 (Daniel Kupper, 2019, p. 3)

“The application of Industry 4.0’s advanced digital technologies to enhance traditional best practices in quality management.”

Quality is often a top priority for business leadership and the application of Industry 4.0 technologies to quality improvement is one method to empower organizations in their quality pursuits. The flow and use of data may allow quality to be more visible within an organization while pushing quality as everyone’s responsibility at the same time (Johnson, 2019).

Quality 4.0 literature highlights strategy and leadership as relevant factors. Strategy development involves planning out Quality 4.0 investment with a long term future in mind (Sony,
Antony, Douglas, & McDermott, 2021). This strategic long-term approach goes beyond technology and competencies, it will involve system design including the human perspective. TQM approaches blend Industry 4.0 and quality together effectively in a strategic, entire-organization based Quality 4.0 approach (Babatunde, 2020). A thorough definition of Quality 4.0 must encompass the quality function in an organization.

2.4.2 Quality 4.0 Definition

The perspectives offered in literature describe Quality 4.0 as applications of Industry 4.0 technologies in the pursuit of quality goals. The human aspects of quality applications as well as overall company strategy and vision are also relevant in defining Quality 4.0. The BCG definition of Quality 4.0 is concise and clear, Jacob offers a definition which captures the essence of what Quality 4.0 should do, and Radziwill proposes another definition which focuses on the revolutionary technological changes being seen. The following definition is proposed for this research:

Quality 4.0 is the application of Industry 4.0 technologies to improve organizational performance towards quality goals.

This definition can be further clarified with the following Quality 4.0 propositions:

1. A quality strategy and goals predicate Quality 4.0 success
2. Quality 4.0 technologies do not replace quality departments and QMSs
3. Quality 4.0 builds and supplements an organization's quality competencies
2.5 Operational Methodologies

The literature on Industry 4.0 and Quality 4.0 provides comparisons between various methodologies already in existence. The overlap between Lean and Industry 4.0 is explored in the literature, with Industry 4.0 technologies potentially leading to an evolution in the application of lean tools (Fortuny-Santos, Lopez, Lujan-Blanco, & Chen, 2020). Industry 4.0 is also viewed in many papers as a potential tool to reduce environmental impacts of manufacturing and improve sustainability (Brozzi, Forti, Rauch, & Matt, 2020). Quality 4.0 is described as having overlap with TQM, due to the overlap of technical and human systems (Babatunde, 2020).

2.5.1 Industry 4.0 and Lean

Lean is defined (Manos & Vincent, 2012, p. 390):

“A systematic approach to identifying and eliminating waste (non-value-added activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection”

Industry 4.0 has been identified as a potential way to implement lean tools effectively, the following lean implementation opportunities through industry 4.0 have been identified (Sanders, Elangeswaran, & Wulfsberg, 2016):

1. Supplier performance may be improved
   a. Supplier feedback can be automated with information shared in real time
   b. Just-in-time (JIT) deliveries can be driven through digital inventory management throughout the delivery
   c. Digital information and knowledge sharing can assist in supplier development
2. Customer involvement may be achieved
   a. Big data and social media allow companies to be more connected to customers than ever before

3. Process improvements can be achieved
   a. Information connectivity can drive pull production, originating with a customer order being immediately communicated throughout the production system
   b. Material flow is easier to manage by tracking WIP throughout the production process
   c. Automation opportunities can reduce setup times

4. Production system improvements
   a. ML can improve maintenance through predictive maintenance and fault detection
   b. Statistical Process Control (SPC) can be built into the data management and automated
   c. Automation of routine tasks allows for greater employee engagement with diversified work and complex tasks

Many of these opportunities appear in other studies linking lean with Industry 4.0. JIT is a method in particular which requires smooth and accurate flow of information between processes. Autonomation is the process of developing smart machines which work with a degree of autonomy with human operators. JIT and Autonomation (also called jidoka) are the two pillars of lean which support a lean production system (Buer, Strandhagen, & Chan, 2018). Lean is also viewed as a baseline for Industry 4.0 in many existing papers with Industry 4.0 being seen as a group of
technologies which enable lean to succeed, as technology in itself is not a strategy but may enhance a strategy (Fortuny-Santos et al., 2020).

The value proposition of lean is in the elimination of wasteful activities. Lean demands a high degree of synergy within a company to be successful, which is achievable without a digitally connected workplace, however connecting information sources to be available where relevant in real time improves the ability to create organizational synergy (Ghobakhloo & Fathi, 2020). Real time data is important in a lean environment, and Industry 4.0 enables real time pull data on what is demanded from customers, both internal and external, real-time work in progress (WIP) data of where inventory exists, real time scheduling and resource management, and much more. This real time information enables lean concepts to be executed effectively (Ghouat, Haddout, & Benhadou, 2021).

While Industry 4.0 enables lean tools, lean methods also have potential to improve Industry 4.0 deployment success. Companies already committed to lean may see more successful sustained results when implementing Industry 4.0 (Rossini, Cifone, Kassem, Costa, & Portioli-Staudacher, 2021). Many lean tools and Industry 4.0 tools are geared towards solving the same manufacturing problems, such as inventory tracking/control and quality control (A. Chiarini & Kumar; Shahin, Chen, Bouzary, & Krishnaiyer, 2020).

2.5.2 Industry 4.0 and Sustainability

The literature identifies a lack of appropriate metrics as a challenge in achieving sustainability goals in manufacturing at the process level (Enyoghasi & Badurdeen, 2021). Industry 4.0 data foundations can enable the development of appropriate metrics. Operationally,
the flexibility of Industry 4.0 systems combined with improved efficiencies and process control can optimize resource management, reducing the material and energy footprints from manufacturing (Furstenau et al., 2020; Machado, Winroth, & da Silva, 2020; Mohamed, Al-Jaroodi, & Lazarova-Molnar, 2019).

Improvements in sustainability may be utilized to help justify implementation of Industry 4.0 technologies. Sustainability can be defined as the overlap between environmental impact, social impact, and economic impact. The benefit of achieving sustainability in this model is that the efforts should result in lasting financial stability and profit, which is derived from the efficiency gains and optimized supply chains in an Industry 4.0 factory (Braccini & Margherita, 2019; Jabbour, Jabbour, Foropon, & Godinho, 2018).

2.5.3 Industry 4.0 and TQM

TQM is a method of quality management in which quality is integrated throughout an entire organization. For TQM to be successful it must be developed into the organizations overall strategy and deployed systematically. The philosophical idea behind TQM is to make quality the job of every individual within the organizations and the goal is to continually improve performance (Evans & Lindsay, 2013, p. 16).

Industry 4.0 as influences quality management, including TQM. This quality overlap includes both the hard and soft factors involved in quality management. Hard quality aspects involve data collection and analytics, while the soft aspects involve management concepts and principles (Babatunde, 2020). These aspects of integration were specified in greater detail by Chiarini (Andrea Chiarini, 2020):
Quality data, analytics, and AI drives value creation

Quality 4.0 skills development drives a quality culture

Customers collaborate with the value creation

CPS data usage for quality monitoring and control

Quality culture in which employee engagement is critical is a key element in TQM. Employee engagement is also a factor in utilizing enabling technologies for improvement. Humans being integrated into Quality 4.0 systems is necessary for success as human-machine interactions are present across autonomous systems, with well executed systems maximizing the flexibility of the human element to perform complex tasks. The human element is also critical in monitoring and controlling many autonomous systems (Souza, Corsi, Pagani, Balbinotti, & Kovaleski, 2021).

2.5.4 Methodology Constructs

The literature indicates a correlation between Quality 4.0 success and other high level business methodologies. Lean, TQM, and sustainability are all explored in the literature as relating to Industry 4.0, however, the literature tends to indicate that Industry 4.0 technologies may be utilized to alleviate sustainability roadblocks. The conceptual model being developed is to support implementation of Quality 4.0. Sustainability isn’t thematically associated with improving quality or Industry 4.0 efforts, so the methodology construct in the initial conceptual model can be broken down into:

1. Lean Manufacturing Construct

2. Total Quality Management Construct
These constructs and their impact on Quality 4.0 implementation are worth exploring.

2.6 Quality 4.0 Enablers

The literature explores the success factors related to Industry 4.0 and Quality 4.0 initiatives. The development of roadmaps and maturity models for Industry 4.0 implementation is also a common thread in the literature (Sjodin, Parida, Leksell, & Petrovic, 2018).

2.6.1 Enabling Factors

Many enabling factors are considered significant, such as company demographic factors, company-wide strategy, management tools, and culture (Bosman, Hartman, & Sutherland, 2020; Cresnar, Potocan, & Nedelko, 2020; Marnewick & Marnewick, 2020). Literature review highlighted concepts relating to business practices and management as success factors more often than the technical skills related to Industry 4.0 technologies.

2.6.1.1 Company Factors

Human capital is a term describing the skills and talents present within a company’s workforce. This human capital includes the skills required for project management and Industry 4.0 technology deployment as well as technical competencies of individuals within the workforce. The human capital outlook present within a company is a factor which can influence the decision of the company on whether to invest in Industry 4.0 technologies (Bosman et al., 2020). Organizational knowledge and management knowledge of Industry 4.0 technologies is also a significant success factor (Patil, 2021). Knowledge management effort is correlated with higher likelihood of success in digital transformation (De la Boutetière et al., 2018, p. 7). Operator engagement is another success factor related to human capital. Operator success in the human-
machine interaction demands the operator to develop the skills required to interface with the machine and active engagement in the process (Vereycken, Ramioul, Desiere, & Bal).

Company size is a factor identified as significant. One challenge with company size is in employee skills. Larger organizations are more likely to have greater technical competencies and small companies may need to reskill their staff prior to successful technology deployment (Moeuf et al., 2020; Rangraz & Pareto, 2021). A benefit for smaller organizations is the lack of hierarchical levels of management. This smaller organizational structure promotes transparency within the organization when it communicates goals for implementing revolutionary changes. Smaller companies also have less organizational silos, which can assist in effective companywide rollouts (Moeuf et al., 2020).

2.6.1.2 Company-Wide Strategy

Successful Industry 4.0 implementations depend on strategy, including developing short, medium, and long-term strategies including time phased planning (Ghobakhloo, 2018). One strategic factor is development of a vision of the digital transformation (Narula, Prakash, Dwivedy, Talwar, & Tiwari, 2020). Conceptualizing the data architecture and framework needed for success will simplify the development process to create a more manageable implementation, including a data collection and management strategy prior to implementation of data collection technologies. The overall strategy for Quality 4.0 should also fit in with the overarching corporate vision and strategy of the company (Sony et al., 2021).

Without strategy in place before deployment it is possible that the data initiatives implemented may not improve performance. Strategically planning which projects are worth
investment is a critical step to successfully driving returns from an Industry 4.0 implementation (Escobar, McGovern, & Morales-Menendez). Modern big data systems are sufficiently complex to justify developing data collection and management strategies prior to architecting the systems themselves. Data strategies should explore what data can be collected, generated, and connected, and it should be contextualized into the business case at hand to understand how value may be realized (Gaurav et al., 2018).

2.6.1.3 Management Tools

A management tool can be defined as a concept which may support the achievement of organizational goals. Within this definition two clusters of management tools can be identified in the context of supporting Industry 4.0 implementations. The first group includes strategic planning, company mission and vision, and other concepts which fit with the company-wide strategy factors. The second group includes management practices such as lean manufacturing, six sigma, TQM, and other improvement focused methods (Cresnar et al., 2020). Industry 4.0 success is positively correlated with the following management tools (R. Lee, 2021):

- Enterprise Resource Planning (ERP) – Systematic integration of resource management
- QMS – Systematic approach to product quality improvement
- Ethical Management – Integration of ethical management techniques into other systems
- Productivity Management – Systematic improvement of productivity measures

Lean and TQM both overlap with Industry 4.0 in the literature (Andrea Chiarini, 2020; Ghouat et al., 2021). Six Sigma can be described as an organized structure aimed at reducing organizations process variation with the aim of achieving strategic objectives (Schroeder, Linderman, Liedtke,
& Choo, 2008). Data collection and analysis is foundational to six sigma, and it also supports the integration of lean and six sigma, which can be referred to as Lean Six Sigma (LSS), which synthesizes well with Industry 4.0 data collection and analysis (Vinodh, Antony, Agrawal, & Douglas, 2021).

QMS deployment may be achieved following comprehensive standards available in industry, such as the 9001 standard from the International Organization for Standardization (ISO) which is also utilized by the American National Standards Institute (ANSI), as well as the Baldrige Excellence Framework. These standards define organizational requirements in a number of categories to develop and maintain an acceptable QMS, shown in Table 2 (ISO, 2015; National Institute of Standards and Technology, 2021). Utilization of standards to audit company practices and develop implementation plans from the results is a practice which may be followed when laying the QMS framework needed for successful Industry 4.0 deployment (Hutton, 2000).
<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Baldrige Excellence Framework</th>
<th>ISO 9001:2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizational Profile / Context</td>
<td>Key organizational characteristics and scope</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Leadership</td>
<td>Top management commitment to QMS, mission, vision, performance, and workforce</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Strategy / Planning</td>
<td>Strategy development, strategic objectives, core competencies, risks and opportunities</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Customers</td>
<td>Listening to current customers and potential customers, customer segmentation and product offerings</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Measurement, Analysis, and Knowledge Management</td>
<td>Data collection and use, metrics and measures for performance, innovation, internal audits</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Workforce</td>
<td>Change management, training and development, compensation and benefits, competency assessment</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Operations</td>
<td>Production process management, product design, innovation process improvement, process control and standards</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Results</td>
<td>Customer key measures, process efficiencies, preparedness</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Support</td>
<td>Resource management, capability analysis, workforce development, documentation of standards</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Improvement</td>
<td>Control of non-conformance, action plans, customer needs analysis, continuous improvement</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
2.6.1.4 Culture

Organizational culture encompasses the values and norms present within an organization (Sony et al., 2020). Many factors have been identified as being specific elements of corporate culture. Narula et al identified four factors as part of culture in digital transformations (Narula et al., 2020):

- Vision for transformation
- Strategy and Leadership
- Knowledge Transfer
- Organizational Structure and People Competency

The overlap with Lean and Industry 4.0 includes Lean culture. Lean culture impacts the success of Industry 4.0 implementation, being identified as leading to successful sustained improvement with new technologies (Rossini et al., 2021). Key factors in Quality 4.0 transformation also include strategy, leadership, and training (Sony et al., 2020).

Lean culture is defined by empowered workforces in which everyone is involved in value creation. Five corporate cultural enablers for Lean have been identified (Manos & Vincent, 2012, p. 3):

- Safety
- Standards
- Leadership
- Empowerment
- Collaboration
These five enablers of lean culture overlap with the cultural components identified in the literature as being necessary or beneficial in Industry 4.0 deployments. To achieve empowerment of a workforce, leadership must exhibit a level of trust in its workforce, and the organization must train those employees in such a way as to allow them to utilize skills with a level of autonomy. Training and re-skilling staff is a critical step when introducing broad sweeping technological changes to a workplace, such as with an Industry 4.0 deployment (Ghobakhloo, 2018). The need to develop staff to handle new technologies may be exaggerated in smaller firms facing the challenge of skills gaps and difficulty hiring against larger competitors (Rangraz & Pareto, 2021). The role of leadership in developing a workforce comes from supporting effort and investment from top management downward (Pozzi et al., 2021).

Development of short, medium, and long-term change management strategies towards the implementation of Industry 4.0 technologies is an enabling factor for deployment (Ghobakhloo, 2018). Realigning the vision of a company to be more flexible and customer focused as well as deploying a corresponding mission and vision statement may help a company become more ready to implement Industry 4.0 technologies (Cresnar et al., 2020).

2.6.2 Barriers

Despite the perceived importance of Quality 4.0 for the future of manufacturing, less than half of companies surveyed in 2019 had even begun to plan how to deploy Quality 4.0 (Daniel Kupper, 2019, p. 7). One issue identified is a lack of sufficient research into barriers for Industry 4.0 technologies, however the available body of literature identifies the following barriers (Raj, Dwivedi, Sharma, Jabbour, & Rajak, 2020):
• Lack of skills within the workforce
• Cost of implementation
• Data security
• Poor standardization or integration of architecture
• Lack of understanding of strategic importance or lack of organizational alignment

Another challenge identified in the literature for Industry 4.0 implementation is the lack of research into implementation readiness (Micheler, Goh, & Lohse, 2019). Companies currently exploring Industry 4.0 transformations are still early movers and have many challenges to navigate without an abundance of available knowledge to draw from. This lack of knowledge compounds other challenges, such as skills gaps, as organizations may not have the ability to easily locate the resources required to enhance their staff skill levels. While it is known that training and development efforts are necessary to achieve Industry 4.0 transformations, including more specifically Quality 4.0 architectures, the knowledge and competencies required from those efforts are not clearly defined (Rangraz & Pareto, 2021).

2.6.3 Enabling Factors Constructs

The literature shows that there are many enabling factors to Quality 4.0 implementation along with some barriers to overcome. These barriers mirror the enabling factors thematically, for example the enabling factor of employee skill is mirrored by the barrier of lack of technical skills within the workforce. The barriers will be represented in the model through their corresponding enabling factors. There is also overlap between the themes present in the enabling factors. To
achieve a manageably clear model, themes between enablers and barriers will be synthesized into appropriate constructs for the model. Themes and their constructs are summarized in Table 3:

### Table 3 - Enabling Factors Constructs

<table>
<thead>
<tr>
<th>Enablers</th>
<th>Constructs</th>
<th>Culture Construct</th>
<th>Strategy / Commitment Construct</th>
<th>Company / Resource Construct</th>
<th>Management Tools / Methods Construct</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Themes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Employee Technical Skills</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Organizational Knowledge Management</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Organizational Investment / Commitment</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operator Engagement</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Company Size</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Leadership Transparency</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Company-Wide Strategy</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Data / Network Architecture</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quality 4.0 Vision</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Localized Implementation Strategy</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enterprise Resource Planning</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quality Management System</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Ethical Management</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Quality Strategy</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Productivity Management</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Standard Audits</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Six Sigma</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strong Leadership</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The four identified enabling factors constructs identified from the literature are:

1. Culture Construct
2. Strategy and Commitment Construct
3. Company and Resources Construct
4. Management Tools and Methods Construct

Each of these constructs is under the Enabling Factors core construct of the initial conceptual model.

**2.7 Case Studies**

**2.7.1 Quality 4.0 Cases**

Case studies form a baseline for defining successful Quality 4.0. The available case studies may demonstrate specific tangible improvements which may not be reflective of the full potential improvement conceptualized in the literature. As Quality 4.0 is defined by the application of
Industry 4.0 technologies to achieve improved performance, a successful Quality 4.0 use case study should demonstrate both the technological element and the performance element.

Case studies from the last five years may be utilized to establish the baseline of what successful Quality 4.0 looks like in practice. The purpose of baselining is to establish a realistic description of success in order to compare results of the study against known success. Due to the relative newness of the concept in industry the study must establish what success looks like today in order to develop a framework for success based in reality, as opposed to a theoretical definition.

10 case studies were identified through literature search of the terms “Quality 4.0”, “Quality 4.0 case studies”, and “Automated quality control”. Within the context of this studies established definition of Quality 4.0 cases have been analyzed to identify the following determinants of success:

- Which Industry 4.0 technologies were utilized in each case?
- How was successful quality improvement determined?
- How did data flow and get utilized, in the context of the Industry 4.0 technology?
- How did the application influence the use of resources?

The 10 analyzed cases are summarized in table 3:
### Table 4 - Quality 4.0 Case Studies

<table>
<thead>
<tr>
<th>Authors</th>
<th>Technologies</th>
<th>Success Measure</th>
<th>Data Usage</th>
<th>Resource Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Ahmad et al., 2018)</td>
<td>Sensors, ML, IoT</td>
<td>Prediction accuracy for water quality</td>
<td>Continuous Variable Data</td>
<td>Reduced need for human inspection</td>
</tr>
<tr>
<td>(Kulkov, Korytov, Popov, &amp; Larionov, 2019)</td>
<td>Sensors, Edge Computing</td>
<td>Defect detection accuracy</td>
<td>Continuous Variable Data</td>
<td>Reduced need for human inspection</td>
</tr>
<tr>
<td>(Logvin, Kulikov, Shurpo, &amp; Yvarova, 2020)</td>
<td>Simulation, Digital Twin</td>
<td>Quality of part surface</td>
<td>Continuous Variable Data</td>
<td>Reduced failure rate during parameter selection</td>
</tr>
<tr>
<td>(Marino et al., 2021)</td>
<td>ML, Sensors, Edge Computing</td>
<td>Processing speed</td>
<td>Vision/Image Data</td>
<td>Improved throughput due to detection speed</td>
</tr>
<tr>
<td>(Massaro, Manfredonia, Galiano, &amp; Contuzzi, 2019)</td>
<td>IoT, Sensors, ML</td>
<td>Tire defect detection rate</td>
<td>Vision/Image Data and Continuous Variable Data</td>
<td>Improved throughput due to detection speed</td>
</tr>
<tr>
<td>(Massaro, Manfredonia, Galiano, Pellicani, &amp; Birardi, 2019)</td>
<td>IoT, Sensors, ML</td>
<td>product traceability, defect detection</td>
<td>Vision/Image Data and Continuous Variable Data</td>
<td>Improved traceability and defect containment</td>
</tr>
<tr>
<td>(Ozdemir &amp; Koc, 2019)</td>
<td>ML, Sensors</td>
<td>Object recognition accuracy</td>
<td>Vision/Image Data</td>
<td>Improved throughput due to detection speed</td>
</tr>
<tr>
<td>(Petritoli, Leccese, &amp; Spagnolo, 2020)</td>
<td>Sensors, IoT</td>
<td>Processing speed, accuracy of detection</td>
<td>Continuous Variable Data</td>
<td>Improved traceability and throughput</td>
</tr>
<tr>
<td>(Pittino, Puggl, Moldaschl, &amp; Hirschl, 2020)</td>
<td>IoT, Sensors, ML</td>
<td>Prediction accuracy for detection</td>
<td>Continuous Variable Data</td>
<td>Reduced unplanned downtime and defect rate</td>
</tr>
<tr>
<td>(Villalba-Diez et al., 2019)</td>
<td>IoT, Sensors, ML</td>
<td>Defect detection accuracy</td>
<td>Vision/Image Data</td>
<td>Improved accuracy of visual inspection and reduced cost of quality</td>
</tr>
</tbody>
</table>
Nine of the cases described automated data collection in the form of various sensors. Vision systems were prevalent in the literature, however data collection also included variable data, such as PH levels in ponds (Ahmed, Rahaman, Rahman, & Kashem, 2019), vibration within machines (Pittino et al., 2020), and laser positional measurements (Massaro, Manfredonia, Galiano, & Contuzzi, 2019).

The applications in each case also described some form of autonomous analysis on the back end of the data collection model. The vision systems in place are paired with ML models in order to accurately identify and classify images. This process is often utilized to perform visual quality inspections (Massaro, Manfredonia, Galiano, & Contuzzi, 2019; Massaro, Manfredonia, Galiano, Pellicani, et al., 2019; Villalba-Diez et al., 2019). Other forms of analysis utilized included statistical process control (Pittino et al., 2020), advanced simulation (Logvin et al., 2020), and continuous measurement of measurable quality parameters for 100% inspections (Kulkov et al., 2019).

The cases described various ways in which the Quality 4.0 application either was or theoretically would improve performance. The outcomes of the cases included improved quality diagnosis due to automated systems being more accurate than human counterparts, improved quality performance due to automated systems being more accurate than human counterparts, improved throughput due to automated systems being able to perform inspections at a faster rate than human counterparts, and improved traceability of product due to automated systems keeping an accurate ledger of WIP. All of these factors demonstrate a tangible improvement to the performance of a production system.
2.7.2 Quality 4.0 Determinants of Success

Three determinants of Quality 4.0 success were identified through case study analysis:

1. The collection and use of real time data
2. Automation of data connectivity and analysis
3. Tangible improvement of an aspect of system performance

These three determinants will serve as the basis for recognizing successful Quality 4.0 applications during data collection.

2.8 Initial Conceptual Model

Quality 4.0 constructs have been thematically identified through the systematic literature review process. These constructs build into the initial conceptual model proposed by this research. The goal of this study is to create a valid conceptual model for Quality 4.0 implementation. To achieve this goal, expert testimony will be used to validate this conceptual model, to ensure that the model reflects the most current knowledge available, in the context of successful applications.
The initial conceptual model displays the four high level constructs:

1. Technology Construct
2. Methodology Construct
3. Enabling Factors Construct
4. Strategy Construct

The technology construct encompasses the utilization of data collection and management, data analytics, and data automation to achieve company quality goals in a Quality 4.0 application.
Any quality improvement that doesn’t fit into the technology construct is by definition not a Quality 4.0 application. The Methodology and Enabling Factors constructs both support the technological execution in this model. Due to the nature of the constructs the model is not expressly cyclical, as the enabling factors and methods may be deployed in an iterative fashion and support one another. Implementing Lean may result in developing a lean culture, which enhances the enablers construct, while deploying the management tool of a QMS audit may enhance a company’s ability to execute TQM principles. The Enablers and Methodology constructs both lay groundwork for success within the Technology construct. To achieve successful Quality 4.0 the application of the Technology construct must improve company performance in the context of quality goals. The strategy construct is one of the enabling factors, however strategic planning and assessment should guide the pursuit of other enablers and methods which merits strategy to become its own construct, as it should chronologically be performed first in the implementation process.

2.9 Research Contributions

The existing cases along with the theoretical concepts in literature demonstrate the potential value of Quality 4.0 when successfully deployed. Where the literature is lacking is a comprehensive model for successful deployment. Much of the literature focuses on architecture and data structures for individual technologies, along with the benefits which may be realized from those technologies. A model for successful deployment of Quality 4.0 both fills a gap in the literature and provides value to the practice of the discipline.

The model proposed in this research is made up of three high level constructs necessary for a manufacturing firm to achieve Quality 4.0 success. It is flexible in its approach to Quality
4.0, encompassing a variety of technologies and approaches. The model encompasses the use of technology, company methodologies, and enablers for success. The model proposes that Quality 4.0 applications enhance the ability to achieve quality goals, but do not supplant the existence of quality strategy or quality goals for an organization. Successful implementation is defined in the model as including automated data collection, automated information flows (potentially including automated information generation in the form of analysis), and tangible performance improvement. This model is designed to identify key factors for successful Quality 4.0 implementation with tangible results.
CHAPTER THREE: METHODOLOGY

3.1 Introduction

The research methodology detailed in this chapter will be applied to achieve the stated research goal of the study, to develop a valid model for successful implementation of Quality 4.0 in manufacturing. This chapter outlines the steps required to collect the necessary data, as well as the rationale for the development of the study.

3.2 Research Design

3.2.1 Design Overview

Semi-standardized interview methodology offers a flexible approach utilizing open ended questions to allow for expert testimony to flow based on the judgement of the interviewee. In execution of a semi-standardized interview, it is valid to design the interview questions in advance to reduce potential bias, while utilizing open ended questions specifically. The interview process is best executed face to face, however video conferencing may be utilized for this study, to allow the interviewer to interpret nonverbal communication and probe for more depth of information on topics which seem relevant (Ryan et al., 2009). The following principles should be adhered to during the interview process by the interviewer (Qu & Dumay, 2011):

1. Maintain the flow of the interview
2. Maintain a positive relationship with the interviewee
3. Avoid interviewer bias
3.2.2 Research Design Validity Measures

Validity is critical to any study design. A valid study is one which adequately measures what is being studied. The validity of the interview must be established for a valid research design.

3.2.2.1 Interview Validity Measures

Expert interview is a method used to collect qualitative data on a topic. Establishing validity for qualitative analyses may be achieved through the following factors (Whittemore, Chase, & Mandle, 2001):

- Primary Validity Measures
  - Credibility
  - Authenticity
  - Integrity
  - Criticality

- Secondary Validity Measures
  - Explicitness
  - Vividness
  - Creativity
  - Thoroughness
  - Congruence
  - Sensitivity

The approach to achieving validity through all of these measures is explored in the following sections.
3.2.2.2 Interview Sample Size

Determining the sample size for qualitative interview research requires consideration for the context of the study. Qualitative research is less focused on statistical sampling, instead emphasizing the exploration of concepts. The goal of interview research is to achieve saturation of concepts, which can be described as the point when further interviews are unlikely to highlight or clarify new relationships within the themes of the research. Achieving saturation may require anywhere between 5 and 50 experts to interview, depending on other factors (Dworkin, 2012). The already explored lack of Quality 4.0 success is a contextual factor in this study, and the pool of experts is likely to be restricted. An initial target sample size of 10 Quality 4.0 experts will be targeted for this study within the context of these factors, however for validity the responses will be analyzed at the conclusion of each interview for concept saturation to determine if further experts are required.

Saturation being the point at which the research is not offering new themes or concepts, when the sample is reviewed during the study saturation will be considered achieved on the condition that each theme is duplicated at least once across the sample. An interview presenting novel themes will indicate that further study may be required and may also prompt a deeper analysis of the themes in the interview sample.

3.3 Research Methodology

The methodology for developing the conceptual model consists of developing the initial model through literature review, developing an interview process to validate the themes in the initial model, and interviewing experts to execute the validation. The literature review formed the conceptual model based on the foundational Quality 4.0 principles. This foundation for Quality
4.0 forms the basis for interview question development. The interview process serves the purpose of refining and validating the conceptual model against expert input, after which the model will be finalized. This Quality 4.0 model for success is the proposed output of this research.

3.4 Literature Review

The literature review for this study explores the topics of Industry 4.0, Quality 4.0, quality management in manufacturing, including a brief history of quality management, total quality management in manufacturing, success factors for Quality 4.0 and Industry 4.0 in manufacturing, and the various standards currently guiding quality management in manufacturing. In the literature review the key factors for successful quality and successful applications of new technologies are explored to develop a framework for the study. Current best practices in quality are reviewed so that their relationship to successful Quality 4.0 implementations may be understood where the literature is available. The body of work surrounding Quality 4.0 in practical application is a key focus of the literature review to build a conceptual model for what is required to make Quality 4.0 successful.

Case study analysis explores the state of the art as it pertains to Quality 4.0 implementation being utilized today. This analysis of the state-of-the-art provides a tangible snapshot of what the baseline for success currently is. This baseline is critical to the development of interview questions to define successful Quality 4.0 for context in the interviews.
3.5 Study Protocols

3.5.1 Study Process

This study follows an expert knowledge-based data collection protocol. Due to the immaturity of Quality 4.0 as an application in industry it is worthwhile to recruit expert knowledge to further refine and validate the initial conceptual model. This will be achieved through focused expert interviews. The conceptual model will be revised along with determinants of Quality 4.0 success based on qualitative data collected through the interview process. The revised model will then be finalized based on the literature and expert testimony. The data collection plan follows the following sequence:

1. Develop interview method
   a. Develop initial questions and concepts to explore
   b. Identify interview candidates
      i. Utilize committee guidance

2. Revise and validate conceptual model
   a. Execute interviews
   b. Revise model where expert testimony deems necessary
   c. Validate the themes of the model which are supported by interviews

3. Finalize Quality 4.0 Framework

These steps will be detailed further in the following sections. The methodology in this chapter will also describe the validity of the proposed study.
3.5.2 Interview Methodology

To offer value in qualitative analysis, interviews must be thoroughly planned prior to execution. Interview candidates, preliminary research on interview topics, and a plan for data analysis are necessary for successfully deploying a research interview. The same set of questions should be administered to each interview candidate (Qu & Dumay, 2011). Discovery interview methodology allows for the interviewee to shape the responses through the use of open-ended lines of questioning (Ryan et al., 2009). Discovery interviews are desirable for this study to allow expert opinion and experience to shape the results of the data collection process.

3.5.2.1 Interview Questions

Interviews should explore the key concepts of Quality 4.0 as identified within the literature and should also be open ended to allow for expert judgement to add to the identified BoK. Open ended question should explore the topics of:

- Industry 4.0 technologies
  - Data Collection
  - Data Analysis
  - Automation
- Overlapping Methodologies
  - Lean
  - TQM
- Success Factors
- Barriers
- Quality Systems and Strategies
- Quality 4.0 Determinants of Success

The interviews will be structured to follow the general flow from technology through methodologies, success factors, system/strategies and conclude with Quality 4.0 determinants of success within the interviewee’s realm of experience. These questions must follow a structure with a consistent, well-designed flow to support the rigor of data collection (Ryan et al., 2009). In the interview process the interviewee must be allowed to develop a complete narrative in order to explore their expertise fully (Qu & Dumay, 2011). The logical flow proceeding from the very objective aspect of technology applications into the established methods related to Quality 4.0 and leading to the more subjective aspects of defining success will allow for rapport building and exploration of the interviewee’s knowledge.

Baseline interview questions are structured in order in Table 4:
Table 5 - Interview Questions

<table>
<thead>
<tr>
<th>Topic</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>What is your role and your background with Quality 4.0?</td>
</tr>
<tr>
<td>Technologies</td>
<td>Can you please describe the state of the art in data collection?</td>
</tr>
<tr>
<td>Technologies</td>
<td>Can you please describe the state of the art in data analysis?</td>
</tr>
<tr>
<td>Technologies</td>
<td>How can automation be applied to data collection and analysis?</td>
</tr>
<tr>
<td>Technologies</td>
<td>What are the most impactful technological changes to the discipline of quality over the last five years?</td>
</tr>
<tr>
<td>Methodologies</td>
<td>Can you describe the relationship between Lean manufacturing and Quality 4.0?</td>
</tr>
<tr>
<td>Methodologies</td>
<td>Can you describe the relationship between Total Quality Management and Quality 4.0?</td>
</tr>
<tr>
<td>Success Factors</td>
<td>What factors enable an organization to implement Quality 4.0?</td>
</tr>
<tr>
<td>Success Factors</td>
<td>How do these factors play a role?</td>
</tr>
<tr>
<td>Barriers</td>
<td>Can you identify barriers likely to interfere with Quality 4.0 implementation?</td>
</tr>
<tr>
<td>Barriers</td>
<td>In what ways do these barriers prevent success?</td>
</tr>
<tr>
<td>Systems</td>
<td>How does the design of an organization’s quality system impact Quality 4.0 implementation?</td>
</tr>
<tr>
<td>Strategies</td>
<td>Are there any strategies you would recommend for Quality 4.0 implementation?</td>
</tr>
<tr>
<td>Success</td>
<td>What does Quality 4.0 success look like?</td>
</tr>
</tbody>
</table>

3.5.2.2 Interview Validity Measures

To ensure a rigorous study with valid results the following measures of qualitative data validity will be established for the interview process (Whittemore et al., 2001):

- Credibility
  - The extent to which the study constructs are reflective of reality
- Authenticity
  - The degree to which qualitative results reflect the judgement of the individuals who provided the data
- Criticality
The level of rigor applied to eliminating researcher bias

- **Integrity**
  - The degree to which the results of the study are not influenced by subjective judgements of the researcher

- **Explicitness**
  - Qualitative research must be auditable, there must exist a clear and traceable path of information from research design through results with logical consistency

- **Vividness**
  - The data must be thoroughly reported such that readers of a study may follow the research through to its conclusions

- **Creativity**
  - Research must be innovative and enhance the BoK in novel ways while maintaining scientific rigor

- **Thoroughness**
  - Sampling in a study must be comprehensive in development of ideas to the point that the research questions are answered completely

- **Congruence**
  - There must be logical consistency between the research methodology, results, and with previous research

- **Sensitivity**
Qualitative research must consider the participants by treating them with dignity and respect, and it should provide some degree of benefit to the community participating in the study.

This study establishes validity comprehensively across these measures in the following ways:

- **Credibility**
  - Case study analysis is utilized to contextualize literature and expert testimony within the framework of reality and the current state of the art.

- **Authenticity**
  - Following established study protocols
  - Literature review of best practices for research interviews
  - Utilizing a standard list of interview questions

- **Criticality**
  - Systematic literature review approach utilizing the established BoK from the literature to develop the conceptual model
  - Iterative dissertation committee feedback to gain approval of constructs through experience and knowledge

- **Integrity**
  - Iterative dissertation committee feedback to validate a robust study design and oversee consistent application of the research methodology
  - Literature guided development of interview method through established best practices
• Explicitness
  o Thorough documentation of the study methodology
  o Designing the method through review of interview best practices in established literature
• Vividness
  o Reporting codes from interview responses with full context of the question and interview circumstances
  o Reporting on the exact wording of interview responses
  o Complete interview transcripts published as appendices
• Creativity
  o Systematic literature review process
  o Iterative dissertation committee feedback process to establish value and validity of the research
• Thoroughness
  o Inclusion of industry and academia professionals
  o Basing interview questions in BoK identified in systematic literature review
  o Allowing experts to drive the narrative and their thoughts through semi-standard interview process
• Congruence
  o Iterative dissertation committee feedback process to include guidance from experienced researchers
• Sensitivity
Respectful administration of interviews
Publication of results that industry and academic communities may utilize them to advance the state of the art

3.5.2.3 Interview Candidate Identification

Potential interviewees will be identified with expert input from the committee overseeing this dissertation. Candidates with enough knowledge to be considered subject matter experts will be considered for the study. A subject matter expert is any individual who has heightened knowledge of a particular topic through their education or experience (Pace & Sheehan, 2002). Potential candidates include quality leaders at industry leading companies, members of the global research community from academia and industry, and members of quality organizations with exposure to global trends. The ideal interviewee will have unique knowledge of Quality 4.0 and a first-hand understanding of successful Quality 4.0 implementation.

3.5.2.4 Interview Data Analysis

Data collected from the interview phase of this research should be used to enhance the conceptual model by extracting themes and significant factors about Quality 4.0. A framework approach will be followed to extract themes from interview responses. The first step in the framework approach will be to analyze interview responses through thematic analysis with the following steps categorically sorting and revising themes (Smith & Firth, 2011). The initial conceptual model will be used as a preliminary framework for Quality 4.0 success serving the twofold purpose of validating the model against expert interview responses while identifying gaps or unnecessary portions of the model.
Execution of the framework approach will begin with a structured thematic analysis of all of the interview responses. It is critical that all themes from the initial conceptual model be identified prior to the analysis of interview responses such that themes which fail to present in expert responses may also be identified as potential candidates for removal from the model. The process for thematic analysis has been detailed as follows (Braun & Clarke, 2012):

1. Familiarization with the data
   a. Reading entirety of the interview transcripts
   b. To be performed at the conclusion of the interview process so that data can be reviewed in its entirety

2. Generating initial codes
   a. Codes are individual insights from a given data set
   b. A code can be seen as a single data point from an interview

3. Searching for themes
   a. Group codes together to begin to identify themes from the responses

4. Reviewing potential themes
   a. Review the potential themes against the entirety of the dataset
   b. Decide if a theme is present or if it is just a single data point
   c. Include the context of the literature review

5. Defining and naming themes
   a. Clarify the identified themes from the complete body of interview data

6. Reporting on the themes
   a. A comprehensive report on the results of the study to be included
3.5.3 Conceptual Model Revision

Once interview results have been analyzed the themes of the conceptual model will be adjusted. Potential new themes emerging from the interview portion of the research will be added to the model as appropriate. Themes from the original model which do not exist in the interview data may be evaluated during the initial revision. Themes present in the initial model which are supported by interview responses may be adjusted based on their prevalence during the interview process or validated as they are currently represented in the model.

These updates to the conceptual model will improve the model by validating or updating the completeness and validity of the model. The completeness of the model represents the degree to which the model covers the domain of Quality 4.0 implementation, and the validity of the model covers the degree to which all elements of the model are relevant to the Quality 4.0 Domain (Moody, Sindre, Brasethvik, & Solvberg, 2003).

3.5.4 Conceptual Model Finalization

The goal of the final conceptual model is to identify factors most important to deploying Quality 4.0 within a manufacturing environment as an early data point to support future deployments and a starting point for future research on implementation.

3.5.4.1 Conceptual Model Measures of Validity

The validity of the conceptual model can be determined through the following key factors (Moody et al., 2003):

- How complete the model is in capturing Quality 4.0 key factors
• This will be the primary purpose of the iterative revision of the model capturing the current literature, expert testimony, and the current state of industry

  • How necessary each element is within the model
    
    o This will be ensured through the elimination of factors not shown to be necessary throughout the iterative revision process

  • How independent each factor in the model is from other factors
    
    o This will be established through the thematic qualitative data analysis beginning with the interview data
CHAPTER FOUR: DATA COLLECTION AND ANALYSIS

4.1 Introduction

Eight candidates for interview were identified based on established subject matter expertise relating to the implementation of Industry 4.0 technologies.

4.1.1 Subject Matter Expert Identification

Interview candidates were identified through academic and industry channels related to Industry 4.0 and digital transformation. The study was presented to university faculty with experience and connection to digital transformation in industry to network with individuals with a high level of technical knowledge. Networking points of contact included the Department of Industrial and Systems Engineering at the University of Central Florida, The Industrial Engineering and Operations Management Society, The Department of Industrial, Systems, and Manufacturing Engineering at Wichita State University, and the Smart Factory @ Wichita partnership between Deloitte and Wichita State University.

4.2 Thematic analysis of conceptual model

High level themes were identified during the systematic literature review and form the basis for initial categorization of interview responses.

4.2.1 Preliminary Themes from Literature

The initial themes are clustered as follows:

- Strategy theme
  - Assessment of current state
  - Leadership commitment
• Digital strategy development

- Enablers theme
  - Culture
  - Company and resources
  - Management tools and methods

- Methodology theme
  - Lean
  - Total Quality Management

- Technology theme
  - Data collection and management
  - Data analytics
  - Data automation

4.3 Thematic Analysis of Interviews

The focus of the conducted expert interviews was on tangible applications of the technology, as the theory being well established through the literature review.

4.3.1 Method

The thematic analysis follows the method established at the end of section 3.5.2. Interviews were assessed individually to identify codes which may provide potential themes and those codes were synthesized into complete themes (Braun & Clarke, 2012).
4.3.1.1 Data Familiarization

Data familiarization is established through the interview, transcription, and code identification processes. A singular interviewer conducted each of the steps in the process, providing a thorough understanding of the sum total of data presented in the interviews. Each interview is examined for codes to build into themes in the following section. Reading textual data, listening to transcripts, and generally reviewing the data multiple times is the key to data familiarization (Braun & Clarke, 2012). This is established through the repetitive exposure to interviews by a singular analyst.

4.3.1.2 Code Identification

A code is a feature identified in the data which may be potentially relevant to the research question, and they may be summarized semantically through description of the identified relevant data (Braun & Clarke, 2012). Each interview was analyzed for codes individually within the context of the following research questions from section 1.4:

- What key factors are significant for manufacturing firms in achieving success with Quality 4.0 implementation?
  - What key factors are influencing Quality 4.0 outcomes in manufacturing firms already attempting any level of Quality 4.0?

Questions were organized in the context of the high-level themes, however initial codification of data from the interviews was done in the context of the research questions, with thematic sorting done post hoc on the body of codes identified from the population. All candidates were asked the
questions from section 3.5.2. Full interview transcripts from all eight experts are recorded in Appendix A.

4.3.2 Interview 1

Dr. Hayder Zghair was the first expert interviewed. His subject matter expertise was established through development of an Industry 4.0 curriculum for Pennsylvania State University. On his background:

“Talking about the topic of today’s matter, Industry 4.0, I’ve worked extensively in developing courses at Pennsylvania State University from scratch from the beginning. And this kind of cutting-edge technology, it requires, you are putting your hands into a place to be able to create a sense of what kind of courses and knowledge are needed for the students and the program directors and that’s exactly what I did. I teamed up with Bosch and their engineering team, the supplier of the technology to that lab at Pennsylvania State University. I’d been introduced to them and paired with them by the school because the deal was already initiated before, and I joined a couple of semesters in and they were wanting me to join them because it’s in my area to create the smart manufacturing for Industry 4.0. That was the title and the content of the course. And I really learned a lot about hands on technology, what’s the component of having smart, of having actually advanced manufacturing systems to be smart. And what the definition of the smart term and how much it connects to industry 4.0 techs so it would be the cutting-edge, kind of smart system, of manufacturing.”

Thorough hands-on development with Bosch Dr. Zghair established his expertise on the implementation of Industry 4.0 technologies, further solidifying his expertise through teaching and
content development for his curriculum. His interview responses generated the following initial codes:

4.3.2.1 Technologies Theme

“Yes, so the data collection for these Industry 4.0 techs, when we specifically are talking about the cloud technology as a whole, is where you’re actually controlling the data. What I mean here is the acquisition of data and where you store the data and later how will you call them, collect on them.”

Initial code 1: data architecture must be designed into the data infrastructure.

“The other form of the data with Industry 4.0, from my standpoint, is the data exchange in the system itself, in the field. So, you’re basically looking for instant data, it doesn’t really necessarily need to be stored, saved, at any place unless you create a pool of this historical data.”

“And the other form of data, actually, the data exchange which doesn’t necessarily need to be stored, it’s gone once done.”

Initial code 2: the use of real time data.

“Actually, that was one of the options that required extra in the deal with them, to actually have some, I would say, extra room in the cloud to store the data and call on it whenever you need and have that back-and-forth access to the data.”

“True, because you want to remember storing data and live data, meaning you go with time, it’s going to create a really massive size of data and that’s one of the challenges when it comes to the cloud technology and how to store this digital data. So you’ve got to make sure the data you’ll store and use your room in that cloud is kind of useful, it’s not just like saving them.”

Initial code 3: data infrastructure cost and ROI must be considered in the use case.
“It’s to provide, actually, those live data. We can kind of pre-show that if-this, that means some explanation so taking this explanation we can build subroutines including some like a list of tasks to be taken when that live data, which basically represents a variable, will help to show in terms of max and minimum what kind of list of actions we are taking as users.”

Initial code 4: data use case must drive tangible action.

“So that’s what I can catch from the data, as two types of data, one we store the data all along that we’re running the system for as long as possible, and looking to that as historical data. And my understanding, one of the ideas that I was planning to take to the next level, was to use it for the quality control by the way, because you will have historical data about your system and the sensors we use have to somehow observe the vibration from the machine.”

Initial code 5: realizing value from historical data collected by the system.

“What my point was, the way I thought about it, I thought as we are moving fast and are still in progress this type of technology, we need to explore the best things that we can catch from it, the best knowledge that we can track. Not actually the, you know we are human beings, sometimes when we feel safe with a data store we may kind of move slower than what’s really needed and what’s really required”

Initial code 6: architect data analysis and use cases to support actionable insights.

“Yes, now I would say all of the manufacturing machines that computers control can be connected to the, we call it the IoT gateway. We have the IoT gateway which is the key of industry 4.0 techs. It’s the combination of hardware and software.”

Initial code 7: fully connected data infrastructure across all devices.
“So, in all we tried to have the 3D printers, it is kind of the educational scale of other machines, it’s going to be the same way when you go to CNCs, by then as we started with the 3D printers because the G code and the programming code with this kind of machine it’s almost the same when we go to the CNC.”

Initial code 8: scalable software infrastructure.

“I think the sensors need to be really the key when it comes to quality, because remember what you’re measuring for quality is the end of the line. And when it comes to the automation, always at the end of the line we’re talking about sensors that can provide an eye for the users to see the adequacy of the process, the machine, the product, the whole operation.”

Initial code 9: technology that observes the operation of the system is key to quality.

4.3.2.2 Methodology Theme

“When you said real time, it’s really challenging because the definition is kind of different from programming standpoints, how long you will take to change the program from the quality manner like real time maybe, so it’s kind of real time has an extension. But to me, we as users as lean manufacturing and industrial system guys, is to have an observation of the current state of the system. If there’s any maintenance requires or failure caught in the system, that’s real time control.”

Initial code 10: real time data supports the Andon principle.

“Wherever you go you don’t need to physically present in the place to make the same change that you can do actually when you present, you can do it remotely. So, having this in hand and you have a system that can communicate with you when things wrong happen, and when I said wrong it’s based on my definition for wrong, like if there’s any failure call that’s considered wrong in my
terminology. So, that system that can communicate with me is the smart system who can communicate with me because I don’t need to sit in front of the system, sit in front of that screen or board and see and keep my eye open to see if there’s any call. The system itself will be able to communicate with me and tell me, notify me basically.”

Initial code 11: a smart system empowers the Gemba to actively communicate with decision makers.

“So, having this tool implemented it will be a great tool for lean, that industrial system that line of manufacturing, you will be able to observe if there’s any downtime to the system. So, you will have enough accessibility and enough to respond to your system so it will keep your system up, not losing, not wasting.”

Initial code 12: smart systems empower waste observation in real time.

“Total Quality Management, to my understanding, it’s the quality of the system and the quality of the product, the operations and the products. So, as I said, this Industry 4.0 with the technologies provided it actually has the two access that you need to control this global quality. The operation itself and the product itself.”

Initial code 13: Industry 4.0 systems streamline data for TQM applications.

“So that will enable, actually, any in-progress or in-process modifications for improving and pushing the quality, and the same thing for the operations, for the machine itself. When things happen related to the machine that cause some defect on the line, industrial line, you will have an idea about that change instead of the machine so you will have the same accessway in modifying and making sure the quality is still under control when it comes to the global quality of your system.”
Initial code 14: Industry 4.0 technologies empower faster response to quality issues.

4.3.2.3 Enablers Theme

“When we’re actually talking about the corporate side of, I would say, the decision or understanding or deciding to implement, I think when we show the value of this system and how it’s connected to the profitability, how it’s actually saving for controlling the machine failures.”

Initial code 15: systems must be designed with a business case in mind.

“It may not really be an encouraging step to take to invest in this. But if we can show to them the value to the long term and what kind of facilitating tools, or variety of tools actually, this technology will provide to the system, I think they will get the courage needed to move to this shift, at the administrative level.”

Initial code 16: ROI may have long lead time.

Initial code 17: business case must drive leadership commitment.

“Yes, now as I said if you have an extra layer of control in your system, at an administrative level all that I see is a daily report on the system, how my system or how my business actually is running. Now if you have an extra control layer it allows you to just observe how the operation runs live and while you don’t really need to be in the place, that’s a great value, I think if they have that access they may think of the extra control layer for their business I think that may be one of the key things that we should provide.”

Initial code 18: developing data architecture to suit leadership needs in addition to operational needs will help with buy in.
“Still, you’re looking for how to manage the action that needs to be taken while remotely controlling the system. Are you going to have robotic arms to do the job for you? Are you going to have a lot of staff running in this system when things happen, and they need some instructions you call them? Or you put them in that email loop, so you have them in your loop when things happen? So, there is an undecided, kind of things need to be done to have that fully automated, fully remote, and real time control system.”

Initial code 19: system design goes beyond data and must extend into the actions driven by the data.

“Yeah, now the barriers, actually, there’s two barriers for having Industry 4.0 as a tool for those industrial engineering experts, specifically quality. The main one on the hands-on level, you don’t have the one man show in this kind of game, in Industry 4.0. You will be dealing with different personnel, different backgrounds, different educational people. You’ll be looking for programming people, you’re looking for hardware people, looking for the manufacturers. So, they all need to come together having the same understanding, the same view to implement the system and make it run.”

Initial code 20: diverse skills are required for system development.

“Most people are concerned about the security, the cybersecurity is a trend now. The way I understand cybersecurity actually is building walls to your business, building warehouses, building gates, building badges to get access going on and off in your facility. So, security is another challenge, it’s kind of at the top level of implementing things, and when it comes to quality you are significantly sharing significant information about your system.”

Initial code 21: cybersecurity must be addressed to drive top level leadership buy in.
“I would rank them I would say the communication first, I don’t know if it’s right to say this, remember I was building things from scratch. So, I’m really sharing a kind of live and fresh things. Even, I heard from the team that I work with as a whole when we talk and as individuals when we talk. We’re taking really long to understand our thoughts, when we share our thoughts in discussions, because when we’re dealing with a programming guy or electric guy it isn’t necessary for them to be really interested in understanding the manufacturing aspect with the quality of production.”

“It’s communication first and human nature that we all love to stay in our comfort zone, to put it this way, and it isn’t necessary to have the shared mission or belief, so that’s actually one challenge. If we succeed to put that mission or that belief, we get to that consensus level that we all agree that this is our objective it will be no problem.”

Initial code 22: cross functional team facilitation is important to achieving system objectives.

Initial code 23: leadership and change management tools are critical to success.

“So, if in case you need to succeed with this you need to have your people have that shared mission, all believing in it. And they need to all affiliate it to the business.”

“Now, different backgrounds, in terms of how it’s done, it’s not encouraging people to learn more about your problems as a manufacturing engineer, as a production engineer, as a quality engineer, as a programming engineer, as a communication engineer, there’s a really, personally there’s a really motivating, it motivated me to learn more about programming, as I know for example my peers, he's the man of those things. And I keep asking questions that may not be possible from his standpoint. So, if I will have this shared mission belief, and so I will spend time and effort to understand his standing.”
Initial code 24: culture must support a shared vision and mission for system development.

4.3.2.4 Strategy Theme

“So, if we clearly define our factors that we’ve leveraged our quality, so if they’re possible to be implemented with the Industry 4.0 technology variable, I think there should be no problem for that, for this quality structure of the company or business. So, the key is to be clear on your quality factors, that’s the thing.”

Initial code 25: clearly defined quality and performance targets must be defined to identify relevant data.

“I have the pieces of markers and I’m producing markers for example, or steel shafts, or for example any type of other products. The quality will have different definitions. So maybe for the shaft it’s possible to control the quality factors and not for the marker for example.”

Initial code 26: data to be collected and utilized within the system must be appropriately defined for the specific technology use case.

“I would actually, first, I would take a strategy that would go parallel in three lines. The first line is making sure the physical equipment or machinery have that connectivity at that level, basically computer control based with a central PLC. That goes very technical and very hands on line. The second line actually focusing on the communication protocol for the IoT gateway. It’s hardware and software, because this is going to be the hub point that connects the physical world with the virtual world of your system.”

Initial code 27: data system infrastructure and architecture are critical early steps to success.
“And for sure being clear on what you want from the cloud control, because it’s a product, so I would say this, for the quality you guys need to deal more with the data that you’ve collected and are storing and what type of strategy that you’re using for the data. For the manufacturing control, or production control, like for a very definitive production term I would say the system adequacy, the system tailor, and any related to this line will be the target of this strategy the third line of strategy.”

Initial code 28: developing a data use case is a critical step in pre implementation strategy.

“Now, when I talk to people in industry, they like the idea, the main fear they may have is their position. If it’s, how new technology will affect their position in the coming ten years, twenty years, twenty-five years. Are they going to be valuable or are they going to be gone, no positions like what they’re doing now. Generally, they like the idea as long as it’s not going to, you know, hit their place. That’s how I see Industry 4.0 in the future and how people actually are happy with it and we can assess this shift.”

Initial code 29: apprehension about automation and job change must be addressed.

“Based on that topic, how are you going to direct those data, for example for the quality purpose, for control, production purpose, for maintenance scheduling, you have raw data collected, pulled, and in the cloud and then whatever technology that you have. Any intelligent kind of advanced tool, you can use the data.”

Initial code 30: data strategy must include tangible use cases.

“Not actually the, you know we are human beings, sometimes when we feel safe with a data store we may kind of move slower than what’s really needed and what’s really required so I thought to focus on what the benefit of the data that we see right there and what we can directly apply in the manufacturing field.”
Initial code 31: transitioning to real time data and new capabilities requires change management and strategy.

4.3.3 Interview 1 Codes

Initial codes are summarized in table 6:
<table>
<thead>
<tr>
<th>Code</th>
<th>Technologies Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Data architecture must be designed into data infrastructure</td>
</tr>
<tr>
<td>2</td>
<td>Use real time data</td>
</tr>
<tr>
<td>3</td>
<td>Data infrastructure, cost, and ROI must be considered in use case</td>
</tr>
<tr>
<td>4</td>
<td>Data use case must drive tangible action</td>
</tr>
<tr>
<td>5</td>
<td>Realization of value from historical data collected by the system</td>
</tr>
<tr>
<td>6</td>
<td>Architect data analysis and use cases to support actionable insights</td>
</tr>
<tr>
<td>7</td>
<td>Fully connect data infrastructure across all devices</td>
</tr>
<tr>
<td>8</td>
<td>Scalable software infrastructure</td>
</tr>
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</tr>
<tr>
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<td>A smart system empowers the Gemba to actively communicate with decision makers</td>
</tr>
<tr>
<td>12</td>
<td>Smart systems empower waste observation in real time</td>
</tr>
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<td>15</td>
<td>Systems must be designed with business case in mind</td>
</tr>
<tr>
<td>16</td>
<td>ROI may have long lead time</td>
</tr>
<tr>
<td>17</td>
<td>Business case must drive leadership commitment</td>
</tr>
<tr>
<td>18</td>
<td>Developing data architecture to suit leadership needs in addition to operational needs will help with buy in</td>
</tr>
<tr>
<td>19</td>
<td>System design goes beyond data and must extend into the actions driven by the data</td>
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<tr>
<td>20</td>
<td>Diverse skills are required for system development</td>
</tr>
<tr>
<td>21</td>
<td>Cybersecurity must be addressed to drive top level leadership buy in</td>
</tr>
<tr>
<td>22</td>
<td>Cross functional team facilitation is important to achieving system objectives</td>
</tr>
<tr>
<td>23</td>
<td>Leadership and change management tools are critical to success</td>
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<td>29</td>
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</tr>
<tr>
<td>31</td>
<td>Transitioning to real time data and new capabilities requires change management and strategy</td>
</tr>
</tbody>
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4.3.4 Interview 2

Mr. Chris Koch was interviewed for his subject matter expertise ranging from the development of products for connected systems as well as process improvement utilizing data automation, including time with Amazon, Ring, and Bosch:

“I was working for a company called Bosch connected devices and solutions, part of Robert Bosch LLC here in the US. And that entire companies’ portfolio revolved around Industry 4.0. And I was a field application engineer for them slash sales engineer slash technical program manager for them and what that enabled me to do was to talk to, interview, you know, and understand what type of technologies were needed in various fields across the Quality 4.0 or as we called it the industrial 4.0 realm. So, I worked with companies in shipping and logistics, companies that worked with solar panels, and companies who wanted to understand how to monitor with freezing technology for medical purposes. We crossed a huge gamut of things, parking lot sensors that will monitor parking spaces. We had vibration sensors that would go onto motors in factories, and we had a myriad of devices that were really geared towards I4.0.”

Working directly with clients to develop data driven solutions towards performance improvement has firmly established Mr. Koch’s expertise on the subject of Quality 4.0 applications. His responses to interview questions provided the following initial codes:

4.3.4.1 Technology Theme

“I mainly focused on sensors and the state of the art now is becoming more in terms of vibration sensors in the industry and factories and things like that. So, between that and between, I would say, audio and visual, so they’re getting much better at looking at, visually being able to inspect certain machines along assembly lines.”
Initial code 32: sensing capabilities observe the operation of a production system in real time.

“They have an insane system where they can visualize almost everything and determine whether things are going down the right path or not going down the right path, whether things are being picked and placed properly.”

Initial code 33: Industry 4.0 systems identify incorrect conditions in real time.

“And I think as you move up that technology also needs to incorporate the data capture and the data presentation, the user presentation of that data, in order for you to enable your customer, in this case would be the user of the product even if it’s your own employee being able to look at the data and do something with it.”

Initial code 34: technology use case must include end users and tangible actionable outputs.

“What I did was work with customers who would show me what they would do with the analytics, and there’s a lot of really great technology out there that is starting to analyze and interpret that data and they have to do it really fast, and they have to do with known variables essentially.”

Initial code 35: analysis should happen in real time.

“So, it’s that type of analysis in the future lets you automate it and use more of an AI I would say, this artificial intelligence that can go into this data capture is going to be able to create its own baseline, hopefully, in the future, of a known good state and then be able to monitor itself after that for more deviation. And I’ve seen some technology that can already do this.”

Initial code 36: analysis and actionable insights can be generated automatically without human intervention.
“So, it really helps these factory workers know exactly what they need to pick, it’ll let you know the amount of torque that you’re putting on screws, and all this is doing is leading to less mistakes. And better-quality products coming off the line, so little things like that, automation like that, is already state of the art.”

Initial code 37: technology should augment human performance within a system.

“So they have all these automated systems now that take thousands of photos of your board when it’s done and they automatically compare to what they know it should be or shouldn’t be, and then they can flag it all automatically without a user doing anything, and unless something is flagged to say “hey we have an issue with this board” so I think technology like that, the automation that is already there has really helped the industry.”

Initial code 38: Industry 4.0 systems can monitor the quality of products in real time.

4.3.4.2 Methodology Theme

“Some technology that I’ve seen that was just developing when I left Bosch was going a little more into, hey we know what’s happening based on their system, based on these anomalies. And I’ve seen people use motors and fans as examples. They can tell you when one of the fan blades is chipped or there is some debris on it or something that is causing it to be skewed in any way. They could quickly tell you that that was the anomaly, or there’s something jammed in the motor that could tell you that was the anomaly. So, there’s a lot of technology that’s already building up towards that automatic detection of problems that you face in the factory.”

Initial theme 39: sensing technology enables the Andon principle to be actively practiced.

“There’s also automation out there that will help workers on the assembly line understand what type of part they need to pick. These are already in operation.
I have seen these visual aids that will point to the part on your assembly line that you need to pick, so which screw do you need, there will be a laser that points to the screw bin that you need to pick from and then it will watch as you take it and screw it in and then it’ll go to the next part.”

Initial theme 40: Industry 4.0 technologies enable Poke-Yoking systems through continuous observation.

Initial theme 41: adaptive visual management tools can be developed with new sensing and data presentation capabilities.

“But yeah, I think where this will move with other things, is you know in terms of factory 4.0 for knowing when machines are, might be, going down. I think that’ll become more automated in the future too.”

“I understand that the bearing on the CNC machine is going bad after a certain number of cycles. And the cycle counter is not exact but it’s close so now you can understand what type of sensors that you need to move forward with. You can have a vibration sensor but if you know that it’s a product that needs to be replaced after so many cycles, but maybe you’re not running just a hundred cycles a day, maybe it’s a hundred one day, ten the next, twenty the next, and you’re not able to record that very easily but you can put a magnetometer on there or some type of orientation sensor on there to say exactly how many cycles you’re running and when you reach a specific threshold that you set, that’s when you can alert the user it’s time to recalibrate, it’s time to replace this part, whatever it might be.”

Initial code 42: data collection on equipment enhances total productive maintenance.

“And so we are constantly reiterating and updating those processes, and it also gives us better insight through all this understanding of how our contract
manufacturers are going about their process and if we see any red flags that could be creating an issue down the line, for example if you’re soldering on a wire early on in the process and then you start to bend and poke and twist at that wire and then the final product has these wires that are frayed and aren’t making good contact anymore you can understand that early on in the process and change where that happens.”

Initial code 43: data and system observation should flow upstream to suppliers.

Initial code 44: deeper data on system operation empowers continuous improvement.

Initial code 45: observing system conditions enables quality to be built into processes.

“And so, in the manufacturing process, when you give people that type of responsibility and you put your trust into them to be able to stop a line, that is what is going to help create this buy in that I was talking about earlier, but it’s also going to allow you to stop bad quality defects early on. And I think that’s one of the things that this Quality 4.0 is going to allow, because it’s going to allow more visualization and it will give people the peace of mind that they’re making the right call early on because they’re going to see the data and eventually the data will probably tell them something is wrong.”

Initial code 46: the Andon principle maximizes the value of observing defects in real time.

“So, it allows you to, and all the workers and all the users of these systems, it gives you to more quickly assess the situation and confidently make a decision with the data that you have. I think it does put quality across the line and across all users.”

Initial Theme 47: Quality 4.0 systems empower lean culture through supporting data.

Initial theme 48: Quality 4.0 systems make quality a shared responsibility.
4.3.4.3 Enablers Theme

“So, you need to get that buy in from your employees, you need to get the buy in from the management too. So, you basically just can’t force it onto people. And getting that buy in is going to be very difficult because a lot of people look at Quality 4.0 as an automated, robotic system that is going to replace your employees.”

“That’s always the biggest issue I think with the Industry 4.0 and Quality 4.0 solutions right now, is so many people think that it’s going to take their jobs so they don’t buy into it because they don’t want to buy into something that they think is going to replace them.”

Initial code 49: employee buy in must address automation job loss fears.

Initial code 50: management buy in is critical to success.

“Instead, what needs to be emphasized to them is that this isn’t to replace you, it’s giving you more skills to make you more valuable and it’s helping you do your job more efficiently, more productively. And those are the key factors that I think need to be relayed across to users.”

Initial code 51: user job design and communication must be addressed to drive buy in.

“Another, of course, you have to worry about security and making sure that the data is secure and that there’s not going to be any issues with corruption of data or stolen data or, you know, anything that could be negative on the security front.”

Initial code 52: cybersecurity must be addressed.
“That’s becoming less the case these days but there are definitely still some cases out there where getting that, getting all the data that you need, centrally in one location becomes harder and harder for some companies.”

Initial code 53: company capabilities must be considered in system development.

“It’s a lot of data that you will be collecting really fast and needing to do something with even faster. So, I think that becomes one of the biggest barriers for most people when they buy in, because you either have to slow down the data collection in order to be able to properly collect it and send it up the line or you’re going to have to start having the processing locally which means you have to have more processing power locally.”

Initial code 54: investment in system capability must match system needs.

“And then a lot of that data gets lost as you move it up the line because instead of sending your raw data up the line, now you’re likely collecting and throwing away the raw data after a short period of time and analyzing it locally and then just sending the analytics up. I think that data collection barrier becomes really big for a lot of people.”

Initial code 55: hesitancy towards not saving historical data may require cultural and behavioral change within the organization.

“But right now, we’re still adopting these tools and it’s a slow adoption because we have some engineers that are older, and they are not used to this and they’re having to switch the way they do things. And that’s a little hard to do. But they’re working towards learning these new systems and moving forward with it and then the younger engineers are, they’re pretty gung-ho about these systems, everybody knows it’s the new wave and the way things are going to go forward.”
Initial code 56: addressing employee skill levels and skill gaps is critical to success.

4.3.4.4 Strategy Theme

“So, the very first thing that you need to do is understand that something is wrong, something can be improved, we have this quality issue, how can we go about resolving it? And whether that is with a specific machine or whether it’s with your assembly line, whatever it is you need to understand what the problem is and get down to the root cause. And once you do that then you can start either your top down or your bottom-up approach to solving the system. And maybe which direction you go will change based on what the root cause of your issue is.”

“So those are becoming more and more state of the art but there’s still, I feel like, some missing pieces out there where it is not so intuitive yet for people to use that data and do something with that data. And it’s not so easy for it to all get set up and start collecting the data and immediately see results.”

Initial code 57: tangible results for data applications must be designed into systems at the ground level.

“But another thing that I’ve noticed is everybody wants a different architecture of their system. Some people are great with Wi-Fi, some people want cellular, some people want Bluetooth, you know or some sub-gigahertz technology, and being able to give them exactly what they need from a data collection standpoint through the cloud or whatever they’re going to use in order to analyze and then push that data out to the respective users, that’s going to be another very key point that could be prohibitive to some users and use cases that won’t allow a solution to get off the ground.”

Initial code 58: initial system architecture must include a use case within the strategy development.
“And if you don’t know what your issue is, if you just want to buy into 4.0 that becomes increasingly difficult, because if you don’t have a problem to solve then it’s really hard to say “oh yeah go out and buy this sensor it’s going to help you out” because it may or may not in the end right?”

Initial code 59: developing a value adding use case drives buy in.

“So, that’s how I would do it, you define the problem and then you can move forward with the solution by understanding what type of sensor would best work for you, understanding what type of data from that sensor is going to work best for you, and how to then move that data up the line, upstream into an analytics platform and into a user interface that can be easily testable and easily read and understood by the relevant parties who need to see that data.”

Initial code 60: developing actionable use cases starting with a value proposition is critical to success.

“Like I mentioned with the automation that I feel like people want to see in the industry, it’s automation that is going to make the workers lives easier. It’s automation that is going to tell you that there’s something wrong, but you still need to do something about it.”

Initial code 61: system automation must be designed to amplify the ability of employees within the system.

“And then they wouldn’t have any worries about unexpected downtime and losing all that money as they shifted from one line to the next. In the end I think that is going to be one of the biggest things for success for a lot of companies is having a longer on time, if you will, a longer production time and having less and less downtime, especially unexpected downtime.”

Initial code 62: a successful use case must drive tangible and financial benefits.
4.3.5 Interview 2 Codes

Initial codes are summarized in table 7:
<table>
<thead>
<tr>
<th>Code</th>
<th>Technologies Codes</th>
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</thead>
<tbody>
<tr>
<td>32</td>
<td>Sensing capabilities observe the operation of a production system in real time</td>
</tr>
<tr>
<td>33</td>
<td>Industry 4.0 systems identify incorrect conditions in real time</td>
</tr>
<tr>
<td>34</td>
<td>Technology use cases must include end users and tangible actionable outputs</td>
</tr>
<tr>
<td>35</td>
<td>Analysis should happen in real time</td>
</tr>
<tr>
<td>36</td>
<td>Analysis and actionable insights can be generated automatically without human intervention</td>
</tr>
<tr>
<td>37</td>
<td>Technology should augment human performance within a system</td>
</tr>
<tr>
<td>38</td>
<td>Industry 4.0 systems can monitor the quality of products in real time</td>
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<table>
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<tr>
<th>Code</th>
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</thead>
<tbody>
<tr>
<td>39</td>
<td>Sensing technology enables the Andon principle to be actively practiced</td>
</tr>
<tr>
<td>40</td>
<td>Industry 4.0 technologies enable Poke-Yoking systems through continuous observation</td>
</tr>
<tr>
<td>41</td>
<td>Adaptive visual management tools can be developed with new sensing and data presentation capabilities</td>
</tr>
<tr>
<td>42</td>
<td>Data collection on equipment enhances total productive maintenance</td>
</tr>
<tr>
<td>43</td>
<td>Data and system observation should flow upstream to suppliers</td>
</tr>
<tr>
<td>44</td>
<td>Deeper data on system operation empowers continuous improvement</td>
</tr>
<tr>
<td>45</td>
<td>Observing system conditions enables quality to be built into the process</td>
</tr>
<tr>
<td>46</td>
<td>The Andon principle maximizes the value of observing defects in real time</td>
</tr>
<tr>
<td>47</td>
<td>Quality 4.0 systems empower lean culture through supporting data</td>
</tr>
<tr>
<td>48</td>
<td>Quality 4.0 systems make quality a shared responsibility</td>
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<table>
<thead>
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<tbody>
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<tr>
<td>50</td>
<td>Management buy in is critical to success</td>
</tr>
<tr>
<td>51</td>
<td>User job design and communication must be addressed to drive buy in</td>
</tr>
<tr>
<td>52</td>
<td>Cybersecurity must be addressed</td>
</tr>
<tr>
<td>53</td>
<td>Company capabilities must be considered in system development</td>
</tr>
<tr>
<td>54</td>
<td>Investment in system capability must match system needs</td>
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<tr>
<td>55</td>
<td>Hesitancy towards not saving historical data may require cultural and behavioral change within the organization</td>
</tr>
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<td>Addressing employee skill levels and skill gaps is critical to success</td>
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<tr>
<th>Code</th>
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<tbody>
<tr>
<td>57</td>
<td>Tangible results for data applications must be designed into systems at the ground level</td>
</tr>
<tr>
<td>58</td>
<td>Initial system architecture must include a use case within the strategy development</td>
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<td>Developing a value adding use case drives buy in</td>
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<td>62</td>
<td>A successful use case must drive tangible financial benefits</td>
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4.3.6 Interview 3

Mr. Kevin Donaldson established subject matter expertise through twenty years of experience consulting, primarily with IBM:

“I have been in the management consulting industry for a little over twenty some odd years. Primarily, almost twenty years with the IBM corporation in global business services. Certainly, have implemented a lot of IBM’s technology as well as third party technologies, you know, throughout my career. We certainly have applied some of our, what I would say advanced analytics, to client problems and opportunities. To deliver what I would say are Industry 4.0 capabilities.”

Through the development of advanced analytics solutions to a wide range of problems Mr. Donaldson’s implementation experience is relevant to the study. From his responses to interview questions the following codes were extracted:

4.3.6.1 Technology Theme

“Once that plane, that aircraft, is turned over to the airline they then own that asset, and they collect data on behalf of that entity. Whether that be American, united, or other. In doing so, what people, many people don’t realize is that the engine that is determined for that particular aircraft is really the decision between the airline in many cases and the engine manufacturer. The data from the engine is between those two parties in most cases, it’s not something that, you know, Boeing will get the full breadth of that data corpus as a part of their ability to evoke a digital twin. So now we’ve got three parties who have a piece of the data if you will, available to them and none of which are willing to share with the others.”

Initial code 63: data infrastructure must provide sufficient data to drive action for a use case.
“So, as we talk about Industry 4.0 I think digital twin or the capability to do a digital twin is probably one of the ones that is top of mind for most of us. And the reason that is, is that you can then make some determination, make some predictions around quality, around the possibility of failure of any given component or aircraft or assembly. The richer the data the better off you’re doing around prediction.”

Initial code 64: focus on high value data use cases in any Industry 4.0 application.

Initial code 65: data value and validity are critical to the overall success of a data system.

“But to get to a data stream. So, to understand how the effect of certain situations would affect the stress that particular aircraft is under over a given period and be able to make some predictions even while the plane is flying.”

Initial code 66: real time data use cases maximize the value of an Industry 4.0 system.

4.3.6.2 Methodology Theme

“And in this particular place this client allowed the scheduling to take place at each cell and then also there was a master schedule for which, that kind of managed the entire flow. What we found, and it wasn’t a very deep assessment, but what we found was that left to their own devices, to their own objectives per cell, that they sub optimized the overall capability of the manufacturing facility. Ok, because really what you have, you had conflicting objectives between the two. Certainly, the objectives would be to fully utilize the human resources. Well in cases where parts were not available, it doesn’t make sense to go on to the next step when the next step would require you to redo, repeat, once the part would arrive. It would make more sense to just sit there and wait for the part to arrive, assuming the part was imminent to arrive, right? But in a manufacturing facility you walk through, and management walks through and they see somebody sitting, that can’t be the case, get busy. Well, some of that busy work
was really a detriment to the overall manufacturing capability… Ok, so you know along with this data capability, these analytics that we describe, we also need to change our objectives. We would need to change our aspirations about what good is, with this new data.”

Initial code 67: integrated data systems empower lean flow.

Initial code 68: Quality 4.0 systems benefit from big picture goals and a lean culture.

“So, I think lean six sigma is something that I think we did in the 80s and 90s and we continue to do so, but I don’t think lean six sigma necessarily is the catalyst for Industry 4.0. I think the advent of video technologies, the advent of the scan and those kind of things are really going to move, I believe will move Industry 4.0 further.”

Initial code 69: technologies that enable monitoring of the process and product empower processes such as lean and six sigma.

4.3.6.3 Enablers Theme

“So now we’ve got three parties who have a piece of the data if you will, available to them and none of which are willing to share with the others because they’re looking to monetize the situation a bit, so and then it could be even as the plane gets older and flies in different locations. There’s a bit of other information that comes about with the sustainment capabilities right, so there’s third parties that will sustain the plane on behalf of the airline. So now we have four parties that have data that would enrich, you know, the data corpus required to do a digital twin.”

Initial code 70: data architecture must include and connect all data relevant to use cases to be effective.
“I mean did it fly through a storm, did it fly through, at certain speeds, did it land faster than normal, what was the operation of the pilot. Those kind of things are going to be critical to really understanding the performance and the predictability of a quality incident if you will, as we would predict going further. How long can that plane fly on those particular tires, I’m using that as an example right, so having that complete data corpus is going to be critical for Industry 4.0 capabilities.”

Initial code 71: establishing a dataset that realizes value is necessary for a use case.

“I mean as an example the 787 when it lands it has a terabyte of data. To be able to take advantage of that, I mean, you’re going to have to have very large systems to do that. You’re going to have to evoke cloud capabilities.”

Initial code 72: infrastructure must be sufficient to handle big data, requiring investment and established value from use cases.

“So, we talk about strategies for digital transformation. I’ll tell you one thing that as we talk about the capabilities, what we’re not talking about is really the human factor. Now as humans I think it’s part of our natural experience to challenge. Is not to accept what we see in front of us or to challenge what we see in front of us. I think to, a person on the shop floor or what I would say close to the processing, close to the manufacturing, close to whatever, is really to accept the information that they see.”

Initial code 73: leadership and change management are necessary for digital transformation.

Initial code 74: human factors must be considered prior to developing a digital system.

“So, we’ve got to, we have to train the human factor as to how we’re going to integrate ourselves with these capabilities, or with all these capabilities, and at what point do we just completely rely on the machine to make the calculations.”
Initial code 75: data inputs and system outputs must be validated.

Initial code 76: trust must be built with the employees for buy in to the system.

4.3.6.4 Strategy Theme

“Ok, so you know along with this data capability, these analytics that we describe, we also need to change our objectives. We would need to change our aspirations about what good is, with this new data.”

Initial code 77: building strategy around data capability is critical.

“I mean did it fly through a storm, did it fly through, at certain speeds, did it land faster than normal, what was the operation of the pilot. Those kind of things are going to be critical to really understanding the performance and the predictability of a quality incident if you will, as we would predict going further. How long can that plane fly on those particular tires, I’m using that as an example right, so having that complete data corpus is going to be critical for Industry 4.0 capabilities. As we talk about systems, I think that corporations are really going to have to look at the ability to do some of the things I’m describing.”

Initial code 78: developing a data use case based on value and actionability is critical to overall system architecture and success.

4.3.7 Interview 3 Codes

Initial codes are summarized in table 8:
Table 8 - Mr. Kevin Donaldson Codes

<table>
<thead>
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<tr>
<td>78</td>
<td>Developing a data use case based on value and actionability is critical to overall system architecture and success</td>
</tr>
</tbody>
</table>

4.3.8 Interview 4

Dr. Alaa Elwany participates in research through his position at Texas A&M University, as well as working with the US federal government, on Industry 4.0 topics. On his subject matter expertise:

“I’m a faculty member at the department of industrial and systems engineering, Texas A&M university, and right now I’m on detail with the US federal government, serving with the department of energy advanced manufacturing
office. My involvement with Industry 4.0 is mainly through my research work. I do work on additive manufacturing which is the technical term for 3D printing. And 3D printing is an integral part, or one of the building blocks of Industry 4.0. I also do a lot of work with using data and the tools of data analytics, machine learning, with advanced additive manufacturing processes which is also an element of Industry 4.0.”

The following codes have been synthesized from his interview responses:

4.3.8.1 Technology Theme

“Now if we talk about quality then I would definitely put new types of sensors and sensing devices, the landscape of sensors keeps expanding and these are definitely essential towards ensuring quality in Industry 4.0 systems.”

Initial code 79: sensing and detection technologies are critical to quality.

“I would regard it as a system where, that is characterized by being autonomous, decisions are autonomous based on sensor data collected from the physical assets in the system, and seamlessly transferred and sent to central processing systems in the cloud.”

Initial code 80: digital transformation should include data and information automation.

4.3.8.2 Methodology Theme

“I see them as pretty much the same. If we talk about lean manufacturing, six sigma, agile manufacturing, all of these are the terms that emerged a decade ago and all of these evolved to what we call Industry 4.0 today. So I see Industry 4.0 as a natural extension of these concepts that takes advantage of new technologies like cloud computing and sensors and the ones that I just mentioned.”
Initial code 81: Industry 4.0 technologies empower lean manufacturing and other management philosophies.

“That’s what Industry 4.0 is all about. Industry 4.0 and quality in Industry 4.0 is about having possibly physically disconnected entities that are connected through the virtual space, and then the responsibility of meeting quality requirements is distributed.”

Initial code 82: Industry 4.0 has the goal of achieving TQM.

4.3.8.3 Enablers Theme

“That’s what Industry 4.0 is all about. Industry 4.0 and quality in Industry 4.0 is about having possibly physically disconnected entities that are connected through the virtual space, and then the responsibility of meeting quality requirements is distributed.”

Initial code 83: to maximize Industry 4.0 technologies a culture of empowerment and accountability for quality is necessary.

“Number one would be the talent, the availability of a trained workforce equipped with the necessary knowledge and tools and training on all these technologies. So that’s number one, the talent and workforce.”

Initial code 84: workforce skill deficit is a primary barrier to Quality 4.0 system implementation.

“And number two would be resistance to change, because many companies just want to follow the “we’ve been doing it like this successfully, why do we need to adopt these new technologies”.”

Initial code 85: change management and leadership are critical success factors for implementation.
Initial code 86: the workforce must be considered in system design beyond the technical feasibility.

“Number three is the, that’s a very practical constraint, is much of the adoption of these new technologies often happens at small and medium enterprises, as opposed to large companies. Large companies do not prefer to work with these emerging technologies that have not been proven yet, and small and medium enterprises have all sorts of finance and economic constraints.”

Initial code 87: organizational structure and culture at small and medium companies is advantageous to implementing digital transformation.

Initial code 88: large companies are more capable of financially implementing the infrastructure for a new technology.

4.3.8.4 Strategy Theme

“So, the barriers really are not technological, the barriers are talent, resistant to change due the need of large companies to de-risk technologies before they use them or adopt them or implement them, and the challenges that the small and medium enterprises have been facing over the past decade or two.”

Initial code 89: implementation strategy must include the workforce to be feasible.

Initial code 90: digital systems must have viable value propositions and achievable, tangible, ROIs.

“No one will be able to do this on their own. This has to be models of partnerships where the private industry, both large and small, and the federal government, and the research institutes and academia have to work together in convening spaces where they work together on defining the obstacles and collaboratively de-risking and implementing these technologies. So, I’m a believer in public-private partnerships.”
Initial code 91: implementation strategy must bridge the gap between theory and use cases which provide value.

Initial code 92: resources and knowledge should be maximized during the strategy phase to develop adequate business cases.

“And then decisions going back with an effective feedback loop such that, and a system that has clearly defined metrics. How do I define whether I have met my objective or not, so if I were to recap or summarize what I just said: that would be a system that’s characterized by being autonomous, having a feedback capability, and well-defined metrics to measure their performance and impact.”

Initial code 93: data strategy must drive actionable insights.

4.3.9 Interview 4 Codes

Initial codes are summarized in table 9:
Table 9 - Dr. Alaa Elwany Codes

<table>
<thead>
<tr>
<th>Code</th>
<th>Dr. Alaa Elwany Codes</th>
<th>Technologies Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td></td>
<td>Sensing and detection technologies are critical to quality</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>Digital transformation should include data and information automation</td>
</tr>
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<thead>
<tr>
<th>Code</th>
<th>Methodology Codes</th>
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</thead>
<tbody>
<tr>
<td>81</td>
<td>Industry 4.0 technologies empower lean manufacturing and other management philosophies</td>
</tr>
<tr>
<td>82</td>
<td>Industry 4.0 has the goal of achieving TQM</td>
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<table>
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<tr>
<th>Code</th>
<th>Enablers Codes</th>
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</thead>
<tbody>
<tr>
<td>83</td>
<td>To maximize Industry 4.0 technologies a culture of empowerment and accountability for quality is necessary</td>
</tr>
<tr>
<td>84</td>
<td>Workforce skill deficit is a primary barrier to Quality 4.0 system implementation</td>
</tr>
<tr>
<td>85</td>
<td>Change management and leadership are critical success factors for implementation</td>
</tr>
<tr>
<td>86</td>
<td>The workforce must be considered in system design beyond the technical feasibility</td>
</tr>
<tr>
<td>87</td>
<td>Organizational structure and culture at small and medium companies is advantageous to implementing digital transformation</td>
</tr>
<tr>
<td>88</td>
<td>Large companies are more capable of financially implementing the infrastructure for a new technology</td>
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<tr>
<th>Code</th>
<th>Strategy Codes</th>
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<tbody>
<tr>
<td>89</td>
<td>Implementation strategy must include the workforce to be feasible</td>
</tr>
<tr>
<td>90</td>
<td>Digital systems must have viable value propositions and achievable, tangible, ROIs</td>
</tr>
<tr>
<td>91</td>
<td>Implementation strategy must bridge the gap between theory and use cases which provide value</td>
</tr>
<tr>
<td>92</td>
<td>Resources and knowledge should be maximized during the strategy phase to develop adequate business cases</td>
</tr>
<tr>
<td>93</td>
<td>Data strategy must drive actionable insights</td>
</tr>
</tbody>
</table>

4.3.10 Interview 5

Mr. Seshu Akella works with applied AI through Deloitte. His expertise on Quality 4.0 is derived from the development of smart factory applications and implementations for companies. On his background:

“I am part of Deloitte’s applied AI group and I specialize primarily in helping enterprises adopt AI and analytics. So having said that, I have been focused
primarily in the smart factory and the smart operations of Deloitte, and helping companies evolve into Industry 4.0 using AI and analytics. As AI and analytics is all driven by data, so the foundation is what we start looking into and my specialization has been primarily in the lines of ensuring, building solutions that will help clients and enterprises, especially in the manufacturing space, take advantage of the technology in the most efficient and effective way.”

From Mr. Akella’s interview responses the following codes have been extracted:

4.3.10.1 Technology Theme

“The basics, anybody and everybody’s favorite would be still an excel file, most of the time the data starts collecting in an excel file, but then as you increase the volume of data then we start seeing the transition from excel into more structured databases and even if you are trying to tap into some more unstructured, and anything like that, then you’re looking at a much more advanced and higher volume scenarios like building data lakes and all that.”

Initial code 94: data infrastructure must be capable of accommodating high-volume data.

“As we’re seeing the variety and the volume of data flowing into classic data lakes that I mentioned earlier it becomes imperative that you no longer need ingestion, or you don’t have to babysit that process anymore quote unquote.”

Initial code 95: real time data can be processed and used without storing historical data.

Initial code 96: data may be automated and not require supervision or action to develop usable information.

“You can build in streams and push data, or ingest data, in very seamless scenarios where you can get data in near real time. So having said that, so to get the data populated and made available, automation is something that everybody
is leaning on so there is tons of opportunities there in automation, especially ingestion of the data, putting triggers on top of it to inform people on notification.”

Initial code 97: automation should drive actionable insights to necessary users.

“If I’m looking at any governance scenarios, automation also is one of the best things that we’re looking at to identify any data quality issues, so on and so forth.”

Initial code 98: system architecture should include quality control to monitor data for abnormalities.

“So having a foundation and building the right infrastructure and pipelines to bring in data to the various hubs, data hubs, to make it available for various uses in the ecosystem is one of the key imperatives and key requirements I’ve been tracking from a technology standpoint of view. In addition to that what we also are looking at is IoT, the internet of things, devices that produce and share data become very important especially in manufacturing.”

Initial code 99: a global data infrastructure should be scalable to allow all inputs and outputs to connect.

“Think of it like you are at a plant and you need to understand how efficiently your machines are performing and/or various aspects about machine health, diagnostics, and all of that. IoT is the best solution for that. Using RFIDs and a combination of different sensors you can collate and collect all the information and pass it along through the other systems which can talk to each other.”

Initial code 100: technology capability should be considered in data collection to prevent limiting necessary data inputs.
“Something very core, which is becoming, which is actually is taking us like a storm, is cloud computing. We talked about AWS, Azure being the hyper scalers. These are the ones which we are seeing a lot of traction as a technology component to take advantage of cloud computing. The key benefit of cloud computing is primarily being scalable and extensible in the very logic construct. And also, the biggest benefit that you get is storage and compute power that is unlimited literally, sky’s the limit.”

Initial code 101: scalable architecture is critical to data system success.

Initial code 102: cloud computing empowers companies to utilize capabilities beyond their current infrastructure.

“And last two topics are AI and ML, I’ll go deeper on AI and ML in a bit, but also the same note are the networks, the 4g and 5g networks are another piece of technology that’s currently definitely making a big difference.”

Initial code 103: data connectivity is a key factor in Quality 4.0 success.

Initial code 104: data analytics capabilities are a key factor in Quality 4.0 success.

4.3.10.2 Methodology Theme

“Lean manufacturing is what I think we are seeing a lot of especially whenever we talked about anomaly detection and predictive scenarios. This is where the whole, from the quality standpoint of view, as less from an overall production line capacity standpoint of view. People are, the manufacturing floors and the managers of the floor, are looking at optimizing these processes in the most efficient way.”

Initial code 105: Industry 4.0 technologies allow the Gemba to be observed and optimized.
Initial code 106: Industry 4.0 capabilities empower quality continuous improvement.

“With the material at hand how efficiently and how best you can build your parts in production becomes very important. So how do you do that? And this is where the technology and the AI pieces are coming into play and people are looking at it from a logistical point of view, so definitely lean manufacturing is imperative.”

Initial code 107: utilizing lean principles is critical to developing a Quality 4.0 system.

“Lean manufacturing and total quality, they go hand in hand in my opinion. As simple as this, the quality of product and preventing any kind of defect in the product is, and has been, the key challenge for most of the manufacturers for a long, long time. With computer vision and a combination of algorithms and even looking at the sensor data, putting into perspective it becomes easier and the quality control can be improved tenfold in my opinion.”

Initial code 108: Industry 4.0 technology allows continuous monitoring of quality KPIs.

Initial code 109: lean and TQM should be implemented together to enhance the outputs of Industry 4.0 technologies.

“So, all said and done the algorithm that we have put together is a combination of understanding the issues of the run using a camera and their technology together and to identify up front so that quality checks are much contained, and you are preventing the issues up front.”

Initial code 110: TQM should be architected into the early parts of the process with monitoring technology.
4.3.10.3 Enablers Theme

“So, the technologies primarily I focus on are in the lines of from a data collection and ingestion point of view very much like cloud-based solutions, such as AWS or Snowflake and Azure, are the key foundational elements I would say on the cloud side. On the other, on prem, if there are customer limitations on using any of the cloud-based technologies or cloud infrastructure then you’re looking at classic tradition RDBMS’s like Oracle.”

Initial code 111: data infrastructure must be architected within company capability/resources.

“So, for success of any Industry 4.0 I would say the way we look at it is defined by three pillars. First is your process, second is your technology, and the third one is your people, or the change management workforce scenario.”

Initial code 112: technology use cases should enhance processes and provide value.

Initial code 113: the human element must be considered within the process for technology deployment.

“To be successful you need to have the right set of processes, update and upgrade your processes to the most relevant and most current, that’s one of the key aspects.”

Initial code 114: technology must support or enhance a process.

“From a technology standpoint of view having the right set of technology is also an enabler. I cannot load volumes of data on a very limited set of storage and also the computing needs to be upgraded. This is where the whole cloud computing comes into picture.”
“Same thing you had to invest in, computer vision related technologies, cameras, IoT devices. This is where the investment needs to be done, and this is where you start looking from a logical point of things.”

Initial code 115: companies must be willing to invest in appropriate data infrastructure to realize value from a use case.

“The people who are taking care of all the business do need to be upgraded and do need to be having all the tools and techniques that they can play with to be more efficient. That’s where the people come into picture, the right training, right awareness, the whole nine yards around change management and the digital workforce is definitely required on that space to be successful.”

Initial code 116: companies must invest in workforce skills relevant to the technology use cases.

“How much do you really want to invest into it and how is your operating cost. This is where I think everyone wants to reduce the OpEx and how do you do that? That’s where the big bucks are, that’s where the whole optimization things come into the picture. But once again, it is all comes down to planning and investing in the right way in my opinion”

Initial code 117: use cases must present a feasible ROI to achieve leadership buy in.

“And many times what you see is the vision is not commonly accepted or shared across Gen X, and Millennials are 3 times ahead of how to adopt the new technology, but at the same time having the view and vision into how it’s going to play out after five to six years becomes a key challenge because technology is evolving, technology is changing.”

Initial code 118: installing a shared organizational vision for the future state is critical to success.

“But once again security becomes one of the key barriers.”
Initial code 119: cybersecurity must be addressed.

“So, with new teams coming in and new way of doing things, what we are seeing is the traditional org structures are breaking down, and we are looking at more agile, more smaller teams with a product mentality that building a product and driving through that is becoming a very common scenario.”

Initial code 120: organizational structure must empower decision making at the appropriate level.

“That is a construct which is kind of helping move faster, it is like the fail fast and learn with your failures kind of scenario which is what everybody is adopting. And those are the changes that you are seeing from an organizational standpoint of view. Your leadership is broken down into multiple silos, not silos, multiple different divisions, and each one of them is operating independently and cohesively on a single platform. That’s the beauty of it. So, technology is a pattern that’s connecting everybody, but when you’re looking at the intelligence or the knowledge is kind of coming from multiple sources together in a small team instead of the team working isolation. It’s a new way of collaborating.”

Initial code 121: culture must empower groups to make decisions and iterate.

4.3.10.4 Strategy Theme

“Strategy to implement 4.0. It will be as follows: first and foremost, understand what are your, what’s your vision and where do you want to see yourself tomorrow. That’s tomorrow as in as a future that you can visualize right, because that’s very important.”

“So to be successful in Industry 4.0 definitely it is time to start looking at the bigger picture and investing in the largest group of things as to what is going to be helping the folks and enterprises to get to the next level.”
Initial code 122: developing an organizational mission is a critical element of strategy.

“So that’s where my strategy is going to be starting, is to understand what is happening in industry today. How this kind of extrapolates to the next five years six years, how these technologies, how these processes are going to evolve, and what is the need for that.”

Initial code 123: benchmark technical capabilities during strategy development.

Initial code 124: develop a value proposition for technology strategy and use cases.

“Once that is established, I start looking into what are my needs and what would it take for me to get there. Once again, the three P’s that I talked of, technology, processes and people are the three grounding principles that I’ll be leaning on, and I typically build on those lines. Do I have the right processes in place, do I have the right technology in place and do I have the right people in place.”

Initial code 125: strategy must include planning for workforce adaptation.

Initial code 126: sound processes must be in place to be enhanced by technology.

4.3.11 Interview 5 Codes

Initial codes are summarized in table 10:
Table 10 - Mr. Seshu Akella Codes

<table>
<thead>
<tr>
<th>Code</th>
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<tr>
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<td>A global data infrastructure should be scalable to allow inputs and outputs to connect</td>
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<tr>
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<td>Technology capability should be considered in data collection to prevent limiting necessary data inputs</td>
<td></td>
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<tr>
<td>101</td>
<td>Scalable architecture is critical to data system success</td>
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<tr>
<td>102</td>
<td>Cloud computing empowers companies to utilize capabilities beyond their current infrastructure</td>
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<tr>
<td>103</td>
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<td>104</td>
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<td></td>
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<tr>
<td>105</td>
<td>Industry 4.0 technologies allow the Gemba to be observed and optimized</td>
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<tr>
<td>106</td>
<td>Industry 4.0 capabilities empower quality continuous improvement</td>
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<tr>
<td>107</td>
<td>Utilizing lean principles is critical to developing a Quality 4.0 system</td>
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<tr>
<td>108</td>
<td>Industry 4.0 technology allows continuous monitoring of quality KPIs</td>
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<tr>
<td>109</td>
<td>Lean and TQM should be implemented together to enhance the outputs of Industry 4.0 technologies</td>
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<tr>
<td>110</td>
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<td>The human element must be considered within the process for technology deployment</td>
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<td>114</td>
<td>Technology must support or enhance a process</td>
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<td>115</td>
<td>Companies must be willing to invest in appropriate data infrastructure to realize value from a use case</td>
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<tr>
<td>116</td>
<td>Companies must invest in workforce skills relevant to the technology use cases</td>
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<td>117</td>
<td>Use cases must present a feasible ROI to achieve leadership buy in</td>
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<td>Installing a shared organizational vision for the future state is critical to success</td>
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<td>119</td>
<td>Cybersecurity must be addressed</td>
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<td>120</td>
<td>Organizational structure must empower decision making at the appropriate level</td>
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<td>121</td>
<td>Culture must empower groups to make decisions and iterate</td>
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<tr>
<th>Code</th>
<th>Enablers Codes</th>
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<tbody>
<tr>
<td>122</td>
<td>Developing an organizational mission is a critical element of strategy</td>
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<tr>
<td>123</td>
<td>Benchmark technical capabilities during strategy development</td>
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<td>124</td>
<td>Develop a value proposition for technology strategy and use cases</td>
</tr>
<tr>
<td>125</td>
<td>Strategy must include planning for workforce adaptation</td>
</tr>
<tr>
<td>126</td>
<td>Sound processes must be in place to be enhanced by technology</td>
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4.3.12 Interview 6

Dr. Tahany El-Wardany works in advanced manufacturing with experience in modeling and simulation of advanced manufacturing processes. On her subject matter expertise:

“My background in general is advanced manufacturing. I look for all the modeling, optimization, for any new manufacturing technologies, available manufacturing technologies and also what we can say, like the, I don’t want to say old manufacturing technology, I can say that for example well developed manufacturing technology like machining, like casting, like forging. So, in general all my area of expertise is really focused on manufacturing, modeling, and simulation of manufacturing processes. In addition to that I have built models for tribology, and I have worked on tribology too.”

From Dr. El-Wardany’s expert interview responses the following codes have been identified:

4.3.12.1 Technology Theme

“You know when you go for digital thread or for process optimization. So in these cases, in manufacturing at least, we always have a lot of sensing that we are using even with additive manufacturing, which is advanced manufacturing, or other processes. We are always using sensors either to collect forces, collect dynamics, vibration, collect temperature, using some thermocouples or other sensors available. Sometimes we need to collect, if we want to look at the quality, want to see how the part as we are fabricating it, gets distorted or dimensions are not the correct ones. So, there is a wide variety of parameters or data we are collecting for analysis.”

Initial code 127: Industry 4.0 capabilities can monitor a large variety of real time data.

“You’re analyzing the data sometimes online, you know, as you are for the digital thread, for example. You’re collecting the data, it's analyzed in sequence,
and after that a decision or something occurs to maybe readjust the process or readjust some of the parameters.”

Initial code 128: real time data drives real time actionable insights and decision making.

“The other analysis is, we are looking for example if the part is distorted. We’re looking to know, as we are moving the part, how much distortion exists so right away we can start running other software or codes to try to do distortion compensation.”

Initial code 129: real time data can adjust processes to accommodate quality needs.

“Application of hybrid manufacturing where they know that the surface finish is going to be rough but at the same time the machine now for additive manufacturing became a combined additive and also subtractive which is machining. So you can control the surface finish, the quality of the surface finish for example.”

Initial code 130: quality can be automated into a digital system.

4.3.12.2 Methodology Theme

“Regarding the application of this digital thread this is part of Industry 4.0 and in most of, I think, in a lot of cases our machines, even if they are old machines, they do have something now, some sensing that is used. For example, I can measure forces as I am cutting and if the forces start to increase because of the tool wear we have to stop the process and change the tool.”

Initial code 131: Industry 4.0 capabilities empower total productive maintenance.

“If we are applying digital thread in this case, we will be able to right away compare this data with what we’re supposed to have. And if there is a difference we directly need to go back and see the depth of cut, or there was some vibration,
or some dynamics, or a thermal heating in the part when we are additively manufacturing it, so we have to try to compensate for the next part.”

Initial code 132: data use cases can be applied with the Andon principle.

Initial code 133: quality should be designed into the process through monitoring the right quality KPIs.

“So, for the defects, for example, you can run pre depositing the part, you can run and see the effect of the process parameter you selected. The scanning strategy you selected, on the origination of defects and in this case before you start depositing you can change some of the process parameters to ensure that you are having a good quality part.”

Initial code 134: real time data empowers TQM through informed decision-making and process adjustment.

“When you’re talking about Industry 4.0, you’re looking for time savings, you’re looking for scalability, you’re looking for control of the process itself. So, when we talk about lean manufacturing, we’re talking about that you are producing parts with, actually, minimum scrap and minimum, avoiding all the associated problems with environment. So, I think there is a very close relationship between Industry 4.0 and lean manufacturing.”

Initial code 135: Industry 4.0 technologies help achieve lean goals.

“Ok when we do digital thread, which means that we are sensing whatever we are producing and correlate whatever we sense with a problem that exists in the part, and we go, we collect all this data, we analyze it within the controller, and we come up with a decision-making tool eliminating any of these issues or problems associated with manufacturing of a part. Why are you doing that?
Because you want to ensure that the quality of the part produced, the total quality of the part produced, is within the specification.”

Initial code 136: TQM is an output of an effective Industry 4.0 system.

4.3.12.3 Enablers Theme

“First of all, you need to start looking for smart manufacturing or smart factories… So definitely there are factories, you need to hire, or your team has to have different knowledge, you know.”

Initial code 137: employee skills gaps are a challenge for digital transformation.

“The second one is the implementation, you know, the implementation in Industry 4.0 it is not something, when you want to adopt Industry 4.0 technologies you need to have several changes in the way you approach or you plan your process. In the way you are transferring the machines you have to be some smart machines and the most important also is that you have the people who believe the need and they want to apply it.”

Initial code 138: processes must be designed in a way that can be enhanced with digitization.

“Very successful, they produce parts the way they like to produce it, and you want to come and say ok let’s make it a little bit smarter and instead of using this tool try to use this tool because it will reduce production time by 90%. Some people are willing to look at that, some people think we’ve been doing it for a long, long time correct and we have really good quality, why do we need to make this transformation. So, this is another factor that’s very important, that people are willing to implement all these new technologies on the machining cell or manufacturing cell to make it faster, to make it more correct, to make it with high quality, to make it cost effective.”

117
“Of course, the organizational fit, I’m not talking about upper management, I’m talking about the whole organization. The whole organization needs to be a big believer of data collection and analysis in sequence and decision-making applications and the changes and the installation of the, all the sensing technologies, to make your factory or your machine smart.”

Initial code 139: companies must develop a Quality 4.0 vision.

Initial code 140: organization-wide buy in to the vision and ideal future state are critical for success.

“The strategy, how are you going to implement it, when are you going to implement it, which parts you are going to implement the technology, is another factor.”

“You have to make sure that you already, thoroughly, planned the technology you are implementing. And thoroughly planned the methods you are going to develop for the digitization. And you have to try it and validate it completely before you do that. Before using any of this technology you have to validate it otherwise you are really, really going towards failing the implementation of the process.”

Initial code 141: lack of a clear and tangible strategy will hinder implementation.

“You need to have, also, inside the machine while it is building, in certain frequency you need to automatically collect data that you will be analyzing to ensure that your system, or the part you’re building is within the quality required. So, the digitization and the automation, automation is part of smart manufacturing, smart machines, and interconnection between the two. Because automation could be collecting data, automatically, you’re not interfering in it, and you’re sending this data for analysis, and there is some interconnection to
get the results or the decision making to change the speed and feed, for example, without any interference from the engineer or without any interference from the technical people or technicians.”

Initial code 142: use cases for data must drive tangible action.

Initial code 143: real time data requires adequate system architecture and decision processes.

“First one is how good is the digitized, or the models you are developing or using. How well calibrated they are for different areas.”

Initial code 144: data validity and trustworthiness is critical to success.

4.3.12.4 Strategy Theme

“I can’t spend ten million dollars in developing process. At the end I will get 5% advancement, there has to be enough planning to whatever manufacturing process you want to implement. And the verification, and the testing, otherwise I don’t think things will go successfully.”

Initial code 145: strategy must include development of a business case with tangible ROI.

Initial code 146: strategy must address the testing and validation of a system.

“, I think I won’t be exaggerating if I said you need, first, to get the confidence and approval of the management that this process is good. You know, when you do any research, you start first writing the idea, explaining it, and planning it. Planning it towards success, right, if you don’t have that how do you expect the managers who are going to say yes, we’re going to go implement Industry 4.0 and yes, we’ll allocate a set amount of money for it? How will you get that if you don’t plan properly to make them see the possible benefits?”

Initial code 147: strategy and planning must achieve leadership buy in.
“So, first thing, I have to study what is needed to make this place a smart factory. What is the target. You have to have an objective. When you’re talking about smart factory technology, what do you need? Do you need to reduce the energy used for manufacturing? Or do you need to enhance the quality of the part? Do you need to apply automation in a way that you reduce the production time, and you reduce the cost?”

Initial code 148: business case must provide a tangible value proposition.

4.3.13 Interview 6 Codes

Initial codes are summarized in table 11:
Table 11 - Dr. Tahany El-Wardany Codes

<table>
<thead>
<tr>
<th>Code</th>
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<tbody>
<tr>
<td>127</td>
<td>Industry 4.0 capabilities can monitor a large variety of real time data</td>
</tr>
<tr>
<td>128</td>
<td>Real time data drives real time actionable insights and decision making</td>
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<tr>
<td>129</td>
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<td>Employee skills gaps are a challenge for digital transformation</td>
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<td>Use cases for data must drive tangible action</td>
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<td>145</td>
<td>Strategy must include development of a business case with tangible ROI</td>
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4.3.14 Interview 7

Mr. Rick Burke developed his digital expertise beginning with consulting for SAP on the development of connected data systems. He has furthered that expertise through developing Industry 4.0 solutions for clients at Deloitte. On his expertise:
“Started out as a PLC programmer man machine interface developer back in the late 80s early 90s. Had an opportunity to get into SAP and SAP consulting so I’m moving kind of up the tech stack to the enterprise level. With a vision in the 90s of being able to connect the shop floor to the top floor, however in the 90s most companies were just focused on getting ERP in for Y2K and the technologies and the politics I would say, of around doing that were very strong headwinds. So, I did a lot of SAP manufacturing consulting work both for clients or working in internal roles. And then joined Deloitte to help them really think through their strategy around digitizing supply chain and one of our first big Industry 4.0 projects I sold and led for a plastic packaging company. And a lot of that involved quality sensing as a very sensitive plastic thermoforming extrusion process, very sensitive. And so, deploying various quality analytic capabilities in order to increase their OEE and their yield. So, I’ve been in and around this space for pretty much my whole career, but some at the plant floor level and some at the enterprise level. And what I do now is work with clients to really think about their Industry 4.0 journey, how to get started, where to hunt for value, what sort of technologies they need to be thinking about or acquiring. And really just help them shape their strategy, vision, roadmap, business case around the problems they’re trying to solve.”

From Mr. Burke’s expert interview responses, the following themes have been generated:

4.3.14.1 Technology Theme

“And then be able to decide what sort of analytics you want to run on that data, what are the outcomes you’re trying to seek.”

Initial code 149: data analytics must drive action towards outcomes.

“You have to think through all those kinds of human form factors. Because at the end of the day it still pretty much requires a human intervention. What we
can do is give them much better, earlier, warnings or insights to solving a quality issue.”

Initial code 150: technology use cases should enhance human capabilities.

“What we’ve found is vision analytics, even if it’s disconnected and you’re doing offline, you know, non-real time analyses on certain quality datasets, can be very impactful. It at least helps you prove hypotheses to then justify making the investments in say the industrialized solution.”

Initial code 151: begin with technology solutions which provide a clear value in the use case.

Initial code 152: develop value propositions to cost justify technology scaling.

“Now people are realizing that it has to be much more targeted and some things you need to be able to process at the edge, due to real time decision-making resiliency, things like that. Others are what you could push, less time sensitive information into the cloud and run your analytics up there and then push the insight, you know, back down to the edge. That’s really getting into a lot of real architecture questions and use case specific solutions.”

Initial code 153: data infrastructure empowers real time decision making.

Initial code 154: systems must be architected based on data use cases.

4.3.14.2 Methodology Theme

“What we see is using video analytics, we’ve done it for like temperature control to make sure that the thermoform plastic sheets were coming out uniformly. All the oven temperatures, we’ve detected sensors being bad therefore it was skewing the quality. We’ve used video analytics to look at human performance and our operators or assembly technicians following the work instructions
properly and being able to notify when the algorithms detect a misstep or an incorrect step.”

Initial code 155: sensing capabilities actively observe the Gemba.

Initial code 156: Industry 4.0 technologies enhance TQM capabilities and defect detection.

“Our perspective is that the traditional lean six sigma capabilities are still pretty essential for a manufacturer to lean out waste in their processes, but we find that that’s kind of incremental returns over time, whereas when you start introducing Industry 4 dot 0 capabilities you really start getting step change performance improvements that, quite frankly, shouldn’t plateau.”

“So, as they kind of evolve their maturity with using these technologies, the value creation should continue to go up where a lot of our clients that have been doing lean been on a lean journey for years, it’s a fifty-thousand-dollar improvement here or a hundred-thousand-dollar improvement there. Where another client we’re trying, we were able to move their overall equipment effectiveness up 9%, which gave them fifty million in incremental revenue.”

Initial code 157: Industry 4.0 technologies enhance lean capabilities.

“So that’s kind of our perspective on how Industry 4 dot 0 and lean they need to coexist together. Layering in tech, Industry 4 dot 0, on sub-optimized processes is usually a bad recipe, and when we see clients that have failed, we often see that they think there’s an easy button with Industry 4 dot 0 that makes it that they don’t have to go fix all their broken mess.”

Initial code 158: lean process improvement sets a foundation for Industry 4.0 technology implementation.

Initial code 159: processes must be established before they can be enhanced by technology.
“I think TQM can be great, can be improved using Industry 4.0 techniques. You know if I look the automotive industry, right. They’ve been doing a lot of work around Industry 4.0 and TQM that, you know, arguably has raised the quality of US car manufacturing over the last couple of decades.”

Initial code 160: Industry 4.0 technology is an enabler of TQM.

“A lot of our clients honestly don’t really have solid TQM programs. They may have a quality department, but they may not actually be a very mature TQM organization. And I don’t know I’m not the deepest expert on TQM, but I would say with my clients I’m starting to see them, if they have the lens they want to be able to start integrating, you know, real time insights into the lens as opposed of being an after the fact quality inspection.”

Initial code 161: Industry 4.0 technology builds quality into the processes.

4.3.14.3 Enablers Theme

“You know it is a fine area and I’m about to address this with one of my clients. We think there’s a strong use case for some video analytics to address a pretty significant quality issue they have in a manual assembly process. And that’s a conversation we’re going to have with them, right. Is it going to cause people to be less motivated to work and don’t want to be in a work environment that’s being surveilled, or do they not care and just want to, you know, get whatever improvement that they can through better training of how they’ve been taught may not be the best way because they may not have been taught to the work instruction.”

Initial code 162: a shared vision for technology use must be developed.

Initial code 163: employee buy in is critical and must be considered and addressed.
“There’s two philosophies I would say, one is just collect everything and either keep it on prem or push it to the cloud. And then what I think we’ve been finding is that’s not the best answer, like data lakes were a huge thing, now you don’t really hear people talk about data lakes anymore. That was just an idea, throw everything in and then magic was going to happen, value was going to fall out of the sky.”

Initial code 164: lack of clear data use cases prevents value realization.

“Certainly, evolution of edge and cloud has been instrumental. And I think a focus on, I keep getting back to it, is the user experience, and making sure that whatever the medium is that you’re interfacing with an operator or a quality supervisor, what have you, that they want to use it, right?”

Initial code 165: employee system interaction must be designed to drive buy in.

“There’s a culture of being willing to experiment and be more of an agile based organization, so the idea of failing fast, learning fast, is important. I think a culture of embracing data and analytics versus human intuition is critical.”

Initial code 166: culture must empower data driven decision making.

Initial code 167: culture must empower employees to act based on data without decision hierarchies.

“I think having IT and OT alignment, and I think just a foundation of technology, you know whether it’s in the plants whether it’s WIFI or its connected. Making sure that you’ve got that backbone to build this on and a company willing to invest in that infrastructure without actually a business case, right. Because you can’t bake some of these investments on a single use case in a single plant.”
“And then having a plant that is willing to be a leader within their organization and invest the time and the people and even the production capacity if you need to run, take some downtime, or run experiments on a line. Those are many of the things that I’ve seen.”

Initial code 168: leadership commitment and buy in is crucial.

Initial code 169: creating collective technology goals and vision is necessary for system development.

“Usually what doesn’t work well, or I would say it pops down ownership, so if you start with, whether it’s the CEO, CFO, CTO kind of championing the program versus it being an innovative electrical engineer working in a plant on a single use case that’s not attached to any real strategy or vision and it’s not scalable. You know, there’s a lot of great ideas that emanate from the plants, but they often don’t get adopted broadly because it’s just disconnected from kind of the enterprise vision.”

Initial code 170: vision must be global within a company.

Initial code 171: solutions must be scalable.

“User adoption is a huge one, I’ve mentioned that a few times, just really thinking about that user experience and that interaction model that, you know, is going to drive the most value. Not being able to manage or, identify and manage, an ecosystem because Industry 4 dot 0 is really about an ecosystem play. Whether that’s service providers or technology providers a lot of clients just aren’t very sophisticated in having to manage that, that’s fairly new to them. And there’s such, just a wide variety of capabilities and startups that, for them, how do they constantly scan and monitor, you know, the capabilities that are out there.”
Initial code 172: change management is critical to success.

Initial code 173: use cases must include the employees use of the technology and skills.

“I think that’s another reason why they tend to fail is just poor ecosystem management. And then lacking of a value case or a business case, right. In being able to measure value over time to show that these are actually making, contributing real value to the organization.”

Initial code 174: lack of a business case for value realization prevents Quality 4.0 success.

4.3.14.4 Strategy Theme

“I would say first you’ve got to look at the level of maturity of the company right, we work with some companies that have zero operational technology infrastructure in place and we have to think about then what use cases are going to drive the most value and then what types of data needs to be collected in order to drive that outcome.”

Initial code 175: technology strategy must be appropriate for company capabilities.

Initial code 176: use cases must drive value for the company.

“And then really the most important thing is if you’re not doing closed loop feedback is what’s that user experience for say the operator on the line to utilize that insight and take the appropriate corrective action in order to, you know, address a potential quality issue hopefully before it even occurs.”

Initial code 177: developing technology use cases should consider tangible action and outcomes.

“Some clients already are well established; they’ve been collecting a lot of data. Obviously, there’s advantages for those companies. A lot of companies also have just tons of data, and they don’t know what to do with it so helping them
think through, again, what data points are going to be most meaningful to drive the quality outcome they’re looking for and really decomposing their process to do that.”

Initial codes 178: data strategy must have use cases architected into the ground level.

“First, we wouldn’t necessarily go in with an Industry 4 dot 0 strategy, right? We would really start and look at what are the business problems and the business outcomes that they’re trying to achieve. Those will often be solved through both, what I like to say, analog and digital capabilities. Analog being, you know, just human interaction, kind of process improvement type things.”

Initial code 179: strategy should center on value proposition over technology.

Initial code 180: digital transformation strategy should employ non-digital methods and tools where appropriate.

“I mean this may be a really hard one to tackle, maybe you’re not mature enough yet for it so why don’t we start with something that’s a quick win, right? Well client’s love quick wins and so, we’ll prioritize from that and get agreement on that and then flesh out what the roadmap is including all of the enablers required, whether it’s people or infrastructure, things like that.”

Initial code 181: strategy should fit company capabilities.

Initial code 182: strategy should address enablers and barriers on a broad scale.

“Often, we find, well you know what you really do need to go on a lean journey before you go screw in these capabilities, right? Because then you’re building on quicksand. And we as a firm, we usually get a little bit nervous, and I get nervous, when a client wants to only talk about advanced capabilities or Industry
4 dot 0 because often, we find that there’s a lot of low hanging fruit just through the analog work before they can really take advantage of the digital work.”

Initial code 183: strategy should address processes first and not just technology implementation.

“I’d say those are probably the biggest, just employee satisfaction, employee experiences, achieving the value case, and generating a pull versus a push on the capabilities.”

Initial code 184: strategy should address workforce change management.

Initial code 185: strategy should target realization of value case.

4.3.15 Interview 7 Codes

Initial codes are summarized in table:
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<thead>
<tr>
<th>Code</th>
<th>Technologies Codes</th>
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<tbody>
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<td>Data analytics must drive action towards outcomes</td>
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<tr>
<td>150</td>
<td>Technology use cases should enhance human capabilities</td>
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<td>151</td>
<td>Begin with technology solutions which provide a clear value in the use case</td>
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<td>152</td>
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<td>153</td>
<td>Data infrastructure empowers real time decision making</td>
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<td>154</td>
<td>Systems must be architected based on data use cases</td>
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<tr>
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<td>155</td>
<td>Sensing capabilities actively observe the Gemba</td>
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<td>Industry 4.0 technologies enhance TQM capabilities and defect detection</td>
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<th>Code</th>
<th>Enablers Codes</th>
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<tr>
<td>162</td>
<td>A shared vision for technology use must be deployed</td>
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<td>163</td>
<td>Employee buy in is critical and must be considered and addressed</td>
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<td>164</td>
<td>Lack of clear data use cases prevents value realization</td>
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<td>165</td>
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<td>Developing technology use cases should consider tangible action and outcomes</td>
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Dr. Elizabeth Cudney has extensive experience in the application of data analytics to drive action. On her background:

“I’m a professor of data analytics. From a six sigma standpoint I went through the six sigma black training in 1998 so I’ve been a six sigma black belt since 1998, and then a master black belt since, that’s a really good question, probably at least fifteen years now. So, I was in industry for ten years, in automotive mainly manufacturing, then went on for my doctorate and I’ve done six sigma, lean and six sigma projects in healthcare, service industry, automotive, aerospace, just about any industry pretty much. And then my research heavily relies on six sigma but, I don’t know what else to kind of add about that but, so over about twenty-five years, over twenty-five years of experience in the area.”

The following codes have been generated by her expert interview:

4.3.16.1 Technology Theme

“Yeah so, I think now, especially with big data, one of the key things we’re seeing is there is so much data available. And so, we’re really switching from more of the, well some industries still do it, the paper and pencil, writing things down, to all the automatic upload.”

Initial code 186: data collection for big data should be automated.

“So from the data analytics perspective six sigma black belts are having to use coding more and more, whether its writing SQL code, to they’re pulling information from various databases and tables so they can really pull that data together.”

Initial code 187: infrastructure should connect data sources.
“So, I think just the visibility from that perspective has been tremendously helpful. Where we can have our key performance indicators and our KPI boards somewhere else that we can see them and track them and whether I’m at a facility, whatever state, wherever in the world, I can see what’s happening. And so, I think that made a huge difference just in the accessibility standpoint.”

Initial code 188: effective data analytics should drive actionable outputs.

“Twenty years ago, when I was still in industry. If I wasn’t in the facility, I didn’t know what was happening unless somebody called me. Now I can be working from home, and I know exactly what’s happening with all production lines. I can see everything. And it’s probably, the internet helped with that, but there’s just better data visualization aspects of it as well too, and real time data.”

Initial code 189: systems should actively drive data outputs to users.

“While there’s the sensors available there’s still so much that’s been missing, so trying to figure out with that kind of effort and that team to see how to best support six sigma projects in terms of data collection and so that the IT people are on board.”

Initial code 190: data infrastructure must support use cases.

“I mean certainly companies have gotten a lot better, but not everyone within the organization has access to the same amount of data and there’s going to have to be some level of data transparency when you’re running this or else there’s a lack of trust with how people are seeing this new transition.”

Initial code 191: data use cases must be validated.
4.3.16.2 Methodology Theme

“But what’s happening in the Gemba, on the shop floor, wherever the data’s being collected, to where it’s being analyzed and scrubbed for trends and everything else, there’s kind of a disconnect in my mind that I’m seeing more and more.”

Initial code 192: lean culture principles are necessary for Industry 4.0 technology success.

“And I think, in some instances, it will probably cause, that confusion, will cause more issues and also since only a handful of people, or a couple of people within the facility that truly understand it, it’s kind of like that tribal knowledge to some extent that if something happens within those individuals, systems that have been set up will go away if those people leave the company.”

Initial code 193: standard work is necessary for Industry 4.0 system sustainment.

“I mean absolutely, so we’ve got all this data and we can use it all for creating our value stream maps. Gosh I mean just the flow of information, so coming over the value stream map I would still want to go out and watch the flow and make sure I’m seeing things but the type of data that I would have would be much more accurate and representative, versus what I was doing before which was going out and timing ten parts in a row. Gosh, I mean SMED I’d have all that data.”

Initial code 194: Industry 4.0 data collection empowers lean tools.

“Just from the data perspective, absolutely there’s so much more that could be done, and with all the sensors on my equipment, from the timing perspective is as an industrial and mechanical engineer, that would make my life so much easier in terms of doing the lean process improvements.”

Initial code 195: Industry 4.0 data collection supports lean improvement and implementation.
“And then back to data visualization, even with how things are happening within the processes and machine learning, when something goes wrong from a lean perspective there’s still waste, which are defects. So, I know exactly what’s happening. All the sensors when it comes to total productive maintenance, taking care of my equipment, knowing when it’s time to change the oil, or vibrations on belts. Just from the sensor technology alone I can, my maintenance is going to be so much better.”

Initial code 196: Industry 4.0 systems actively monitor the Gemba.

Initial code 197: Industry 4.0 empowers total productive maintenance.

“From a total quality management perspective, it’s more about how do you manage and focus on what’s important right. So using that information, your pareto charts are always updated with what’s happening, you know even down to tracking production, understanding what’s happening within your processes for process improvement, yeah absolutely.”

Initial code 198: Industry 4.0 data provides TQM inputs.

“And I, so in my head I kind of keep thinking about how empowering employees, understanding what’s happening within their processes, it’s much easier for them to understand what’s happening as well and take action.”

Initial code 199: insights from a Quality 4.0 system empower a lean culture.

Initial code 200: data on process performance feeds TQM shared quality accountability.

4.3.16.3 Enablers Theme

“And so, from a data collection standpoint it’s almost an, to some extent, overload of data that we’re dealing with in some instances. And so, I don’t want to kind of jump ahead in case you have this question later, but, tons of data, but
what I’m seeing is it’s very easy to get the data but not everybody now understands where the data’s coming from with data analytics, and kind of everything being automatic, the upload, and collected for us.”

Initial code 201: lack of understanding of data use cases creates skill deficits.

“I don’t think people are as familiar with the data because they’re not out there having to collect it and be so personally involved within the process. And that ties into the data analytics side as well too, because data analysts are often given data and told to kind of go analyze it, go look for trends.”

Initial code 202: employee skill and knowledge should include understanding of the process.

“And then more and more with writing code whether its in R or Python so that they can analyze the code a lot better, and getting away from, whether it’s Minitab, SPSS, whatever software package they might be using. So, I think trends are going more and more, and going to continue going more and more, into the coding side of it.”

“What I have seen more and more is there’s still a lack of understanding of how that works. There might be one or two people within the organization that kind of know and understand it but the rest are still novices in terms of it and they don’t understand the nuances of machine learning, what it’s really doing, how it works, and so there’s kind of that buzzword that’s out there without much understanding whatsoever.”

“So, I think one of the big barriers is going to be that we might have a much smaller workforce, and I’m trying not to be too biased as an engineer, but as an engineer most degreed engineers have enough of a statistics background, a mathematical background, and a coding background, that this isn’t a huge hurdle for them. But individuals coming up from the softer side and from humanities that have been able to be very successful in the lean and six sigma world now,
from the cultural side, I think will struggle to really, to make that transition. Unless they really go back and do some pretty advanced training on statistics and software and coding.”

Initial code 203: employee technical skill gaps must be addressed.

“And there’s just something so valuable about still going to the Gemba, seeing what’s happening in the process, and you’re, they’re missing that, right. So when you’re looking for root cause analysis, what all could be happening, and I don’t have any data whatsoever to prove this at this point, but my feeling is from little bits of information that I’ve seen, is that if you were to have created a cause and effect diagram six years ago even, or five ten years ago, it would be very different than what we’re creating now, because we’re not out there actually seeing it we’re trying to do this in so many remote locations that we’re not really living and seeing the process. And that’s really impacting the process improvements that we could be implementing. I mean just the cultural side, working with people, everything else.”

Initial code 204: culture should support prioritizing processes over technology.

Initial code 205: use cases should unify process and people through technology.

“So, management is going to have to have enough of a foresight to understand that this is not going to happen overnight whatsoever. It’s going to be a fairly large investment, not only from understanding and the amount of sensors that are going to be needed, putting the systems in place, but then also training people.”

Initial code 206: leadership commitment and resources must be in place for successful implementation.
“And then the cybersecurity aspect of it of making sure that when we’re pulling things down from wherever we’re finding code that it’s doing, there aren’t any bugs.”

Initial code 207: cybersecurity must be addressed.

“So one of the first things I would probably do would be to get people on board with software such as power BI for data visualization just because it’s a nice stepping stone in terms of learning new software, getting people comfortable with learning new software, that ties in very nicely with different software packages.”

Initial code 208: employee buy in is required for success.

“I would have my IT group kind of in parallel, starting to look and working with the six sigma black belts who are at a facility, on how to start getting some data upload if it wasn’t there already. Most organizations are in pretty good shape already, where I see a lot of organizations struggle is where they’ve got these data lakes, but they haven’t put the thought into how the information is collected, how it’s stored, how to make it user friendly. So I would probably have some sort of team, for lack of a better word, that would start looking at data storage to make sure that it’s secure but that we’re also collecting data in a way that’s very useful so that we could use it for any sort of process quality improvement aspect.”

Initial code 209: data infrastructure must support usability.

Initial code 210: data use cases must achieve tangible value propositions.

“Hopefully that’s where they would be, everybody would be well versed in the software, and they would make data driven decisions.”

Initial code 211: culture should empower data driven decision making.
4.3.16.4 Strategy Theme

“So when you’re trained on the DMAIC methodology, you’re not coding typically, so now with big data you’re really going to have to still pick up all those skills in SQL, R, Python, data visualization so there’s Tableau, Power BI, and so there needs to be some sort of boot camps or something to go along with that to make sure that people can understand that data and how to represent it in a meaningful way.”

“Absolutely because I don’t think this is anything that, with current academic programs, I don’t know that there are many, if any, that are graduating say with an undergrad, that would be able to do this. They’d have some basic coding skills, all engineers take some, they might have a basic understanding of six sigma or just quality in general, they might have a good statistics knowledge, but this isn’t somebody that comes out of any program right now, I think, ready to hit the ground running. It’s a combination of skills from different places.”

Initial code 212: strategy must address future skills needed in the workplace.

Initial code 213: strategy must account for internal development of skills.

“I think the biggest one is probably going to be something around training. Making sure people have the right training. And probably even before that, honestly, looking at what type of systems that they have and what systems need to be set up.”

Initial code 214: strategy must develop system parameters to design actionable training plans.

“So, hiring the right personnel, the right people that can come in and say based on the type of data that they have how are we going to store it, how are we going to systematically kind of link all of our systems so that we have that data that’s easily accessible. So oftentimes that’s going to start with more of the IT,
somebody that’s a nice conduit between manufacturing and IT from that data perspective, because we’re going to be creating a lot of data lakes with all of the data that’s being collected, and then more of the data science people and someone from the, I think it’s going to be the six sigma, lean six sigma black belt, is going to have to be more of the data analyst that’s still going to have to be able to pull that code, I’m sorry pull that data by writing whatever code they need to get the information that they need.”

Initial code 215: strategy development requires multifunctional knowledge.

Initial code 216: cross functional teams are necessary to develop value propositions and use cases.

“But I would have some sort of overarching plan as well, too. So, what companies did, you know the master black belt, the black belts, the green belts, how would I get everybody, to start getting everybody on board with the data and data usage. So, getting people and being very intentional in terms of selection so that we’re permeating all the different business units so I have someone in each one that can really help people with getting the data that they need.”

Initial code 217: strategy should generate companywide vision.

“Yeah, you’ve got those people that are just going to be, I’m out what can I still do where I don’t have to write in code, I don’t have to do anything. And there’s going to have to be a strategy on how to do that. And it might be just to let them leave, but there might be also to kind of reinvention the workforce. And their roles.”

Initial code 218: strategy must accommodate how operational changes affect personnel.

“Everybody has access to all the data they need to do their job effectively. It’s right there at their fingertips. It’s a transparent organization, you know what’s
happening. The metrics tell you; you’ve got your metrics that are linked to the strategic goals, and you know exactly how everything’s running and what needs to be done. You’re not searching for data and information.”

Initial code 219: strategy should link data, processes, and personnel to goals and value propositions.

4.3.17 Interview 8 Codes

Initial codes are summarized in table 13:
### Table 13 - Dr. Elizabeth Cudney Codes

<table>
<thead>
<tr>
<th>Code</th>
<th>Technologies Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>186</td>
<td>Data collection for big data should be automated</td>
</tr>
<tr>
<td>187</td>
<td>Infrastructure should connect data sources</td>
</tr>
<tr>
<td>188</td>
<td>Effective data analytics should drive actionable outputs</td>
</tr>
<tr>
<td>189</td>
<td>Systems should actively drive data outputs to users</td>
</tr>
<tr>
<td>190</td>
<td>Data infrastructure must support use cases</td>
</tr>
<tr>
<td>191</td>
<td>Data use cases must be validated</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Methodology Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>192</td>
<td>Lean culture principles are necessary for Industry 4.0 technology success</td>
</tr>
<tr>
<td>193</td>
<td>Standard work is necessary for Industry 4.0 system sustainment</td>
</tr>
<tr>
<td>194</td>
<td>Industry 4.0 data collection empowers lean tools</td>
</tr>
<tr>
<td>195</td>
<td>Industry 4.0 data collection supports lean improvement and implementation</td>
</tr>
<tr>
<td>196</td>
<td>Industry 4.0 systems actively monitor the Gemba</td>
</tr>
<tr>
<td>197</td>
<td>Industry 4.0 empowers total productive maintenance</td>
</tr>
<tr>
<td>198</td>
<td>Industry 4.0 data provides TQM inputs</td>
</tr>
<tr>
<td>199</td>
<td>Insights from a Quality 4.0 system empower a lean culture</td>
</tr>
<tr>
<td>200</td>
<td>Data on process performance feeds TQM shared quality accountability</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Enablers Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>201</td>
<td>Lack of understanding of data use cases creates skill deficits</td>
</tr>
<tr>
<td>202</td>
<td>Employee skill and knowledge should include understanding of the process</td>
</tr>
<tr>
<td>203</td>
<td>Employee technical skill gaps must be addressed</td>
</tr>
<tr>
<td>204</td>
<td>Culture should support prioritizing processes over technology</td>
</tr>
<tr>
<td>205</td>
<td>Use cases should unify processes and people through technology</td>
</tr>
<tr>
<td>206</td>
<td>Leadership commitment and resources must be in place for successful implementation</td>
</tr>
<tr>
<td>207</td>
<td>Cybersecurity must be addressed</td>
</tr>
<tr>
<td>208</td>
<td>Employee buy in is required for success</td>
</tr>
<tr>
<td>209</td>
<td>Data infrastructure must support usability</td>
</tr>
<tr>
<td>210</td>
<td>Data use cases must achieve tangible value propositions</td>
</tr>
<tr>
<td>211</td>
<td>Culture should empower data driven decision making</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Strategy Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>212</td>
<td>Strategy must address future skills needed in the workplace</td>
</tr>
<tr>
<td>213</td>
<td>Strategy must account for internal development of skills</td>
</tr>
<tr>
<td>214</td>
<td>Strategy must develop system parameters to design actionable training plans</td>
</tr>
<tr>
<td>215</td>
<td>Strategy development requires multifunctional knowledge</td>
</tr>
<tr>
<td>216</td>
<td>Cross functional teams are necessary to develop value propositions and use cases</td>
</tr>
<tr>
<td>217</td>
<td>Strategy should generate company wide vision</td>
</tr>
<tr>
<td>218</td>
<td>Strategy must accommodate how operational changes affect personnel</td>
</tr>
<tr>
<td>219</td>
<td>Strategy should link data, processes, and personnel to goals and value propositions</td>
</tr>
</tbody>
</table>

142
4.4 Collective Analysis of Themes

4.4.1 Theme Searching

The next step in the thematic analysis of the body of expert knowledge collected through the interview process was to search for themes within the codes. Theme searching is described as a review of the generated codes to identify areas of similarity where the codes overlap and to group those codes together to make a potential theme (Braun & Clarke, 2012). High level themes from literature review were used as a starting point for searching, with clusters of codes being synthesized in the four domains of technology, methodology, enablers, and strategy. Initial synthesis of themes from the 219 identified codes did not explore the relationship of individual themes with top level themes, nor with other individual themes as comparing the themes is encompassed in the next step. Due to the semi-structured nature of the interviews some codes were reflective of multiple themes.

4.4.1.1 Technologies Themes

Six clusters of codes emerged from expert responses on technology. Tables 14-19 compile all codes related to the technology theme in Quality 4.0 implementation:
### Table 14 - Theme 1

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 1 - Data infrastructure must be designed with data use cases and value in mind</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Data architecture must be designed into data infrastructure</td>
</tr>
<tr>
<td>8</td>
<td>187</td>
<td>Infrastructure should connect data sources</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>Scalable software infrastructure</td>
</tr>
<tr>
<td>5</td>
<td>98</td>
<td>System architecture should include quality control to monitor data for abnormalities</td>
</tr>
<tr>
<td>7</td>
<td>154</td>
<td>Systems must be architected based on data use cases</td>
</tr>
<tr>
<td>8</td>
<td>190</td>
<td>Data infrastructure must support use cases</td>
</tr>
<tr>
<td>5</td>
<td>99</td>
<td>A global data infrastructure should be scalable to allow inputs and outputs to connect</td>
</tr>
<tr>
<td>5</td>
<td>101</td>
<td>Scalable architecture is critical to data system success</td>
</tr>
<tr>
<td>5</td>
<td>102</td>
<td>Cloud computing empowers companies to utilize capabilities beyond their current infrastructure</td>
</tr>
<tr>
<td>5</td>
<td>103</td>
<td>Data connectivity is a key factor in Quality 4.0 success</td>
</tr>
</tbody>
</table>

### Table 15 - Theme 2

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 2 - Quality 4.0 systems utilize real time data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>Use real time data</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>Fully connect data infrastructure across all devices</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
<td>Industry 4.0 systems identify incorrect conditions in real time</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>Sensing capabilities observe the operation of a production system in real time</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>Analysis should happen in real time</td>
</tr>
<tr>
<td>3</td>
<td>66</td>
<td>Real time data use cases maximize the value of an Industry 4.0 system</td>
</tr>
<tr>
<td>6</td>
<td>129</td>
<td>Real time data can adjust processes to accommodate quality needs</td>
</tr>
<tr>
<td>5</td>
<td>95</td>
<td>Real time data can be processed and used without storing historical data</td>
</tr>
<tr>
<td>2</td>
<td>38</td>
<td>Industry 4.0 systems can monitor the quality of products in real time</td>
</tr>
<tr>
<td>6</td>
<td>128</td>
<td>Real time data drives real time actionable insights and decision making</td>
</tr>
<tr>
<td>7</td>
<td>153</td>
<td>Data infrastructure empowers real time decision making</td>
</tr>
</tbody>
</table>
### Table 16 - Theme 3

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 3 - Sensing technologies should be used to monitor system quality performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>79</td>
<td>Sensing and detection technologies are critical to quality</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>Technology that observes operation of the system is key to quality</td>
</tr>
<tr>
<td>6</td>
<td>130</td>
<td>Quality can be automated into digital system</td>
</tr>
<tr>
<td>2</td>
<td>38</td>
<td>Industry 4.0 systems can monitor the quality of products in real time</td>
</tr>
<tr>
<td>5</td>
<td>98</td>
<td>System architecture should include quality control to monitor data for abnormalities</td>
</tr>
</tbody>
</table>

### Table 17 - Theme 4

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 4 - System must provide actionable insights about operational performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>63</td>
<td>Data infrastructure must provide sufficient data to drive action for a use case</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>Analysis and actionable insights can be generated automatically without human intervention</td>
</tr>
<tr>
<td>5</td>
<td>94</td>
<td>Data infrastructure must be capable of accommodating high-volume data</td>
</tr>
<tr>
<td>2</td>
<td>37</td>
<td>Technology should augment human performance within a system</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>Data use case must drive tangible action</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>Architect data analysis and use cases to support actionable insights</td>
</tr>
<tr>
<td>7</td>
<td>149</td>
<td>Data analytics must drive action towards outcomes</td>
</tr>
<tr>
<td>5</td>
<td>97</td>
<td>Automation should drive actionable insights to necessary users</td>
</tr>
<tr>
<td>2</td>
<td>34</td>
<td>Technology use cases must include end users and tangible actionable outputs</td>
</tr>
<tr>
<td>6</td>
<td>128</td>
<td>Real time data drives real time actionable insights and decision making</td>
</tr>
<tr>
<td>5</td>
<td>96</td>
<td>Data may be automated and not require supervision or action to develop usable information</td>
</tr>
<tr>
<td>7</td>
<td>150</td>
<td>Technology use cases should enhance human capabilities</td>
</tr>
<tr>
<td>8</td>
<td>188</td>
<td>Effective data analytics should drive actionable outputs</td>
</tr>
<tr>
<td>5</td>
<td>104</td>
<td>Data analytics capabilities are a key factor in Quality 4.0 success</td>
</tr>
</tbody>
</table>
Table 18 - Theme 5

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 5 - Data systems should be automated to realize Quality 4.0 value</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>130</td>
<td>Quality can be automated into digital system</td>
</tr>
<tr>
<td>5</td>
<td>96</td>
<td>Data may be automated and not require supervision or action to develop usable information</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>Digital transformation should include data and information automation</td>
</tr>
<tr>
<td>8</td>
<td>189</td>
<td>Systems should actively drive data outputs to users</td>
</tr>
<tr>
<td>8</td>
<td>186</td>
<td>Data collection for big data should be automated</td>
</tr>
</tbody>
</table>

Table 19 - Theme 6

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 6 - Technology should be developed to support a tangible and value-added data strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>151</td>
<td>Begin with technology solutions which provide a clear value in the use case</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>Realization of value from historical data collected by the system</td>
</tr>
<tr>
<td>7</td>
<td>152</td>
<td>Develop value propositions to cost justify technology scaling</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>Data infrastructure, cost, and ROI must be considered in use case</td>
</tr>
<tr>
<td>8</td>
<td>191</td>
<td>Data use cases must be validated</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>Technology capability should be considered in data collection to prevent limiting necessary data inputs</td>
</tr>
<tr>
<td>3</td>
<td>64</td>
<td>Focus on high value data use cases in any Industry 4.0 application</td>
</tr>
<tr>
<td>3</td>
<td>65</td>
<td>Data value and validity are critical to the overall success of a data system</td>
</tr>
<tr>
<td>7</td>
<td>175</td>
<td>Technology strategy must be appropriate for company capabilities</td>
</tr>
<tr>
<td>6</td>
<td>127</td>
<td>Industry 4.0 capabilities can monitor a large variety of real time data</td>
</tr>
</tbody>
</table>

The themes which have emerged around technology for Quality 4.0 implementation are:

- Data infrastructure must be designed with data use cases and value in mind
- Quality 4.0 systems utilize real time data
- Sensing technologies should be used to monitor system quality performance
- System must provide actionable insights about operational performance
• Data systems should be automated to realize Quality 4.0 value

• Technology should be developed to support a tangible and value-added data strategy

4.4.1.2 Methodology Themes

Five specific themes were identified from codes related to the methodology construct from literature. Codes and themes are compiled in tables 20-24:

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 7 - Data automation enhances lean tool use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>Real time data supports the Andon principle</td>
</tr>
<tr>
<td>2</td>
<td>39</td>
<td>Sensing technology enables the Andon principle to be actively practiced</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>Industry 4.0 technologies enable Poke-Yoking systems through continuous observation</td>
</tr>
<tr>
<td>2</td>
<td>41</td>
<td>Adaptive visual management tools can be developed with new sensing and data presentation capabilities</td>
</tr>
<tr>
<td>2</td>
<td>42</td>
<td>Data collection on equipment enhances total productive maintenance</td>
</tr>
<tr>
<td>2</td>
<td>46</td>
<td>The Andon principle maximizes the value of observing defects in real time</td>
</tr>
<tr>
<td>4</td>
<td>81</td>
<td>Industry 4.0 technologies empower lean manufacturing and other management philosophies</td>
</tr>
<tr>
<td>7</td>
<td>157</td>
<td>Industry 4.0 technologies enhance lean capabilities</td>
</tr>
<tr>
<td>3</td>
<td>67</td>
<td>Integrated data systems empower lean flow</td>
</tr>
<tr>
<td>6</td>
<td>131</td>
<td>Industry 4.0 capabilities empower total productive maintenance</td>
</tr>
<tr>
<td>6</td>
<td>132</td>
<td>Data use cases can be applied with the Andon principle</td>
</tr>
<tr>
<td>8</td>
<td>194</td>
<td>Industry 4.0 data collection empowers lean tools</td>
</tr>
<tr>
<td>8</td>
<td>195</td>
<td>Industry 4.0 data collection supports lean improvement and implementation</td>
</tr>
<tr>
<td>8</td>
<td>197</td>
<td>Industry 4.0 empowers total productive maintenance</td>
</tr>
</tbody>
</table>
### Table 21 - Theme 8

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 8 - Quality 4.0 systems actively and continuously monitor the Gemba</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>A smart system empowers the Gemba to actively communicate with decision makers</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>Smart systems empower waste observation in real time</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>Observing system conditions enables quality to be built into the process</td>
</tr>
<tr>
<td>5</td>
<td>105</td>
<td>Industry 4.0 technologies allow the Gemba to be observed and optimized</td>
</tr>
<tr>
<td>5</td>
<td>108</td>
<td>Industry 4.0 technology allows continuous monitoring of quality KPIs</td>
</tr>
<tr>
<td>5</td>
<td>110</td>
<td>TQM should be architected into the early parts of the process with monitoring technology</td>
</tr>
<tr>
<td>7</td>
<td>155</td>
<td>Sensing capabilities actively observe the Gemba</td>
</tr>
<tr>
<td>3</td>
<td>69</td>
<td>Technologies that enable monitoring of the process and product empower processes such as lean and six sigma</td>
</tr>
<tr>
<td>8</td>
<td>196</td>
<td>Industry 4.0 systems actively monitor the Gemba</td>
</tr>
</tbody>
</table>

### Table 22 - Theme 9

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 9 - Quality data collection enables Total Quality Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13</td>
<td>Industry 4.0 systems streamline data for TQM applications</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
<td>Industry 4.0 technologies empower faster response to quality issues</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>Observing system conditions enables quality to be built into the process</td>
</tr>
<tr>
<td>2</td>
<td>48</td>
<td>Quality 4.0 systems make quality a shared responsibility</td>
</tr>
<tr>
<td>5</td>
<td>106</td>
<td>Industry 4.0 capabilities empower quality continuous improvement</td>
</tr>
<tr>
<td>5</td>
<td>109</td>
<td>Lean and TQM should be implemented together to enhance the outputs of Industry 4.0 technologies</td>
</tr>
<tr>
<td>5</td>
<td>110</td>
<td>TQM should be architected into the early parts of the process with monitoring technology</td>
</tr>
<tr>
<td>4</td>
<td>82</td>
<td>Industry 4.0 has the goal of achieving TQM</td>
</tr>
<tr>
<td>7</td>
<td>156</td>
<td>Industry 4.0 technologies enhance TQM capabilities and defect detection</td>
</tr>
<tr>
<td>7</td>
<td>160</td>
<td>Industry 4.0 technology is an enabler of TQM</td>
</tr>
<tr>
<td>7</td>
<td>161</td>
<td>Industry 4.0 technology builds quality into the processes</td>
</tr>
<tr>
<td>6</td>
<td>133</td>
<td>Quality should be designed into the process through monitoring the right quality KPIs</td>
</tr>
<tr>
<td>6</td>
<td>134</td>
<td>Real time data empowers TQM through informed decision making and process adjustment</td>
</tr>
<tr>
<td>6</td>
<td>136</td>
<td>TQM is an output of an effective Industry 4.0 system</td>
</tr>
<tr>
<td>8</td>
<td>198</td>
<td>Industry 4.0 data provides TQM inputs</td>
</tr>
<tr>
<td>8</td>
<td>200</td>
<td>Data on process performance feeds TQM shared quality accountability</td>
</tr>
</tbody>
</table>
The methodology themes which have been identified for Quality 4.0 implementation are:

- Data automation enhances lean tool use
- Quality 4.0 systems actively and continuously monitor the Gemba
- Quality data collection enables Total Quality Management
• Lean culture of empowerment is needed for Quality 4.0 success
• Lean process development comes before Quality 4.0 system deployment

4.4.1.3 Enablers Themes

Ten themes relating to enablers and barriers have been identified through the interview process. The codes and themes are collected in tables 25-34:

Table 25 - Theme 12

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 12 - Must have a clear strategy and use case for data and system design</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>Systems must be designed with business case in mind</td>
</tr>
<tr>
<td>1</td>
<td>16</td>
<td>ROI may have long lead time</td>
</tr>
<tr>
<td>1</td>
<td>19</td>
<td>System design goes beyond data and must extend into the actions driven by the data</td>
</tr>
<tr>
<td>2</td>
<td>53</td>
<td>Company capabilities must be considered in system development</td>
</tr>
<tr>
<td>3</td>
<td>70</td>
<td>Data architecture must include and connect all data relevant to use cases to be effective</td>
</tr>
<tr>
<td>3</td>
<td>75</td>
<td>Data inputs and system outputs must be validated</td>
</tr>
<tr>
<td>6</td>
<td>138</td>
<td>Processes must be designed in a way that can be enhanced with digitization</td>
</tr>
<tr>
<td>6</td>
<td>141</td>
<td>Lack of a clear and tangible strategy will hinder implementation</td>
</tr>
<tr>
<td>6</td>
<td>142</td>
<td>Use cases for data must drive tangible action</td>
</tr>
<tr>
<td>5</td>
<td>111</td>
<td>Data infrastructure must be architected within company capability/resources</td>
</tr>
<tr>
<td>7</td>
<td>167</td>
<td>Culture must empower employees to act based on data without decision hierarchies</td>
</tr>
<tr>
<td>8</td>
<td>202</td>
<td>Employee skill and knowledge should include understanding of the process</td>
</tr>
<tr>
<td>8</td>
<td>205</td>
<td>Use cases should unify processes and people through technology</td>
</tr>
</tbody>
</table>
### Table 26 - Theme 13

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 13 - Data use cases must provide value to the business</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>71</td>
<td>Establishing a dataset that realizes value is necessary for a use case</td>
</tr>
<tr>
<td>3</td>
<td>72</td>
<td>Infrastructure must be sufficient to handle big data, requiring investment and established value from use cases</td>
</tr>
<tr>
<td>5</td>
<td>112</td>
<td>Technology use cases should enhance processes and provide value</td>
</tr>
<tr>
<td>5</td>
<td>114</td>
<td>Technology must support or enhance a process</td>
</tr>
<tr>
<td>5</td>
<td>117</td>
<td>Use cases must present a feasible ROI to achieve leadership buy in</td>
</tr>
<tr>
<td>7</td>
<td>164</td>
<td>Lack of clear data use cases prevents value realization</td>
</tr>
<tr>
<td>7</td>
<td>174</td>
<td>Lack of a business case for value realization prevents Quality 4.0 success</td>
</tr>
<tr>
<td>8</td>
<td>210</td>
<td>Data use cases must achieve tangible value propositions</td>
</tr>
</tbody>
</table>

### Table 27 - Theme 14

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 14 - Leadership must fully commit to digital transformations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17</td>
<td>Business case must drive leadership commitment</td>
</tr>
<tr>
<td>1</td>
<td>18</td>
<td>Developing data architecture to suit leadership needs in addition to operational needs will help with buy in</td>
</tr>
<tr>
<td>1</td>
<td>23</td>
<td>Leadership and change management tools are critical to success</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>Management buy in is critical to success</td>
</tr>
<tr>
<td>2</td>
<td>54</td>
<td>Investment in system capability must match system needs</td>
</tr>
<tr>
<td>3</td>
<td>73</td>
<td>Leadership and change management are necessary for digital transformation</td>
</tr>
<tr>
<td>4</td>
<td>85</td>
<td>Change management and leadership are critical success factors for implementation</td>
</tr>
<tr>
<td>5</td>
<td>117</td>
<td>Use cases must present a feasible ROI to achieve leadership buy in</td>
</tr>
<tr>
<td>7</td>
<td>168</td>
<td>Leadership commitment and buy in is crucial</td>
</tr>
<tr>
<td>7</td>
<td>172</td>
<td>Change management is critical to success</td>
</tr>
<tr>
<td>8</td>
<td>206</td>
<td>Leadership commitment and resources must be in place for successful implementation</td>
</tr>
</tbody>
</table>
Table 28 - Theme 15

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 15 - Company must invest sufficient resources for infrastructure and system deployment</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>88</td>
<td>Large companies are more capable of financially implementing the infrastructure for a new technology</td>
</tr>
<tr>
<td>2</td>
<td>54</td>
<td>Investment in system capability must match system needs</td>
</tr>
<tr>
<td>3</td>
<td>72</td>
<td>Infrastructure must be sufficient to handle big data, requiring investment and established value from use cases</td>
</tr>
<tr>
<td>1</td>
<td>18</td>
<td>Developing data architecture to suit leadership needs in addition to operational needs will help with buy in</td>
</tr>
<tr>
<td>6</td>
<td>143</td>
<td>Real time data requires adequate system architecture and decision processes</td>
</tr>
<tr>
<td>5</td>
<td>111</td>
<td>Data infrastructure must be architected within company capability/resources</td>
</tr>
<tr>
<td>5</td>
<td>115</td>
<td>Companies must be willing to invest in appropriate data infrastructure to realize value from a use case</td>
</tr>
<tr>
<td>7</td>
<td>171</td>
<td>Solutions must be scalable</td>
</tr>
<tr>
<td>8</td>
<td>209</td>
<td>Data infrastructure must support usability</td>
</tr>
</tbody>
</table>

Table 29 - Theme 16

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 16 - Strategy design and system development require cross functional team inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>Diverse skills are required for system development</td>
</tr>
<tr>
<td>1</td>
<td>22</td>
<td>Cross functional team facilitation is important to achieving system objectives</td>
</tr>
<tr>
<td>2</td>
<td>53</td>
<td>Company capabilities must be considered in system development</td>
</tr>
<tr>
<td>6</td>
<td>142</td>
<td>Use cases for data must drive tangible action</td>
</tr>
</tbody>
</table>

Table 30 - Theme 17

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 17 - Cybersecurity must be built into the system</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>Cybersecurity must be addressed to drive top level leadership buy in</td>
</tr>
<tr>
<td>2</td>
<td>52</td>
<td>Cybersecurity must be addressed</td>
</tr>
<tr>
<td>5</td>
<td>119</td>
<td>Cybersecurity must be addressed</td>
</tr>
<tr>
<td>8</td>
<td>207</td>
<td>Cybersecurity must be addressed</td>
</tr>
</tbody>
</table>
### Table 31 - Theme 18

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 18 - An empowered culture is required to realize value from system generated actionable insights</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>Culture must support a shared vision and mission for system development</td>
</tr>
<tr>
<td>2</td>
<td>55</td>
<td>Hesitancy towards not saving historical data may require cultural and behavioral change within the organization</td>
</tr>
<tr>
<td>4</td>
<td>83</td>
<td>To maximize Industry 4.0 technologies a culture of empowerment and accountability for quality is necessary</td>
</tr>
<tr>
<td>4</td>
<td>87</td>
<td>Organizational structure and culture at small and medium companies is advantageous to implementing digital transformation</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
<td>Organizational structure must empower decision making at the appropriate level</td>
</tr>
<tr>
<td>5</td>
<td>121</td>
<td>Culture must empower groups to make decisions and iterate</td>
</tr>
<tr>
<td>7</td>
<td>166</td>
<td>Culture must empower data driven decision making</td>
</tr>
<tr>
<td>7</td>
<td>167</td>
<td>Culture must empower employees to act based on data without decision hierarchies</td>
</tr>
<tr>
<td>7</td>
<td>169</td>
<td>Creating collective technology goals and vision is necessary for system development</td>
</tr>
<tr>
<td>8</td>
<td>204</td>
<td>Culture should support prioritizing processes over technology</td>
</tr>
<tr>
<td>8</td>
<td>211</td>
<td>Culture should empower data driven decision making</td>
</tr>
</tbody>
</table>

### Table 32 - Theme 19

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 19 - A shared company vision for technology goals must be implemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>Culture must support a shared vision and mission for system development</td>
</tr>
<tr>
<td>6</td>
<td>139</td>
<td>Companies must develop a Quality 4.0 vision</td>
</tr>
<tr>
<td>5</td>
<td>118</td>
<td>Installing a shared organizational vision for the future state is critical to success</td>
</tr>
<tr>
<td>7</td>
<td>162</td>
<td>A shared vision for technology use must be deployed</td>
</tr>
<tr>
<td>7</td>
<td>170</td>
<td>Vision must be global within a company</td>
</tr>
</tbody>
</table>

153
Table 33 - Theme 20

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 20 - Employee buy in must be secured</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>49</td>
<td>Employee buy in must address automation job loss fears</td>
</tr>
<tr>
<td>2</td>
<td>51</td>
<td>User job design and communication must be addressed to drive buy in</td>
</tr>
<tr>
<td>3</td>
<td>74</td>
<td>Human factors must be considered prior to developing a digital system</td>
</tr>
<tr>
<td>3</td>
<td>76</td>
<td>Trust must be built with the employees for buy in to the system</td>
</tr>
<tr>
<td>6</td>
<td>140</td>
<td>Organization wide buy in to the vision and ideal future state are critical for success</td>
</tr>
<tr>
<td>6</td>
<td>144</td>
<td>Data validity and trustworthiness is critical to success</td>
</tr>
<tr>
<td>5</td>
<td>113</td>
<td>The human element must be considered within the process for technology deployment</td>
</tr>
<tr>
<td>7</td>
<td>163</td>
<td>Employee buy in is critical and must be considered and addressed</td>
</tr>
<tr>
<td>7</td>
<td>165</td>
<td>Employee system interaction must be designed to drive buy in</td>
</tr>
<tr>
<td>8</td>
<td>208</td>
<td>Employee buy in is required for success</td>
</tr>
</tbody>
</table>

Table 34 - Theme 21

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 21 - Company must invest in necessary skills for the workforce</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>74</td>
<td>Human factors must be considered prior to developing a digital system</td>
</tr>
<tr>
<td>4</td>
<td>84</td>
<td>Workforce skill deficit is a primary barrier to Quality 4.0 system implementation</td>
</tr>
<tr>
<td>4</td>
<td>86</td>
<td>The workforce must be considered in system design beyond the technical feasibility</td>
</tr>
<tr>
<td>6</td>
<td>137</td>
<td>Employee skills gaps are a challenge for digital transformation</td>
</tr>
<tr>
<td>5</td>
<td>116</td>
<td>Companies must invest in workforce skills relevant to the technology use cases</td>
</tr>
<tr>
<td>7</td>
<td>173</td>
<td>Use cases must include the employees use of the technology and skills</td>
</tr>
<tr>
<td>8</td>
<td>201</td>
<td>Lack of understanding of data use cases creates skill deficits</td>
</tr>
<tr>
<td>8</td>
<td>202</td>
<td>Employee skill and knowledge should include understanding of the process</td>
</tr>
<tr>
<td>2</td>
<td>56</td>
<td>Addressing employee skill levels and skill gaps is critical to success</td>
</tr>
<tr>
<td>8</td>
<td>203</td>
<td>Employee technical skill gaps must be addressed</td>
</tr>
</tbody>
</table>

Themes related to enabling factors and barriers to Quality 4.0 implementation are:

- Must have a clear strategy and use case for data and system design
- Data use cases must provide value to the business
• Leadership must fully commit to digital transformation
• Company must invest sufficient resources for infrastructure and system deployment
• Strategy design and system development require cross functional team inputs
• Cybersecurity must be built into the system
• An empowered culture is required to realize value from system generated actionable insights
• A shared company vision for technology goals must be implemented
• Employee buy in must be secured
• Company must invest in necessary skills for the workforce

4.4.1.4 Strategy Themes

Expert insights generated seven themes related to Quality 4.0 implementation strategy. Codes and themes related to strategy are compiled in tables 35-41:

*Table 35 - Theme 22*

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 22 - Strategize necessary data outputs and use cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>Clearly defined quality and performance targets must be defined to identify relevant data</td>
</tr>
<tr>
<td>1</td>
<td>28</td>
<td>Developing a data use case is a critical step in pre-implementation strategy</td>
</tr>
<tr>
<td>2</td>
<td>57</td>
<td>Tangible results for data applications must be designed into systems at the ground level</td>
</tr>
<tr>
<td>8</td>
<td>214</td>
<td>Strategy must develop system parameters to design actionable training plans</td>
</tr>
<tr>
<td>8</td>
<td>219</td>
<td>Strategy should link data, processes, and personnel to goals and value propositions</td>
</tr>
</tbody>
</table>
### Table 36 - Theme 23

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 23 - Develop data input strategy to support necessary data outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>Data to be collected and utilized within the system must be appropriately defined for the specific technology use case</td>
</tr>
<tr>
<td>1</td>
<td>28</td>
<td>Developing a data use case is a critical step in pre-implementation strategy</td>
</tr>
<tr>
<td>8</td>
<td>214</td>
<td>Strategy must develop system parameters to design actionable training plans</td>
</tr>
<tr>
<td>8</td>
<td>219</td>
<td>Strategy should link data, processes, and personnel to goals and value propositions</td>
</tr>
</tbody>
</table>

### Table 37 - Theme 24

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 24 - Ensure that data outputs will drive tangible actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>Data strategy must include tangible use cases</td>
</tr>
<tr>
<td>2</td>
<td>57</td>
<td>Tangible results for data applications must be designed into systems at the ground level</td>
</tr>
<tr>
<td>2</td>
<td>59</td>
<td>Developing a value adding use case drives buy in</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>Developing actionable use cases starting with a value proposition is critical to success</td>
</tr>
<tr>
<td>3</td>
<td>78</td>
<td>Developing a data use case based on value and actionability is critical to overall system architecture and success</td>
</tr>
<tr>
<td>4</td>
<td>91</td>
<td>Implementation strategy must bridge the gap between theory and use cases which provide value</td>
</tr>
<tr>
<td>4</td>
<td>93</td>
<td>Data strategy must drive actionable insights</td>
</tr>
<tr>
<td>5</td>
<td>124</td>
<td>Develop a value proposition for technology strategy and use cases</td>
</tr>
<tr>
<td>7</td>
<td>177</td>
<td>Developing technology use cases should consider tangible action and outcomes</td>
</tr>
<tr>
<td>7</td>
<td>185</td>
<td>Strategy should target realization of value case</td>
</tr>
<tr>
<td>8</td>
<td>216</td>
<td>Cross functional teams are necessary to develop value propositions and use cases</td>
</tr>
<tr>
<td>8</td>
<td>219</td>
<td>Strategy should link data, processes, and personnel to goals and value propositions</td>
</tr>
</tbody>
</table>
### Table 38 - Theme 25

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 25 - Assess business case of data system requirements to achieve actionable outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>145</td>
<td>Strategy must include development of a business case with tangible ROI</td>
</tr>
<tr>
<td>4</td>
<td>90</td>
<td>Digital systems must have viable value propositions and achievable, tangible, ROIs</td>
</tr>
<tr>
<td>2</td>
<td>62</td>
<td>A successful use case must drive tangible financial benefits</td>
</tr>
<tr>
<td>6</td>
<td>148</td>
<td>Business case must provide a tangible value proposition</td>
</tr>
<tr>
<td>7</td>
<td>176</td>
<td>Use cases must drive value for the company</td>
</tr>
</tbody>
</table>

### Table 39 - Theme 26

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 26 - Design data infrastructure to support data system needs and be scalable to the future</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
<td>Data system infrastructure and architecture are critical early steps to success.</td>
</tr>
<tr>
<td>2</td>
<td>58</td>
<td>Initial system architecture must include a use case within the strategy development</td>
</tr>
<tr>
<td>2</td>
<td>61</td>
<td>System automation must be designed to amplify the ability of employees within the system</td>
</tr>
<tr>
<td>6</td>
<td>146</td>
<td>Strategy must address the testing and validation of a system</td>
</tr>
<tr>
<td>5</td>
<td>123</td>
<td>Benchmark technical capabilities during strategy development</td>
</tr>
<tr>
<td>7</td>
<td>178</td>
<td>Data strategy must have use cases architected into the ground level</td>
</tr>
<tr>
<td>7</td>
<td>181</td>
<td>Strategy should fit company capabilities</td>
</tr>
</tbody>
</table>
Table 40 - Theme 27

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 27 - Assess company and promote enablers/address barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29</td>
<td>Apprehension about automation and job change must be addressed</td>
</tr>
<tr>
<td>1</td>
<td>31</td>
<td>Transitioning to real time data and new capabilities requires change management and strategy</td>
</tr>
<tr>
<td>2</td>
<td>59</td>
<td>Developing a value adding use case drives buy in</td>
</tr>
<tr>
<td>3</td>
<td>77</td>
<td>Building strategy around data capability is critical</td>
</tr>
<tr>
<td>4</td>
<td>89</td>
<td>Implementation strategy must include the workforce to be feasible</td>
</tr>
<tr>
<td>4</td>
<td>92</td>
<td>Resources and knowledge should be maximized during the strategy phase to develop adequate business cases</td>
</tr>
<tr>
<td>6</td>
<td>147</td>
<td>Strategy and planning must achieve leadership buy in</td>
</tr>
<tr>
<td>5</td>
<td>122</td>
<td>Developing an organizational mission is a critical element of strategy</td>
</tr>
<tr>
<td>5</td>
<td>125</td>
<td>Strategy must include planning for workforce adaptation</td>
</tr>
<tr>
<td>5</td>
<td>126</td>
<td>Sound processes must be in place to be enhanced by technology</td>
</tr>
<tr>
<td>7</td>
<td>182</td>
<td>Strategy should address enablers and barriers on a broad scale</td>
</tr>
<tr>
<td>7</td>
<td>184</td>
<td>Strategy should address workforce change management</td>
</tr>
<tr>
<td>8</td>
<td>212</td>
<td>Strategy must address future skills needed in the workplace</td>
</tr>
<tr>
<td>8</td>
<td>213</td>
<td>Strategy must account for internal development of skills</td>
</tr>
<tr>
<td>8</td>
<td>214</td>
<td>Strategy must develop system parameters to design actionable training plans</td>
</tr>
<tr>
<td>8</td>
<td>215</td>
<td>Strategy development requires multifunctional knowledge</td>
</tr>
<tr>
<td>8</td>
<td>216</td>
<td>Cross functional teams are necessary to develop value propositions and use cases</td>
</tr>
<tr>
<td>8</td>
<td>217</td>
<td>Strategy should generate company wide vision</td>
</tr>
<tr>
<td>8</td>
<td>218</td>
<td>Strategy must accommodate how operational changes affect personnel</td>
</tr>
</tbody>
</table>

Table 41 - Theme 28

<table>
<thead>
<tr>
<th>Interview</th>
<th>Code</th>
<th>Theme 28 - Develop implementation plan for supporting methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>180</td>
<td>Digital transformation strategy should employ non-digital methods and tools where appropriate</td>
</tr>
<tr>
<td>7</td>
<td>179</td>
<td>Strategy should center on value proposition over technology</td>
</tr>
<tr>
<td>7</td>
<td>183</td>
<td>Strategy should address processes first and not just technology implementation</td>
</tr>
<tr>
<td>8</td>
<td>219</td>
<td>Strategy should link data, processes, and personnel to goals and value propositions</td>
</tr>
</tbody>
</table>

The seven themes emerging around strategy are:
• Strategize necessary data outputs and use cases
• Develop data input strategy to support necessary data outputs
• Ensure that data outputs will drive tangible actions
• Assess business case of data system requirements to achieve actionable outputs
• Design data infrastructure to support data system needs and be scalable to the future
• Assess company and promote enablers/address barriers
• Develop implementation plan for supporting methodologies

4.4.2 Theme Review

Review of the themes involves contextualizing the individual themes within the entire dataset to determine the valid themes from the research (Braun & Clarke, 2012). To compile the entirety of the data set each set of themes within one of the high level domains of technology, methodology, enablers, and strategy, will be considered within the domain. This will be followed up with a consideration of the four top level domains themes and their overlap.

4.4.2.1 Technology Themes

The six technology themes can be described in terms of system performance requirements. The themes of data infrastructure being designed in the context of the value proposition, the system providing actionable insights, and technology supporting value-added strategy all describe considerations to be taken when designing a Quality 4.0 system. This could be represented as an intermediate-level theme, however designing infrastructure to support value added use cases, designing data use cases to drive value, and designing outputs to drive action are all unique themes in their own right. These themes have a logical flow when it comes to the technical design of a
Quality 4.0 system which is that value should be defined, actions to support that value must be identified, and data infrastructure to drive those actions must be developed.

The other three technology themes form a second grouping. Using real time data, deploying sensing technologies for quality purposes, and applying automation are all more tangible elements of technical system requirements. These themes are also unique in that they all define a distinctly different element required in the architecture of the system, namely sensors, real time data, and automation. The second intermediate theme for technologies is the system parameter’s theme of system requirements to be a Quality 4.0 system.

The two intermediate themes in the technology domain, encompassing the six technology themes are:

- **Technology Design Theme**
  - Begin with a value proposition which can be data driven
  - Develop actions to support achieving the value proposition
  - Architect a system which uses data effectively to drive those actions

- **Quality 4.0 System Parameters Theme**
  - Systematic use of data must be automated
  - Data should be utilized in real time
  - Sensing technology should be used to observe quality performance

4.4.2.2 Methodology Themes

Five themes describe the relationships between lean and Industry 4.0 technologies as well as TQM and Industry 4.0 technologies. With the definition of Quality 4.0 being the utilization of
Industry 4.0 technologies to achieve quality goals, any system using Industry 4.0 to achieve TQM is, by default, going to be a Quality 4.0 system. Themes related to lean include automated data enhancing the capabilities of lean tools such as Andon, TPM, SMED, Poke-Yoke and Value Stream Mapping (VSM), Quality 4.0 systems continuously monitoring the performance of the Gemba, lean culture of empowerment is needed for Quality 4.0 success, and lean standard work and process development must happen prior to technology deployment. These can break down into two intermediate thematic ideas, first that Quality 4.0 systems can utilize data to make all advanced lean tools more impactful and always keep the Gemba on display, second, the foundational lean pieces of empowered culture and standard processes should be implemented prior to a Quality 4.0 system. The relationship between Quality 4.0 and TQM is reflected in the theme that a Quality 4.0 system provides data to enable TQM to be practiced at a high level. This relationship may be best maximized through architecting proven TQM principles into a Quality 4.0 system design to streamline improved results after system implementation, which relates well to the pieces of lean which should be developed prior to technology deployment.

The two intermediate themes relating to lean and TQM methodologies are:

- Pre-Technology Deployment Methods
  - Develop lean empowered culture
  - Develop standard work
  - Architect TQM principles

- Post-Technology Deployment Methods
  - Maximize advanced lean tool capabilities
    - Andon, Poke-Yoke, VSM, TPM, SMED
Continuously observe the conditions of the Gemba through active data systems

4.4.2.3 Enablers Themes

Ten themes were identified surrounding enablers. The enablers of clear strategy and data use case for system design, value addition of data use cases, and cross functional team inputs to strategy and design are strongly related in the aspect of they are guiding principles to the development of a strategy. They are all unique from one another in that they are different elements of strategy guidance, strategy must have data use cases, those data use cases must bring value, and developing those use cases requires the inputs of multiple disciplines.

The themes of leadership commitment, resource investment, empowered culture, and shared vision are also related, and they synthesize into two intermediate themes. The first of these intermediate themes is leadership inputs, which are full commitment and resource allocation. These are distinctly different themes because commitment should be a general method of management and behavior, while resource allocation should be influenced by business cases and developed technology strategies. The second intermediate theme with leaders is their outputs, which are an empowered culture and a shared company vision. Leadership must embrace an empowered culture for it to thrive, and it is the responsibility of leadership to develop and promote the shared vision for the technology transformation of the business.

Cybersecurity stands alone as a theme and it serves as a baseline system requirement for implementation. It is a much more technical enabler.

The employee themes may also be paired together as an intermediate theme which includes investment in employee skill development for technology change, and securing employee buy in.
These themes may be circular in nature, with skills development helping promote buy in, while employees who are bought in may be prime candidates for upskilling. This theme covers deployment of the labor force.

The five intermediate themes related to enablers are:

- **Strategy Enabler**
  - Develop clear data use cases
  - Establish value propositions of data use cases
  - Utilize cross functional teams to develop data use cases

- **Leadership Inputs Enabler**
  - Commitment to the change
  - Financial investment in infrastructure

- **Leadership Outputs Enabler**
  - Deployment of companywide technology vision
  - Support of empowered culture

- **Cybersecurity Enabler**
  - System design must be secure to move forward

- **Workforce Enabler**
  - Invest in employee skills development related to technology use cases
  - Secure buy in from employees through change management
4.4.2.4 Strategy Themes

Seven themes emerged from the codes identified in the arena of strategy. There is a clear intermediate theme of use cases which includes architecting data inputs, outputs, actionability, and business case/value. These themes flow linearly in a typical process design fashion with a clear process of determining data driven actions, identifying the necessary data outputs to drive the action, developing the inputs to achieve the outputs, and then assessing the value proposition and business case of the infrastructure needed to realize the action versus the financial value of the output. A clear intermediate theme of data architecture strategy emerges from those themes.

The other three themes under strategy stand alone as other components of the strategy development. Designing infrastructure to be scalable to the future should be considered after establishing use cases, assessing company barriers and enablers and creating action plans around them stands alone as well, and the deployment of the methodologies of lean and TQM also is a standalone strategic component.

The themes which emerge from the strategy domain are:

- Data Architecture Strategy
  - Identify actionable, tangible opportunities for data use
  - Develop outputs to drive action
  - Develop inputs to drive outputs
  - Assess tech requirements and value to determine business case feasibility
- Infrastructure scalability for future needs
- Perform company assessment for barriers and enablers and address weaknesses
• Strategize lean and TQM deployment prior to technology deployment

4.4.2.5 Technology/Strategy Overlap

The technology and strategy themes overlap in the development of the technology design theme. The data architecture strategy should develop the use cases to be designed into the technical blueprint of the system.

4.4.2.6 Technology/Methodology Overlap

Technology and methodologies overlap in the Quality 4.0 parameters theme, the process data that will be collected with sensing technologies to observe the Gemba and the enabling of TQM fall under the Quality 4.0 parameters theme.

4.4.2.7 Technology/Enablers Overlap

Technologies and enabling factors overlap in the technology design theme. The workforce enabling theme of employee skills development should be designed based on the technical needs of the system.

4.4.2.8 Methodology/Strategy Overlap

The methodology theme overlaps with the strategy theme in the data architecture theme. Quality data for TQM use cases should be developed into the use cases of the data architecture.

4.4.2.9 Methodology/Enabler Overlap

Within methodology the pre-technology deployment methodology should include development of an empowered lean culture to satisfy the workforce enabling theme.
4.4.2.10 Enabler/Strategy Overlap

The development of a strategy is one of the key enablers to digital transformation, so the strategy theme satisfies one of the enabling themes on its own. Furthermore, an organizational assessment of overall barriers should be undertaken to address all observed barriers during strategy development. Strategy should begin with development of a Quality 4.0 vision and assembly of a multifunctional team to satisfy two enabling themes.

4.4.3 Defining and Naming Themes

Defining and naming themes has three requirements (Braun & Clarke, 2012):

1. Themes have a singular focus
2. Themes may be related but are unique
3. Themes must be relevant to the research question

Through the exploration of the relationships between themes in the previous section and all themes building into the final conceptual model these requirements are explored and met.

4.4.4 Reporting Themes

Theme reporting is satisfied through the publication of this dissertation. Reporting qualitative thematic analysis dictates that analysis of said themes should address the research question which prompted the research (Braun & Clarke, 2012). The revision of the initial conceptual model into the final model proposed for Quality 4.0 implementation satisfies this requirement at the time of publication.
4.4.5 Interview Validity Measures

Saturation is the validity measure for interview sample size which could not be pre-established due to the nature of how saturation is achieved. Through code analysis of each interview saturation has been satisfied by the fact that none of the body of interviews provided any novel codes. Demonstration of repetition of themes requires the validation that each theme is present in more than one interview. This is developed through a matrix of themes and interviews. The interviews are sequentially numbered one through eight following the headings in this chapter and the themes from the interview analysis are numbered as follows:

1. Data infrastructure must be designed with data use cases and value in mind
2. Quality 4.0 system utilize real time data
3. Sensing technologies should be used to monitor system quality performance
4. System must provide actionable insights about operational performance
5. Data systems should be automated to realize Quality 4.0 value
6. Technology should be developed to support tangible and value-added data strategy
7. Data automation enhances lean tool use
8. Quality 4.0 systems actively and continuously monitor the Gemba
9. Quality data collection enables total quality management
10. Lean culture of empowerment is needed for Quality 4.0 success
11. Lean process development comes before quality 4.0 system deployment
12. Must have a clear strategy and use case for data and system design
13. Data use cases must provide value to the business
14. Leadership must fully commit to digital transformation
15. Company must invest sufficient resources for infrastructure and system deployment

16. Strategy design and system development require cross functional team inputs

17. Cybersecurity must be built into the system

18. An empowered culture is required to realize value from system generated actionable insights

19. A shared company vision for technology goals must be implemented

20. Employee buy in must be secured

21. Company must invest in necessary skills for the workforce

22. Strategize necessary data outputs and use cases

23. Develop data input strategy to support necessary data outputs

24. Ensure that data outputs will drive tangible actions

25. Assess business case of data system requirements to achieve actionable outputs

26. Design data infrastructure to support data system needs and be scalable to the future

27. Assess company and promote enablers/address barriers

28. Develop implementation plan for supporting methodologies

Summary results collected from the tables of codes and the source quotes of those codes. With iterative thematic analysis for assessing the saturation validity all interview responses are compiled sequentially in table 42 below. Saturation was achieved when themes 23 and 28 were both reflected in the 8th interview.
<table>
<thead>
<tr>
<th>Theme</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Methodology</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Enablers</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Strategy</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

*Table 42 - Interview Saturation Validity*
4.5 Revision of conceptual model based on Framework Methodology

The relationship between themes from the top-level down is used to develop a more specific order of precedents for the conceptual model of Quality 4.0 deployment. Referencing back to the original model:

Layering expert input into the model provides validation for established high level themes but also iterates the model to a greater degree of accuracy.
4.5.1 Iterating the Conceptual Model

The original conceptual model provided top level themes of strategy, enablers, methodology, and technology. Iterating the model with expert input involves thematically relating existing themes to new themes and adding in the identified precedents.

4.5.1.1 Strategy Theme

The initial themes under strategy were assessing the current state, achieving leadership commitment, and developing a digital strategy. These are directly validated by the themes extracted from expert input. Assessment of the current state is validated by the assessment of barriers and enablers theme from expert input. The leadership commitment theme is also validated through the assessment of enablers and barriers, as leadership commitment is an enabling theme, and it is further validated through the development of business case to drive leadership buy in as established by codes from interviews. Development of a digital strategy is reflected in the data architecture strategy theme from expert input.

Applying precedent which has been generated by expert input the iteration of the strategy theme can be broken into two main components, organizational pre-work, and technology strategy development. These two constructs of the model are concurrent entities with the following themes, note that the strategy enabler is reflected in the existence of the strategy construct in the top-level of the model:

- Organizational Pre-Work
  - Lean and TQM best practice deployment
    - Lean standardization
- Lean empowered culture
- Designing TQM into processes
- Creating TQM quality accountability
  - Assessment of organizational enablers
    - Leadership inputs
    - Leadership outputs
    - Cybersecurity
    - Workforce enablers
- Technology strategy development
  - Data use cases with value proposition
  - Actionable outputs
  - Data inputs
  - Infrastructure requirements and business case

This step of the model should be driven by leadership and include a multifunctional team. A high level of benchmarking technology capability may be necessary to develop an effective technology strategy. Output of the strategy portion of the model should address enablers in an implementation strategy.

4.5.1.2 Methodology Theme

Initial methodology themes included TQM and lean. These are both directly validated by expert testimony with further detail added. Developing specific targets for implementing methodologies should be established in the strategy phase following the pre-work and technology strategy constructs. Theme breakdown for methodology is as follows:
• Following organizational pre-work
  o Develop lean empowered culture
  o Drive lean standard work
  o Implement TQM core principles

• Following the technology strategy
  o Implementation of data driven lean tools
  o Implementation of digitally enhanced Gemba monitoring

4.5.1.3 Enablers Theme

Strategy for all enablers should be addressed during the strategy portion of the model. The initial model had the enabling themes of culture, company and resources, and management tools and methods. These themes are all validated through expert input with some rearrangement based on precedent and overlap. Culture is a key enabler that is highlighted by lean culture development, company and resources are validated by the leadership commitment and infrastructure investment themes, and management tools and methods are specifically addressed through change management and the lean and TQM methodologies. The established enablers from expert input fall under these umbrellas with a higher degree of specificity. The precedent of enablers follows the pre-work and technology sides of the model similarly to the methodologies themes with enabling themes as follows, with the strategy enabler covered through the existence of the strategy construct:

• Following organizational pre-work
  o Leadership Inputs Enabler
    • Commitment to the change
Leadership Outputs Enabler
- Deployment of companywide technology vision
- Support of empowered culture

Workforce Enabler
- Secure buy in from employees through change management

Following the technology strategy

Leadership inputs enabler
- Financial investment in infrastructure

Cybersecurity Enabler
- System design must be secure to move forward

Workforce enabler
- Invest in employee skills development related to technology use cases

4.5.1.4 Technology theme

The technology theme should largely come into existence as an output of the rest of the model. Technology implementation is the resulting output of the entire digital transformation process. Initial technology themes included data collection and management, data analytics, and data automation. These themes are validate directly through expert input. Data collection and management is validated by real time data and infrastructure design themes. Data analytics is also validate by the real time use of data, the design of data use cases, and systematic support of a value-adding strategy for data. Data automation is reiterated directly in the expert input.
The culmination of the model is the technology theme. The technology strategy themes have been migrated into the strategy portion of the model. The technology themes in the final model are:

- Technology
  - Sensing technology collecting data
  - Infrastructure to support value added use cases
  - Use of real time data and analytics
  - Data automation with actionable outputs

Expert input validated literature constructs while supplying a greater level of detail and a degree of precedent allowing the finalized model to be more thorough and provide a better understanding of Quality 4.0 implementation. The final model can be seen in section 5.2.
CHAPTER FIVE: CONCLUSIONS

5.1 Findings

Results from expert interviews validated the model generated from literature. The expert inputs provided a greater degree of clarity on detail on the constructs of the model. Not all technologies or enablers were highlighted to the same extent, which highlights the benefit of the study exploring experts’ tangible experiences on the topic of implementing Quality 4.0. Much of what is highlighted in the model for deployment utilizes existing organizational resources and methods without needing technical experts to reinvent the wheel of how business is practiced. Each of the 28 themes identified as important to the deployment of Quality 4.0 is sufficiently complex to merit deliberate effort if a company is going to undertake a quality centered digital transformation, however many of the themes will provide benefits on a standalone basis during the process of developing a company’s technical capability in the digital age.

5.2 Contribution to Body of Knowledge

The primary contribution of this research is a model for the implementation of Quality 4.0 in US based manufacturing firms, which can be seen below in figure 5. This model explores the specific nuance of developing and deploying a digital transformation strategy with quality as a primary end goal. The world is undergoing the fourth industrial revolution, which means, if the first three revolutions are to guide our expectations, every business will eventually have adopted the technologies of the revolution. Adopting these technologies is a difficult task with the current available BoK on implementation and this research provides the groundwork to further development of road maps and detailed plans for succeeding in a digital transformation.
Development of this implementation model drew upon the experience of individuals who have implemented digital technologies successfully in a broad range of settings. Worth noting is that not all theoretical ideals from literature are created equal when it comes to application. Bridging the gap between theory and practice is a critical step towards future advancement. Literature provided the examples that lean and TQM are correlated to digital transformation success which promotes the idea that a quality centered strategy is an effective method. Expert input identifies TQM concepts of quality being built into the architecture of processes and quality becoming everyone’s responsibility as simple inputs and outputs of any digital system. This highlights the value of exploring successful implementation as well as the value of Quality 4.0. If a digital system has an intuitive or implied quality goal then models for how to deploy said systems with quality as a primary goal have great value.

Expert input also highlights nontechnical aspects of revolutionizing the technology landscape of how business is done. People are still at the core of most business processes and the culture surrounding those people is a critical element to success with technology. This research highlights legacy ideas around general best practices with leadership, change, and empowerment as being major factors beyond just technical skill. Moving forward those factors will likely need to be maximized due to the revolutionary nature of the technologies at hand and the relative lack of technical skill that will continue to exist as the workforce and the world continue to adapt.

In addition to the model, the research also provides clarity on definitions of key terms which are sometimes ambiguous in the various literature. By clarifying that Industry 4.0 represents technology deployment of a specific set of technologies, and Quality 4.0 is that technology deployment with quality as the main goal, implementation models and strategies can be made
much clearer than the sometimes vague idea of Industry 4.0 when it’s published as a strategy or methodology on its own.
5.2.1 Final Conceptual Model

Figure 5 - Final Quality 4.0 Implementation Model
5.2.2 Final Conceptual Model Measures of Validity

The following factors establish the models validity (Moody et al., 2003):

- Model Completeness for Quality 4.0
  - Achieved through reaching interview saturation and total validation of literature constructs
- Model element necessity
  - All elements in the model exist in literature and expert testimony
- Model factor independence
  - The codification process established each code as unique

5.3 Research Limitations

The state of the art in implementing Industry 4.0 technologies is very limited which provides a significant challenge in sampling successful digital transformations. Thematic analysis was chosen for this research due to the lack of potential population of successful digital transformations which might be available for survey. Qualitative analysis and expert interview are valid methods, however quantitative conclusions should not be drawn from a qualitative model. While establishing saturation it was tempting to provide weights to themes based on prevalence, however it is impossible to validate the weight of one experts experience against another. Quantitative measures over a broader sample are necessary for establishing any type of weight of importance on the themes presented in this model. Precedent may be established between themes from a time ordered standpoint based on the qualitative flow of expert input.
The research is also limited by a lack of supporting case studies specifically in the domain of Quality 4.0. Unclear definitions of terminology and digital strategies available on the market lumps all available cases under the Industry 4.0 umbrella. Clarifying the line between Quality 4.0 and other “4.0” terminology was critical in the early part of this research, and a lack of clarity in the literature landscape poses challenges when attempting to research specific “4.0” applications.

5.4 Conclusion

Benchmarking successful processes has always been a business best practice and will continue to be so. As the fourth industrial revolution continues, more companies will find success in applying digital technologies and more companies will be forced to adapt to keep up with the landscape of business overall. Industry 4.0 technologies have significant quality implications and capabilities, and Quality 4.0 strategies are worth considering.

Quality 4.0 implementation starts with strategy development. To be successful with Quality 4.0 companies must deploy best practices in addition to technology. Technology is not a fix for process issues, and setting quality baselines in company best practices is a precursor to technology deployment in a Quality 4.0 strategy. Lean culture and TQM principles are both industry practices which can be implemented in the absence of technology, and both will help a Quality 4.0 implementation realize maximum benefits.

Quality 4.0 ultimately is about data. Without data driven technologies these changes wouldn’t be happening, and data should be a key element to any digital transformation strategy. With Quality 4.0 a strategy for how data will be used to improve quality performance should be developed and when deployed the data component of the process should be as automated as
possible. It is critical to alleviate job loss fears when discussing automation with employees, and a Quality 4.0 system should highlight how that data will augment human performance by empowering data driven decision-making and prompting fast response to any measurable issue.

Digital systems must attempt to maximize their value, as ROI on such systems may be prohibitively long in the context of traditional project execution. Designing a Quality 4.0 technology use case should consider every possible benefit when creating a data ecosystem, and ecosystem design should always be scalable. It is critical for leadership to take charge with Quality 4.0 due to the benefits likely being spread out, and one of the most important aspects of leadership in a digital transformation is creating a company wide shared vision for the system itself. Siloed departments focusing on their own metrics may create a lack of cohesion in system design, and a Quality 4.0 system should be cohesive for the company.

The implementation model developed in this study offers a starting point with a high level sequence to deploying Quality 4.0 in manufacturing. The ideas presented in the model may be addressed to craft specific implementation plans, and the importance of planning and strategy should not be overlooked.

5.5 Future Research

Research that bridges the gap between theory and practice in business starts with theory and works towards practice. The logical extension of this research is in case study applications and the development of more tangible guidelines for specific steps. Exploring specific themes in greater detail is a significant opportunity moving forward. Research opportunities include:

- How to drive buy in for digital transformation
- Achieving ROI on Quality 4.0 technology solutions
- Development of roadmaps for making a digital transformation strategy
- Highest value skills for digital and how to develop them
- Does the combination of culture and standardization assessment make the Baldrige Framework a good assessment for digital transformation readiness
- Case studies on digital transformation

For this model specifically case study analysis on applying the model, with several repetitions, would allow for iteration to move from a model of deployment towards a roadmap of more step-by-step implementation guidelines.
APPENDIX A:

INTERVIEW TRANSCRIPTS
Dr. Hayder Zghair Interview 10.28.2022

Tom Jones: Ok, so thank you for your time today. What I’m doing is I’m doing expert interviews on the topic of Quality 4.0 so that I can understand the successes and failures and some of the factors surrounding and failure of implementing Quality 4.0. So Quality 4.0 is a term that represents a quality centered digital transformation strategy, so essentially you’ve got smart factory you’ve got digital transformation, you’ve got a lot of terms out there that represent using modern technologies to use data, to collect data, to analyze data, and Quality 4.0 is the application of those technologies and the data usage towards improving quality performance. The primary focus of this study is on manufacturing firms. However, your subject matter expertise may come from a different arena from manufacturing, such as I believe in your case academia, and you’ve been selected for interview because of a demonstrated level of subject matter expertise on that topic. So does that all make sense?

Dr. Hayder Zghair: Yes, it does.

Tom Jones: Perfect, before I get into my interview questions this is a semi-structured interview so you’re welcome to take as much time and go to as much detail as you’d like answering any of the questions, because it’s all about your expertise it’s not yes/no such as a survey. I have fourteen questions and they are grouped by higher level topic. And, I’ll introduce the topic and then ask the first question and just let the interview flow from there. And before we get started on that if you could, please give me your background and kind of an explanation of your experience and expertise on the topic.

Dr. Hayder Zghair: Yes, so my name Hayder Zghiar. I’m a manufacturing and industrial engineer by training. My bachelors, my first masters, my second masters, and doctoral, all of them in manufacturing. I started the bachelors and the first masters were industrial engineering and then the second masters and the doctoral was manufacturing engineering, so I kind of have that combination of industrial and manufacturing engineering. Talking about my academic experience in that realm, I am currently an assistant professor at Southern Arkansas university as an assistant professor of industrial engineering, and my responsibilities include teaching a variety of engineering courses, and more of the industrial and manufacturing mid-level and high-level courses and I’m the director of the industrial engineering and center of engineering program. I started this career back in 2015 and I moved from Kettering University from Michigan to Pennsylvania State University in Pennsylvania and then recently joined Arkansas and Southern Arkansas University. Talking about the topic of today’s matter, Industry 4.0, I’ve worked extensively in developing courses at Pennsylvania State University from scratch from the beginning. And this kind of cutting-edge technology, it requires, you are putting your hands into a place to be able to create a sense of what kind of courses and knowledge are needed for the students and the program directors and that’s exactly what I did. I teamed up with Bosch and their engineering team, the supplier of the technology to that lab at Pennsylvania State University. I’d been introduced to them and paired with them by the school because the deal was already initiated before, and I joined a couple of semesters in and they were wanting me to join them because it’s in my area to create the smart manufacturing for Industry 4.0. That was the title and the content of the course. And I really learned a lot about hands on technology, what’s the component of having smart, of having actually advanced manufacturing systems to be smart. And what the definition of the smart term and how much it connects to industry 4.0 techs so it would be the
cutting-edge, kind of smart system, of manufacturing. So that’s briefly introducing myself and giving some details about the topic of today’s matter, and I feel like that’s a good introduction.

**Tom Jones:** Yeah, no, that’s perfect, definitely have subject matter expertise there. I think working with companies hand on so that you could then develop a curriculum from it, that’s about as thorough as you could be, so that is fantastic. So I’m really glad that we’ve got your experience on board for my study here, I think it’s going to be very valuable. So then the first question I think you actually just answered is what’s your role and background with Quality 4.0 establishing your subject matter expertise. So, I’ll jump right into the Quality 4.0 questions. So, the questions are broken down, I’m not going to lead with the model that I’ve developed, but the questions are broken down into some high-level topics and when we’re done if you are curious about the topics and why they’re grouped that way I’m more than happy to flow information back the other way as well. So, the first topic is technology, which I think is a pretty straightforward topic for this content. So within the technology domain, can you start by from your experience describing the state of the art in data collection?

**Dr. Hayder Zghair:** Yes, so the data collection for these Industry 4.0 techs, when we specifically are talking about the cloud technology as a whole, is where you’re actually controlling the data. What I mean here is the acquisition of data and where you store the data and later how will you call them, collect on them. Based on that topic, how are you going to direct those data, for example for the quality purpose, for control, production purpose, for maintenance scheduling, you have raw data collected, pulled, and in the cloud and then whatever technology that you have. Any intelligent kind of advanced tool, you can use the data. The other form of the data with Industry 4.0, from my standpoint, is the data exchange in the system itself, in the field. So, you’re basically looking for instant data, it doesn’t really necessarily need to be stored, saved, at any place unless you create a pool of this historical data. So, talking about the case study that I work with, and the system that we adapted in our course, that was the second level of having the data in that course curriculum, as content. Because the course that we created, it was for entry-level, basically undergrad students at entry level, it was one of the high-level electives, but it didn’t really require then, as it was the first time, a strong knowledge of algorithms, programming, you know advanced mathematics tools. It was kind of open for all of the manufacturing and industrial engineering students and we actually got some mechanical engineering interested in it. But then at that time we didn’t decide to go to that level of playing with the data that we collected on the cloud and was from our outline side, as professors, and from the company we worked with, Bosch. Actually, that was one of the options that required extra in the deal with them, to actually have some, I would say, extra room in the cloud to store the data and call on it whenever you need and have that back-and-forth access to the data. But seeing the data on the cloud was a live display. When they are uplinked to the cloud I can see it, I can build a control strategy for them, I can put any interpretation that I need for my students because we have this interface layer on the cloud. It’s based on Microsoft Azure, but it’s owned by Bosch also, so they cannot put an extra Azure layer, a current production planning and manufacturing layer. It’s really a local kind of name for that layer of cloud technology. It’s to provide, actually, those live data. We can kind of pre-show that if this, that means some explanation so taking this explanation we can build subroutines including some like a list of tasks to be taken when that live data, which basically represents a variable, will help to show in terms of max and minimum what kind of list of actions we are taking as users. Basically as manufacturers in the field what needs to be taken. An example of this, for example, in
emergency cases, what the next list of procedures users need to take when, for example, the extensive heat collected from the place. Because what we actually implemented there, it was a set of 3D printers, and you know molding and injecting those fluid drops from that filament was one big sensitive factor for our observation as we were screening the data. So that’s what I can catch from the data, as two types of data, one we store the data all along that we’re running the system for as long as possible, and looking to that as historical data. And my understanding, one of the ideas that I was planning to take to the next level, was to use it for the quality control by the way, because you will have historical data about your system and the sensors we use have to somehow observe the vibration from the machine. So, we all know from manufacturing if the machine changes its vibration level that mean’s a lot about the adequacy of the machines. Maybe tooling failure is around or it’s already in place. So that causes quality consequences. So that was one of the ideas, actually, what it takes at the front level to look at those stored historical data to kind of find a pattern for if we’re running for this long, or if we’re running for this type of product, or if we’re running for this type of specific material, what does the historical data look like and what type of pattern can we extract from this historical data? And the other form of data, actually, the data exchange which doesn’t necessarily need to be stored, it’s gone once done.

**Tom Jones:** Yeah, so that’s an interesting one that I’d like to explore with you a little bit just before we move on to the next question. So essentially with the state of the art in data collection things move fast enough that we can make instantaneous use of data and, I will admit, using data myself I’ve never considered not storing data in any context, but essentially you’re saying the state of the art is fast enough that we can use it instantaneously and then its gone? There’s no reason, if we use it correctly then it can just go away and not hurt anything?

**Dr. Hayder Zghair:** True.

**Tom Jones:** That’s incredible.

**Dr. Hayder Zghair:** True, because you want to remember storing data and live data, meaning you go with time, it’s going to create a really massive size of data and that’s one of the challenges when it comes to the cloud technology and how to store this digital data. So you’ve got to make sure the data you’ll store and use your room in that cloud is kind of useful, it’s not just like saving them.

**Tom Jones:** Yes, gotcha, ok that’s a good insight I like that one. I think that feeds pretty well into my next question, which is the same question, but can you please describe, from your experience, the state of the art in data analysis.

**Dr. Hayder Zghair:** Yes, for my data analysis I was actually planning to kind of run the regression model for the data trying to find any type of pattern when I change variables. Not taking things for a really high level and using a high-level algorithm tools like neural networks, as we know this is kind of route to todays intelligence, artificial intelligence basically. That was the intention actually to use the data for a regression model that can predict for any of those patterns if we have a machine issue, a product issue, or actually sometimes part design issues. That was actually my intention to go to the extra level with manipulating data. Basically see what variable I’ve collected and how they affect my objective and try to manipulate them based on empirical, like building a regression model for them.

**Tom Jones:** Gotcha, and then in the context of the data collection, essentially whereas historically we may have done a regression by collecting a bunch of data and then distinctly doing a regression and then taking action, instead now it’s essentially happening simultaneously?

**Dr. Hayder Zghair:** Yes.
Tom Jones: So we go straight from data to action, that’s also a perfect case study to support what I’m working on, that make sense.

Dr. Hayder Zghair: What my point was, the way I thought about it, I thought as we are moving fast and are still in progress this type of technology, we need to explore the best things that we can catch from it, the best knowledge that we can track. Not actually the, you know we are human beings, sometimes when we feel safe with a data store we may kind of move slower than what’s really needed and what’s really required so I thought to focus on what the benefit of the data that we see right there and what we can directly apply in the manufacturing field. That was the intention actually.

Tom Jones: Gotcha, that feeds pretty well with a later question so I’m going to circle back to that thought. But we’ll continue through the technologies, so my next technology question is how can automation be applied to the data collection and data analysis? And I think that you’ve already started to explore those topics pretty well, because I think that a lot of the technology ideas are very merged.

Dr. Hayder Zghair: Yes, now I would say all of the manufacturing machines that computers control can be connected to the, we call it the IoT gateway. We have the IoT gateway which is the key of industry 4.0 techs. It’s the combination of hardware and software. The main thing of this is that connectivity protocol and we’re using MQTT still. The very fundamental connectivity protocol as an operating system. So in all we tried to have the 3D printers, it is kind of the educational scale of other machines, it’s going to be the same way when you go to CNCs, by then as we started with the 3D printers because the G code and the programming code with this kind of machine it’s almost the same when we go to the CNC. It’s the same G code programming and almost the same that you can run the machine on the CAD file and you can convert that CAD file to a compatible extension with your machine, 3D printer or CNC, and you just run it. So what I’m trying to say here, those machines have the ability of that control system that can connect with the IoT gateway hardware and software. And that’s the key if you’ve got your machine, the manufacturing machines have the connectivity, ability, available you will be actually screening, observing, and doing whatever you can do in the physical world to your machine when you go with like cloud control things.

Tom Jones: Gotcha, ok fantastic, so I have two more technology questions, no sorry, last technology question is; from your experience which technology changes have been the most impactful to the discipline of quality over the last five years.

Dr. Hayder Zghair: I think the sensors need to be really the key when it comes to quality, because remember what you’re measuring for quality is the end of the line. And when it comes to the automation, always at the end of the line we’re talking about sensors that can provide an eye for the users to see the adequacy of the process, the machine, the product, the whole operation. So I think focusing on sensors, and what I see they are kind of revolutionary progressing now, I can talk to my experience, I’ve worked with Bosch and they, then it was the end of 2020 and beginning with January February 2021, we worked with XDK as an integrated sensor. It can sense a broad array of variables. It can sense vibration, sound, gyroscopic, it has a variety of very fundamental physical variables that it can observe and the thing that surprised me when we were closing the project they said, this kind of sensor it was the last batch from this generation and we are getting the next generation. To me it was just amazing because the one they consider its kind of, its just like a revolutionary type of sensors. So if we can catch up as quality people with the sensors when
it comes to manufacturing, when it comes to having that access and eye on the system, our sensors
will be just great. That’s the trend I feel.

**Tom Jones:** Ok, nice I like that. I’ve never heard of those multifunctional sensors that you just
described.

**Dr. Hayder Zghair:** Oh yeah, my thought was to have that, because I still have one from Bosch,
they granted me one actually at the end because they’re not actually affordable. It looks like a
little guy but they’re kind of expensive, we’re talking about one hundred and two thousand dollars
per each, but they granted me one, I thought to bring it with me but it’s at home. Yeah,
unfortunately I didn’t bring that with me today.

**Tom Jones:** Definitely sounds revolutionary so, ok so I think that’s a good snapshot on
technology. My next two questions are specifically related to higher level methodologies, and so
with your IE background I know you’ll have familiarity. So my first methodology question is; can
you describe if you’ve seen a relationship between Quality 4.0 or Industry 4.0 and Lean
manufacturing?

**Dr. Hayder Zghair:** Oh yeah, they have a strong relationship actually. The way I put that smart
manufacturing class and implemented that live technology it was this: I was advised that we need
to have a way of control that goes at real time, that’s the first thing, and here’s the thing, when you
said real time, it’s really challenging because the definition is kind of different from programming
standpoints, how long you will take to change the program from the quality manner like real time
maybe, so it’s kind of real time has an extension. But to me, we as users as lean manufacturing
and industrial system guys, is to have an observation of the current state of the system. If there’s
any maintenance requires or failure caught in the system, that’s real time control. And the other
way of that kind of control, actually, of the real time, is remotely. Wherever you go you don’t
need to physically present in the place to make the same change that you can do actually when you
present, you can do it remotely. So, having this in hand and you have a system that can
communicate with you when things wrong happen, and when I said wrong it’s based on my
definition for wrong, like if there’s any failure call that’s considered wrong in my terminology.
So, that system that can communicate with me is the smart system who can communicate with me
because I don’t need to sit in front of the system, sit in front of that screen or board and see and
keep my eye open to see if there’s any call. The system itself will be able to communicate with
me and tell me, notify me basically, I prefer kind of a pattern in email that’s sent to my inbox with
a level of priorities, actually, when those real world control factors are, in my definition, having
something wrong happening with my system. So, having this tool implemented it will be a great
tool for lean, that industrial system that line of manufacturing, you will be able to observe if there’s
any downtime to the system. So, you will have enough accessibility and enough to respond to
your system so it will keep your system up, not losing, not wasting. And in addition to that you
will have this customized way for that layer, that cloud layer, so you can customize your
observations, the data that you specifically look into and when you have an offline tool for leaning
your system you can connect it to that live data. So it’s a great tool actually and it has in my view
a strong relationship to lean manufacturing or in general an industrial system, any industrial system
actually.

**Tom Jones:** Ok, fantastic, yeah if I can explore just a little bit further, when you’re talking about
the live communication what popped into my head was almost the Gemba principle without
needing to “go and see”, instead the factory actively shows you. So it’s almost like you take the
Gemba walk where you go and get information that we put on display and instead of just having it on display the factory says, ohhey here’s information that you need in the real time condition. The way you described it that felt like a huge lean enhancement to me.

**Dr. Hayder Zghair:** Oh yeah, that was the move actually, that was the thing that really makes this system a smart system.

**Tom Jones:** Yeah, that makes sense, awesome. Ok I have one more methodology question which is; with your experience with your systems can you describe the relationship between Quality 4.0 and Total Quality Management?

**Dr. Hayder Zghair:** Yes. Total Quality Management, to my understanding, it’s the quality of the system and the quality of the product, the operations and the products. So, as I said, this Industry 4.0 with the technologies provided it actually has the two access that you need to control this global quality. The operation itself and the product itself. Because if things happen related to the product itself and then things may be selecting may be selecting material, changing or modifying the design itself, and you have an offline setup for that you have the algorithm to select the material for the product and you have your CAD model. They’re already in place and in your cloud interface you have the option or the activity to connect these offline tools. So that will enable, actually, any in-progress or in-process modifications for improving and pushing the quality, and the same thing for the operations, for the machine itself. When things happen related to the machine that cause some defect on the line, industrial line, you will have an idea about that change instead of the machine so you will have the same accessway in modifying and making sure the quality is still under control when it comes to the global quality of your system. So that’s the relationship that’s how Industry 4.0 is connected to quality.

**Tom Jones:** So essentially it marries both your typical process quality approaches and your inspection-based product quality approaches and it can link everything together and creates more communication?

**Dr. Hayder Zghair:** Yes, and remember Industry 4.0, it provided the connectivity. So IoT gateway software and hardware, it’s all about connectivity. So what we missed we have everything advanced but it works on islands separately, now the IoT gateway gets them all connected, lets them all talk together and by data exchange, if all the data are compatible and they have a way to connect to that connectivity protocol its just like giving me everything open and accessible.

**Tom Jones:** That makes total sense. Ok so now I have a couple of questions about factors for success. These ones are a bit more open ended than the last few. So, the first one is; which key factors really enable an organization to implement Quality 4.0?

**Dr. Hayder Zghair:** When we’re actually talking about the corporate side of, I would say, the decision or understanding or deciding to implement, I think when we show the value of this system and how it’s connected to the profitability, how it’s actually saving for controlling the machine failures. How it’s saving in terms of having an eye into, because remember it is possible that you have an eye with Industry 4.0 to the store, or in terms of supply chain points. So as a point in that supply chain, you at some point as a manager you look into how much you have in place in your store. So, what I’m trying to say it may be like a lean example here, but I’m trying to say here the way that when you go to the corporate administrative level, they will approve, and what type of challenge in the way of implementing Industry 4.0 systems. Making this shift is just to understand how much value this technology will add to the business. That’s actually, in my view, the trick, the key to implement Industry 4.0 systems. Now, you may see and I see, actually, as long as the
system is running and we are responsive to the market demands, it doesn’t really require for all of
the companies to grow, to look into gaining more market share, being more competitive, as long
as the things, what we’re actually gaining and what we’re expensing is balanced in a way and
making sense for running our business for upcoming years. It may not really be an encouraging
step to take to invest in this. But if we can show to them the value to the long term and what kind
of facilitating tools, or variety of tools actually, this technology will provide to the system, I think
they will get the courage needed to move to this shift, at the administrative level. Because
remember, their screen is different than our screen as users. That’s my thought on this.

**Tom Jones:** Ok, and my second question in this, which I think the fact that you’re my first
interview is showing that my questions have a flow, is how do these factors play a role, but I
believe that you answered that with your answer to the first question, so I think that those two are
more connected, but you’re welcome to if you feel like expanding on any specific details further
on how to make them see the value or what not, but if not we can move on to barriers.

**Dr. Hayder Zghair:** Yes, now as I said if you have an extra layer of control in your system, at an
administrative level all that I see is a daily report on the system, how my system or how my
business actually is running. Now if you have an extra control layer it allows you to just observe
how the operation runs live and while you don’t really need to be in the place, that’s a great value,
I think if they have that access they may think of the extra control layer for their business I think
that may be one of the key things that we should provide. Now if that will be available for them
it is not going to be just like that, a lot of work needs to be done improving the system and making
sure this loop will be closed and modifying and updating itself correctly and for the long run. So
it’s going to be kind of a result that’s kind of key for them to see if they can get it done. And by
the way, up until I left this kind of access is still not fully connected. Still, you’re looking for how
to manage the action that needs to be taken while remotely controlling the system. Are you going
to have robotic arms to do the job for you? Are you going to have a lot of staff running in this
system when things happen, and they need some instructions you call them? Or you put them in
that email loop, so you have them in your loop when things happen? So, there is an undecided,
kind of things need to be done to have that fully automated, fully remote, and real time control
system. If we provide this complete to them, to this decision maker, I think we’ll be good.

**Tom Jones:** Fantastic, ok so the next topic which mirrors success factors is barriers. So kind of
the same question, can you identify the biggest barriers that are likely to interfere with a Quality
4.0 implementation and how do they prevent the implementation?

**Dr. Hayder Zghair:** Yeah, now the barriers, actually, there’s two barriers for having Industry 4.0
as a tool for those industrial engineering experts, specifically quality. The main one on the hands-
on level, you don’t have the one man show in this kind of game, in Industry 4.0. You will be
dealing with different personnel, different backgrounds, different educational people. You’ll be
looking for programming people, you’re looking for hardware people, looking for the
manufacturers. So, they all need to come together having the same understanding, the same view
to implement the system and make it run. So that maybe, in my experience, will be challenging to
move fast, to apply what new things are possible and can be proved. And you will have some
quality people on that team that have a different perspective to this system, how it’s being
implemented and designed. So that’s on the hands on level and challenging and there may be
obstacles in your way. The other thing is the security, when you connect your property, when
we’re talking about your business it’s your property right? So, when you connect your property
in any unusual way, now in the physical world we know how to protect our property, our business, like securing data, securing certain information. When we implement technology, we’re planning to have in the future we know how to, we’ve been trained to do that for a really long time in terms of securing this kind of, in terms of competition, open market, open training, open trade. Now when you put all of what you own, all of your property on the cloud that’s the challenge actually. Most people are concerned about the security, the cybersecurity is a trend now. The way I understand cybersecurity actually is building walls to your business, building warehouses, building gates, building badges to get access going on and off in your facility. So, security is another challenge, it’s kind of at the top level of implementing things, and when it comes to quality you are significantly sharing significant information about your system, so it may have another layer of screening to decide are we going to store that quality data for our system of global quality. We’re talking about the operation, the processes, the products, the material we use, the design. So all those fundamentals are connected when it comes to quality. So, I think that’s the challenge with this.

Tom Jones: Gotcha, ok very nice. So that one, if we can expand a little bit on the first part, so there was the multifunctional team that you described has to be involved. With that being a potential barrier is it more about a multifunctional teams skills or communication gaps or what’s the big challenge with getting a team like that to successfully implement a system like this?

Dr. Hayder Zghair: I think I would say if I would rank them I would say the communication first, I don’t know if it’s right to say this, remember I was building things from scratch. So, I’m really sharing a kind of live and fresh things. Even, I heard from the team that I work with as a whole when we talk and as individuals when we talk. We’re taking really long to understand our thoughts, when we share our thoughts in discussions, because when we’re dealing with a programming guy or electric guy it isn’t necessary for them to be really interested in understanding the manufacturing aspect with the quality of production. As long as the system runs, and the job is done they consider that their job is done. So, if in case you need to succeed with this you need to have your people have that shared mission, all believing in it. And they need to all affiliate it to the business. Not to have an adjunct setup or externally hiring people to serve if you want to move fast in your system. But if we all, our whole team, are affiliated to this business and they all believe in this mission I think things will move fast. That’s when it comes to the communications. Now, different backgrounds, in terms of how it’s done, it’s not encouraging people to learn more about your problems as a manufacturing engineer, as a production engineer, as a quality engineer, as a programming engineer, as a communication engineer, there’s a really, personally there’s a really motivating, it motivated me to learn more about programming, as I know for example my peers, he’s the man of those things. And I keep asking questions that may not be possible from his standpoint. So, if I will have this shared mission belief, and so I will spend time and effort to understand his standing. It's communication first and human nature that we all love to stay in our comfort zone, to put it this way, and it isn’t necessary to have the shared mission or belief, so that’s actually one challenge. If we succeed to put that mission or that belief, we get to that consensus level that we all agree that this is our objective it will be no problem.

Tom Jones: Ok, perfect that’s good clarification. So, the next topic is systems. So my next interview question is; how does the design of the organizations quality system impact Quality 4.0 implementation, and I would expand that to say potentially the organizations Quality Management System or how the organization manages it’s processes.
Dr. Hayder Zghair: I just missed the first part of your question, will you please repeat the question?

Tom Jones: Oh yeah, you’re fine, so how does the design of an organizations quality system or Quality Management System impact implementation of the Quality 4.0?

Dr. Hayder Zghair: I think that’s a very local kind of thing in how to define the quality of that business. What type of variables what type of factors are defining your product quality. So if it’s possible to be part of the hardware and software technologies for industry 4.0. So, if we clearly define our factors that we’ve leveraged our quality, so if they’re possible to be implemented with the Industry 4.0 technology variable, I think there should be no problem for that, for this quality structure of the company or business. So, the key is to be clear on your quality factors, that’s the thing.

Tom Jones: Ok, gotcha that makes sense.

Dr. Hayder Zghair: So for me it’s kind of local things.

Tom Jones: Yeah, so the answer to that question is going to be very contextualized by the company itself?

Dr. Hayder Zghair: Yeah, if I’m a manufacturing workshop running shafts I will have a different definition for my quality than if I’m sampling, for example, a marker. I have the pieces of markers and I’m producing markers for example, or steel shafts, or for example any type of other products. The quality will have different definitions. So maybe for the shaft it’s possible to control the quality factors and not for the marker for example. Not currently, maybe in the future possibly.

Tom Jones: Ok to dig a little further into that its that we need for the system to support quality, the quality has to have measures that are able to be observed and managed by the system?

Dr. Hayder Zghair: Sure, that’s it.

Tom Jones: That makes sense that’s kind of what I was taking from that I wanted to make sure I had that clarified. Ok next topic is strategy, this one is again fairly broad. So, the strategy question is; what strategy would you recommend to implement a Quality 4.0 or Industry 4.0 system?

Dr. Hayder Zghair: I would actually, first, I would take a strategy that would go parallel in three lines. The first line is making sure the physical equipment or machinery have that connectivity at that level, basically computer control based with a central PLC. That goes very technical and very hands on line. The second line actually focusing on the communication protocol for the IoT gateway. It’s hardware and software, because this is going to be the hub point that connects the physical world with the virtual world of your system. And for sure being clear on what you want from the cloud control, because it’s a product, so I would say this, for the quality you guys need to deal more with the data that you’ve collected and are storing and what type of strategy that you’re using for the data. For the manufacturing control, or production control, like for a very definitive production term I would say the system adequacy, the system tailor, and any related to this line will be the target of this strategy the third line of strategy. So the strategy, again it’s kind of an interdisciplinary kind of thing that will come to one platform. It is hard to have one common strategy to go with this. So the best way, in my understanding, is to break down your main strategy into lines and they should go parallel because they will work independently.

Tom Jones: Ok that makes sense, that’s a very tangible strategy for the technology implementation there. I can track that pretty well. Ok so, last question is totally open ended and this is where earlier I said that you kind of touched on a topic but I was going to wait, because I think you were
starting to get into this, but the last questions about success. So how would you measure, how would you describe success of one of these systems?

Dr. Hayder Zghair: Well first as we are an academic business in academic industry, the way we’re measuring our performance in general is how it reflects on the students. If the reflection that you get from the students that are really, specifically for engineering students in junior standing and up, they’ve all got some idea about industry, they went to internships, they went for co-ops, so they know what the real industry looks like now compared to us. As professors what our role is into articles, into research, into books, and when it comes to the real-world applications it is going to be more about lab skills. So, personally I observe my students feedback and their connectivity, their engaging to this type of knowledge, and when, in that specific course the feedback that I heard from the students was just encouraging and amazing actually. They bought into it they actually added onto what we actually started, and we ended with constructive feedback on how this kind of thing could be taken to the next or the best level. That’s from the academic. Now, when I talk to people in industry, they like the idea, the main fear they may have is their position. If it’s, how new technology will affect their position in the coming ten years, twenty years, twenty-five years. Are they going to be valuable or are they going to be gone, no positions like what they’re doing now. Generally, they like the idea as long as it’s not going to, you know, hit their place. That’s how I see Industry 4.0 in the future and how people actually are happy with it and we can assess this shift. That’s how I measure, feedback from the students basically based on what they’re seeing now, and I’ve got one student actually whose already worked on a similar project and what he was getting from the class really made some value to his project in the workforce. And if I remember, he secured a position and he got hired because of my class. I think what I remember from him is that. The last time he and I talked was January 2021, almost a year ago now was our conversation. That was the feeling actually, so it is promising, it is applicable, it is right there it’s needed even if we keep putting that resistance in its way. But we’re going to end up with it for sure. I’m hoping that answered the question.

Tom Jones: Oh yeah, with the semi-structured interview the biggest thing is for me to take what’s given, sort of like an audit, so yes it absolutely does. So I think that has kind of covered the body of everything I was exploring. Do you have any questions for me or follow up on any of the topics that I asked about?

Dr. Hayder Zghair: Just, it looks great, the structure that you put for your questionnaire, this interview. If I may think of some feedback or comments, I think of you may add to the introduction an example or a case study. It may help to set your interviewees mind more and let them kind of be focused more. Because if for example, if we talk about manufacturing this specific product and we’re basically using this CNC or this set of CNCs and this is our inspection, like an Xray inspection, you know just a little example may be helpful. It may not be applicable in your case just this is one of the things I’d like to share with you.

Tom Jones: Yeah, that’s good. I think I will add that in just to make sure I have clarity and consistency with defining the Quality 4.0 topic moving forward because I think that of everyone that I’m going to interview you’ve probably got the most familiarity with the terminology already and the clarification may be good. I appreciate that feedback a lot.
Tom Jones: I’m interviewing you about your experience with a topic called Quality 4.0 which is the application of digital technologies, it might be under the title of the fourth industrial revolution, Industry 4.0, smart factory, digital transformation, towards achieving a companies strategic quality goals, so any application of those digital technologies to improve your companies quality performance is kind of the relevant experience, so in that context of what quality 4.0 is, my first question is, I’d like to know what your role and background with quality 4.0 is and what your experience is with this arena.

Chris Koch: Ok, yeah, absolutely, so prior to my current work within Amazon and Ring, where I’m more of a developmental engineer, so I do hardware design now, and I do have some experience in terms of working with our CMs, our contract manufacturers, in working with them to define better practices, better automated practices to enable us to have higher yields and higher quality products. So, I’m doing that now but before that I was working for a company called Bosch connected devices and solutions, part of Robert Bosch LLC here in the US. And that entire companies’ portfolio revolved around Industry 4.0. And I was a field application engineer for them slash sales engineer slash technical program manager for them and what that enabled me to do was to talk to, interview, you know, and understand what type of technologies were needed in various fields across the Quality 4.0 or as we called it the industrial 4.0 realm. So, I worked with companies in shipping and logistics, companies that worked with solar panels, and companies who wanted to understand how to monitor with freezing technology for medical purposes. We crossed a huge gamut of things, parking lot sensors that will monitor parking spaces. We had vibration sensors that would go onto motors in factories, and we had a myriad of devices that were really geared towards I4.0. But I mentioned before the parking lot sensor because a lot of the industrial 4.0 and a lot of the IoT sector they all kind of start to run very parallel in terms of what you need in order to move forward and to be successful on that. And we can get into that later I’m sure it’ll come up during the interview with the questions.

Tom Jones: Sure, and that’s pretty much a perfect snapshot of the type of experience that makes you a valid candidate with this interview is working directly with the actual application of these technologies beyond the theory so I appreciate that. Yeah, we can just move right forward. My first few questions are kind of under the shared umbrella of technology, asking a little bit about the state of the art so they may flow together a little bit. So, I’ll just jump right into that, but my first technology question is with your background and experience, what would you say you’ve experienced as the state of the art in our data collection technologies?

Chris Koch: So, state of the art technologies, really you can look at it from a few different angles, and that’s the thing with Quality 4.0, industrial 4.0, applications is that it’s not just the sensors. I mainly focused on sensors and the state of the art now is becoming more in terms of vibration sensors in the industry and factories and things like that. So, between that and between, I would say, audio and visual, so they’re getting much better at looking at, visually being able to inspect certain machines along assembly lines and this is true, I’ve seen this at certain manufacturers, not manufacturers but distribution houses like Mauser for example. They have an insane system where they can visualize almost everything and determine whether things are going down the right path or not going down the right path, whether things are being picked and placed properly. It’s really amazing what they can do there. But in terms of a lot of the other industries, the vibration sensing
that you can get and the orientation sensing that you can get through these advanced sensors that they have out there, the IMUs that they have out there, is becoming more and more state of the art. And I think as you move up that technology also needs to incorporate the data capture and the data presentation, the user presentation of that data, in order for you to enable your customer, in this case would be the user of the product even if it’s your own employee being able to look at the data and do something with it. So those are becoming more and more state of the art but there’s still, I feel like, some missing pieces out there where it is not so intuitive yet for people to use that data and do something with that data. And its not so easy for it to all get set up and start collecting the data and immediately see results. So, I think those are a couple of the missing pieces that still need to be reiterated upon in order for businesses to really start to grasp and take hold of this industrial 4.0, this Quality 4.0 experience that’s available.

Tom Jones: Perfect, yeah, so I like where your headed with that last part, it actually kind of feeds into the next topic pretty well, so I have a follow-on question for that but I’ll circle back to it after we’ve closed the loop on technologies. I think you were also kind of moving right towards my next question, which is if you could describe the state of the art in the data analysis, so kind of expand maybe on your thoughts on taking that data further beyond just collecting it, what we can do with it and what we should be doing with it.

Chris Koch: Yeah, so what I’ve seen, my focus was never on the data analytics and what you can do with it, because I was selling sensors. But what I did was work with customers who would show me what they would do with the analytics, and there’s a lot of really great technology out there that is starting to analyze and interpret that data and they have to do it really fast, and they have to do with known variables essentially. And that’s where this Quality 4.0 really needs to be understood by industry, is that you can’t just put on a vibration sensor and an IMU and get data that’s going to be useful to you, you need to know what the baseline is. So any good system is going to figure out that baseline, figure out your known good, and then from there find the deviations and find the anomalies in your system when they happen to let you know something is wrong, and then as you continue to collect this data you’re going to be able to say I know when this happens a is wrong, and I know when this second wave form happens b is wrong. So, it’s that type of analysis in the future lets you automate it and use more of an AI I would say, this artificial intelligence that can go into this data capture is going to be able to create its own baseline, hopefully, in the future, of a known good state and then be able to monitor itself after that for more deviation. And I’ve seen some technology that can already do this. It’s not in a factory setting it’s more of a user base setting. As I mentioned before I worked with a parking lot sensor, and what that sensor was able to do was to kind of self-learn. So, you would need to calibrate it originally, and after ten times of saying the spot was occupied or not occupied it would then know what it’s steady state was. Because over time based on the technology, we’re using here there’s drift. And that drift will change what is a good state and what is a bad state. But if your algorithm is able to continually learn and know what the good state and the bad state is you can automatically up your reference point, your threshold, and so instead of having to recalibrate over time you’re self-learning. The AI is self-learning within itself and then it makes it easier in the end for the users. So that type of technology, that type of self-learning algorithm will need to be, in the future, applied, in my mind, to the Quality 4.0 solutions because that’s what people are going to want in the future, they’re not going to want to have to recalibrate devices every year, every six months, three months, whatever it might be in order to say, alright I know this looks like I’m starting to get
an anomaly but it’s really just that my sensor needs to be recalibrated. People don’t want to do that, they want to put it on, read the data, and have it tell you when it’s good and bad. It’s going to be an install and forget kind of thing for them, until something necessary happens to alarm. So, that’s the type of technology that I see us going towards and as I mentioned before the type of technology that we have now is a lot more user intensive in terms of collecting the data and setting up your baselines and then having that baseline be reviewed against the new incoming data. And will get flagged, now a days that does get flagged after you collect that baseline, and you have to manually figure out what to do with that data to understand what is going on. Some technology that I’ve seen that was just developing when I left Bosch was going a little more into, hey we know what’s happening based on their system, based on these anomalies. And I’ve seen people use motors and fans as examples. They can tell you when one of the fan blades is chipped or there is some debris on it or something that is causing it to be skewed in any way. They could quickly tell you that was the anomaly, or there’s something jammed in the motor that could tell you that was the anomaly. So, there’s a lot of technology that’s already building up towards that automatic detection of problems that you face in the factory.

**Tom Jones:** Very nice, yes, there was, so the topic that you were really hitting on there, which was actually totally new for me, I think it’s really interesting, is the state of the art is leaning more towards self-calibration and I want to describe it as a second level automation where we’re already automating collecting the data but now we’re automating managing the system that collects the data to a degree, with what you were describing sounds like?

**Chris Koch:** Yeah that’s the way I would see this moving forward, in my mind in order to be a really successful movement is the more automated you can make it, the easier you can make it on the end user, that’s what’s going to really make this really good moving forward I think. And we’ll probably get into this in the future, if you do that you need the buy-in from the users of the system and you need to let them know that these devices are here to help and not to replace workers. That’s always the biggest issue I think with the Industry 4.0 and Quality 4.0 solutions right now, is so many people think that it’s going to take their jobs so they don’t buy into it because they don’t want to buy into something that they think is going to replace them.

**Tom Jones:** Yeah, that’s the automation fear, that’s a very good point. I think you, so the next question I’ve got lined up I think you were already speaking to pretty thoroughly there, but the next question was about the state of the art in automation with our data collection and analysis. So, I think you were already speaking to that but if there’s anything that you’d like to add about automation specifically beyond where you were, go ahead.

**Chris Koch:** I’m not sure there’s too much more to add. Like I mentioned with the automation that I feel like people want to see in the industry, it’s automation that is going to make the workers lives easier. It’s automation that is going to tell you that there’s something wrong, but you still need to do something about it. There’s also automation out there that will help workers on the assembly line understand what type of part they need to pick. These are already in operation. I have seen these visual aids that will point to the part on your assembly line that you need to pick, so which screw do you need, there will be a laser that points to the screw bin that you need to pick from and then it will watch as you take it and screw it in and then it’ll go to the next part. So, it really helps these factory workers know exactly what they need to pick, it’ll let you know the amount of torque that you’re putting on screws, and all this is doing is leading to less mistakes. And better-quality products coming off the line, so little things like that, automation like that, is
already state of the art. Those systems can get expensive of course, but they really do help with the quality and yield of your products, the output yield of your products. So just another example of what’s already out there in the field, I think, in terms of automation. But yeah, I think where this will move with other things, is you know in terms of factory 4.0 for knowing when machines are, might be, going down. I think that’ll become more automated in the future too.

**Tom Jones:** Fantastic. So, to round out the, my questions about technologies, from your experience over the last five years which of these technologies that you’ve experienced do you think have been the most impactful in improving our quality and improving our performance as companies.

**Chris Koch:** So I think the most impactful so far is the, so I mentioned the automation in terms of helping the factory workers understand what they need to do at each step. And this eliminates a lot of mistakes that are made, it allows you to have higher yield on your factory floor so less throwaway parts, less parts that fail your testing. But leading into that the testing that happens also is becoming more and more automated. You have all these systems in place that are taking thousands of photos, so if you are producing a printed circuit board, and after the assembly process you need to make sure that the MCU is oriented properly, that the diodes are oriented properly, you need to make sure that you’re not missing a resistor here or there. Some resisters could be very critical to your board and if it’s off you could have a fire explode on it, if you’re working with AC/DC power supplies for example. So they have all these automated systems now that take thousands of photos of your board when it’s done and they automatically compare to what they know it should be or shouldn’t be, and then they can flag it all automatically without a user doing anything, and unless something is flagged to say “hey we have an issue with this board” so I think technology like that, the automation that is already there has really helped the industry and we are seeing yields now better than ever with our products and I know the yields that we have to meet are, it used to be you could probably have ten thousand parts per million and you’d be ok with a loss that big but now its tens or hundreds. It’s very small, you want to get as much out of each run, production run, as possible, and all these technologies are allowing that to happen. Which is fantastic for businesses, especially consumer model businesses.

**Tom Jones:** Yeah, for sure, so with the thousands and thousands of photos that you’re talking about it’s sort of like the technologies that have been incredibly impactful have been the ones that have allowed us to put, essentially, permanent monitoring on key elements of our processes?

**Chris Koch:** Yeah exactly.

**Tom Jones:** Definitely makes sense, especially if you identify those key elements as well. Perfect, so, I think you spoke pretty well to all the technology concepts that I like to explore. That’s kind of the baseline because obviously this whole methodology doesn’t exist without the new technologies and how we’re using them. So, my next couple of questions are kind of more related to higher level processes. So, I’ll start by baselining and asking do you have a level of familiarity with lean manufacturing?

**Chris Koch:** Very little, I didn’t work too much in lean manufacturing. But I was kind of on the tail end of working with Bosch I was just starting to get into that and understanding it a bit.

**Tom Jones:** Ok perfect, then I don’t want to bias the understanding that you currently have. It’s a-ok that you don’t have a ton of lean experience, but my next question is with the lean experience that you do have, what is the relationship that you can see between the Quality 4.0 applications and the lean experience that you have, and lean as a methodology?
**Chris Koch:** Yeah so, my understanding of lean is using PLM, product lifecycle management systems, in order to better monitor your manufacturing process, right? So, you get a better understanding of what needs to be done at each step so you get better sign off and all things like that through these systems like agile that are allowing you to really monitor that lifecycle of your product. Is that the correct understanding or am I thinking of a different process? I just want to make sure that I’m thinking of the right thing, lean manufacturing.

**Tom Jones:** So that understanding is totally appropriate, there’s, I will say there’s definite overlap with lean and agile. Agile is kind of a similar set of concepts that were named differently coming out of the software engineering world. So, you’re on the right track there, and yeah if you want to just speak to your experience on that I’m happy to expand on the lean stuff a little bit, later though, I don’t want to bias you is all.

**Chris Koch:** Yeah, ok, I understand. So, my side is looking at the product lifecycle management. And with that your, and I guess the other part of it is with lean you’re trying to constantly improve, right? So that goes into the product lifecycle management too because you figure out a way that you think works and then you learn more about how the manufacturing system works itself, if that makes sense. So, a lot of things that we’ve been doing is reiterating our agile process as we get a better and deeper understanding of how our contract manufacturers are actually performing and doing each step of the manufacturing process. This allows us to better create the product lifecycle management that meets the actual assembly and manufacturing process. So, this way as we release things in our product lifecycle and management it flows evenly with what our contract manufacturers are actually doing. And so we are constantly reiterating and updating those processes, and it also gives us better insight through all this understanding of how our contract manufacturers are going about their process and if we see any red flags that could be creating an issue down the line, for example if you’re soldering on a wire early on in the process and then you start to bend and poke and twist at that wire and then the final product has these wires that are frayed and aren’t making good contact anymore you can understand that early on in the process and change where that happens. Change where you solder that on and if it can be soldered on later and you don’t have to bend it and break the wire bond then you would do that. So that is kind of like this continual improvement process through agile, through our product lifecycle management that we are currently seeing. And that helps with this kind of lean manufacturing when you’re constantly improving all of the processes that go into the manufacturing process.

**Tom Jones:** Very nice, yeah, I would say with what you know from agile your awareness of lean is pretty good. The continuous improvement and the addressing issues at the cause is kind of the core tenant of lean so you’re spot on there. And I wouldn’t have biased you that much if I explained it because it would have been pretty similar. I think that one with what you were talking about actually feeds pretty well into the next question of methodologies as well. Are you, do you have awareness of the Total Quality or Total Quality Management approach?

**Chris Koch:** I don’t, I don’t think I have too much knowledge on that one.

**Tom Jones:** Ok I will give you a little bit of background on that one then. So total quality management at the highest level simply says that quality becomes the job of everyone at the company and quality needs to be built into everything that the company does, as opposed to the company operates and there’s a quality department that polices quality in. So, with that high level description do you see any overlap with that summary and with the quality 4.0 approach as I’ve described it?
**Chris Koch:** Ok, yeah so, yes that’s actually one of the tenants that is on, people call it different things. So, yeah, I definitely, it’s something that our company really enforces, I didn’t see it all the time with other companies that I’ve worked for in the past, but definitely something that I see now. And this idea of everybody having a role in the quality assurance of the company is becoming bigger and bigger and these little tools that we have are starting to enforce that. So, we have implemented a ton of measures in order for everybody to be a part of this quality assurance, if you will, or quality management for the products that we put out. We have a lot more accountability for people through JIRA tickets and through wiki pages being defined and we’re starting to bring, work more as a team from the get-go, right? So, everybody is involved from the beginning in terms of defining the product and reviewing the product, and we create these various product development cycles and milestones. Those milestones are met in new, and you can only move on from those milestones with these, what we call, design reviews, these critical design reviews where people have to get on. They have to understand the project and the design and then what’s going on and they have to approve it. This is less of a Quality 4.0 issue that I’m talking about compared to a company problem that people are solving through their, the way that they do their design processes if you will. This of course can be applied to Quality 4.0 in various ways, in my mind. It can be applied to the factory floor through these automated systems because it’s giving a voice to everyone. There is, I’m trying to remember, there is some lever that Toyota described a long time ago and they would allow any manufacturing worker, if they saw a quality defect along their line, you could pull this and it would stop everything, everything would come to a halt until they fixed that issue. And that’s the type of accountability and responsibility that you want to give to everybody on your line. And so, in the manufacturing process, when you give people that type of responsibility and you put your trust into them to be able to stop a line, that is what is going to help create this buy in that I was talking about earlier, but it’s also going to allow you to stop bad quality defects early on. And I think that’s one of the things that this Quality 4.0 is going to allow, because it’s going to allow more visualization and it will give people the peace of mind that they’re making the right call early on because they’re going to see the data and eventually the data will probably tell them something is wrong. So, it allows you to, and all the workers and all the users of these systems, it gives you to more quickly assess the situation and confidently make a decision with the data that you have. I think it does put quality across the line and across all users.

**Tom Jones:** Absolutely, it’s a, I really like that answer and I think you did a really good job answering in the context of a method that I just introduced to you. The lever that you’re talking about is called an Andon switch. So, in case you wanted to know the term for the future, but that’s very insightful and I like the way that you have experience with the technology, the methodology from the tech side and when I threw the quality concept at you, you synthesized a really intuitive answer so that’s going to be valuable from my data, I appreciate that. So, I think those two questions were the ones that dabble in areas that were maybe a bit more out of your realm, the rest should be more straightforward. Next, I want to ask about success factors, so when it comes to implementing a sensor package and IoT and Industry 4.0 implementation, what are the biggest key factors in getting it successfully implemented with a company and what are the specific roles of those factors? So how do they impact the outcome?

**Chris Koch:** Yeah, well I think one of the biggest impacts, or one of the biggest key factors in getting anybody to have a successful I4.0 system or Quality 4.0 system is going to be the user buy in. I mentioned this a little bit before, if you cant get your employees to buy into a system it’s...
going to fail or you’re going to have to fire a lot of people and hire a lot more and go through training with a lot more, which nobody wants to do, right? You don’t want to fire your most senior guys who make your whole operation run just to try out a new system. So, you need to get that buy in from your employees, you need to get the buy in from the management too. So, you basically just can’t force it onto people. And getting that buy in is going to be very difficult because a lot of people look at Quality 4.0 as an automated, robotic system that is going to replace your employees. Instead, what needs to be emphasized to them is that this isn’t to replace you, it’s giving you more skills to make you more valuable and it’s helping you do your job more efficiently, more productively. And those are the key factors that I think need to be relayed across to users. A lot of people still won’t buy in but if you can get enough to buy in you can have a very successful implementation of your I4.0. So that’s going to be one of the key things I think for anybody to go through. Another, of course, you have to worry about security and making sure that the data is secure and that there’s not going to be any issues with corruption of data or stolen data or, you know, anything that could be negative on the security front. So that’s going to be a key factor. But another thing that I’ve noticed is everybody wants a different architecture of their system. Some people are great with Wi-Fi, some people want cellular, some people want Bluetooth, you know or some sub-gigahertz technology, and being able to give them exactly what they need from a data collection standpoint through the cloud or whatever they’re going to use in order to analyze and then push that data out to the respective users, that’s going to be another very key point that could be prohibitive to some users and use cases that won’t allow a solution to get off the ground. So, there’s a lot of thought in this technology as to how to make it all operate and how to make it all work for each individual user and use case. Because factories, not all factories are created equal. Some are very rural; some have multiple buildings and they’re not all tied together with Wi-Fi. That’s becoming less the case these days but there are definitely still some cases out there where getting that, getting all the data that you need, centrally in one location becomes harder and harder for some companies. So, I think those are a lot of the restrictions, I would say, to getting a good 4.0 solution off the ground. First and foremost, of course, I still say is, getting that buy in, but beyond that it’s more of an implementation and architecture problem that you will have to face.

**Tom Jones:** Very nice, the, so the next thing I ask about is the inverse of that, and these answers it’s ok if they totally blend together. So, success factors, you identified having the buy in and having good architecture. So, the inverse would be what are the biggest barriers and how do they prevent us from getting these systems implemented.

**Chris Koch:** Yeah, well on top of the users I think another huge barrier is going to be the data collection itself. Motors, machines, they vibrate at a very high frequency. In order to collect that data, it’s very difficult to collect a three axis sensor at ten kilohertz or a hundred kilohertz. It’s a lot of data that you will be collecting really fast and needing to do something with even faster. So, I think that becomes one of the biggest barriers for most people when they buy in, because you either have to slow down the data collection in order to be able to properly collect it and send it up the line or you’re going to have to start having the processing locally which means you have to have more processing power locally. And then a lot of that data gets lost as you move it up the line because instead of sending your raw data up the line, now you’re likely collecting and throwing away the raw data after a short period of time and analyzing it locally and then just sending the analytics up. I think that data collection barrier becomes really big for a lot of people
who are working with machines and they’re trying to really understand at a very minute, small, level, those variations in vibration. So, I think that’s a really big barrier in the system right now. **Tom Jones:** Ok, nice. Alright so we’ve got success factors we’ve got barriers. And so, this next question kind of flows in with a lot of what you were just talking about as well as far as infrastructure and architecture, which again it’s ok if the answers have a lot of overlap or if you’ve already touched on your answer to these questions because it’s supposed to be a very focused interview so it’s not a problem. So, the next question is: how does the design of a companies systems impact Quality 4.0 implementation, and when I say systems in this sense I’m referring to the production system itself and the quality system, so the overall, how the factory runs, and not specifically the IT and infrastructure systems. If that makes sense?

**Chris Koch:** Yeah, so it’s not necessarily their Wi-Fi network so much as the software that they’re using within their I4.0 product, right?

**Tom Jones:** Software and also just general processes and how the company operates.

**Chris Koch:** Yeah, so I think that’s going to have a big, obviously that’s going to have a big impact, and with 4.0 being such a new concept it’s something that people really need to understand is it’s not an overnight solution. So, there’s going to need to be iteration upon iteration to figure out what works best for you, your company, your factory, and your product. So, I think that’s going to be one of the biggest keys that companies are going to need to be able to work through, is this concept of this re-iterate. Develop these mechanisms within your company in order to make your product, make your quality assurance, make your manufacturing and all that stuff. It’s really, with the processes that you pick it’s not necessarily picking one particular software or doing anything in a very particular way that’s going to work universally across the system. You’ve got to find things that work for you and your employees and the types of products that you’re developing. I can relate this again to the product lifecycle management tools that we have. They are going to be really great when we implement them the exact way that we need to implement them. But right now, we’re still adopting these tools and it’s a slow adoption because we have some engineers that are older and they are not used to this and they’re having to switch the way they do things. And that’s a little hard to do. But they’re working towards learning these new systems and moving forward with it and then the younger engineers are, they’re pretty gung-ho about these systems, everybody knows it’s the new wave and the way things are going to go forward. But we also have hired somebody within the team to really manage our PLM systems and so they are, they have the final say on releasing these, any design that goes through these PLMs. So having the right employees in place in order to manage your processes is also going to be really key. So, you can have people who are able to understand the type of system that you want as a company and start to enforce those requirements and the roles and the structure that you want across the board, and I think that would be key for any 4.0 also because you’re going to need to have repeatability throughout all the processes that you have. You can’t have everybody doing something different and expect the same quality. You need this buy in and you need to have people who are willing to follow a set of rules and a certain structure moving forward. So, I think that’s kind of what I would say here.

**Tom Jones:** Ok, perfect. I’ve got just a couple of questions left, they’re a bit more open ended. So, your answers can go really any direction. The first one is about strategy, so if you were going to implement Quality 4.0 as I’ve described, an industry 4.0 system towards improving a companies quality goals, what would your strategy be? How would you approach that?
Chris Koch: Well I’m always a fan of the bottom up one, just because I’m a hardware and I’m a sensor guy. So, I like to start at the bottom and move up, but the first thing that you need to do before you even start is define what you want to solve. So, the very first thing that you need to do is understand that something is wrong, something can be improved, we have this quality issue, how can we go about resolving it? And whether that is with a specific machine or whether it’s with your assembly line, whatever it is you need to understand what the problem is and get down to the root cause. And once you do that then you can start either your top down or your bottom-up approach to solving the system. And maybe which direction you go will change based on what the root cause of your issue is. And if you don’t know what your issue is, if you just want to buy into 4.0 that becomes increasingly difficult, because if you don’t have a problem to solve then it’s really hard to say “oh yeah go out and buy this sensor it’s going to help you out” because it may or may not in the end right? So, for me I think that the first step for any situation is going to be, alright I have this issue and I need to solve it, but what is that issue really. And there’s a lot of different ways you can go about it. I’ve seen these charts where you list off ten or fifteen things that could be wrong and then you have this process of elimination to get down to the root cause. Because there’s often times in electronic design, for example, where it’s really hard to get down to the true root cause of what could be the issue. So, it’s this process of elimination that will point you in the right path to say Ok well I’m actually having some creepage issue with my PCB traces, they’re just a little too close on this board and I know that because it’s not any of these other five reasons that I defined that I was able to rule out. And little things like creepage it’s very hard to really say with 100 percent certainty through any specific test that that is the issue, so that’s why this process of elimination is so good. But once you get that root cause then you can start to understand, ok I have a problem with my CNC machine, and I understand that the bearing on the CNC machine is going bad after a certain number of cycles. And the cycle counter is not exact but it’s close so now you can understand what type of sensors that you need to move forward with. You can have a vibration sensor but if you know that it’s a product that needs to be replaced after so many cycles, but maybe you’re not running just a hundred cycles a day, maybe it’s a hundred one day, ten the next, twenty the next, and you’re not able to record that very easily but you can put a magnetometer on there or some type of orientation sensor on there to say exactly how many cycles you’re running and when you reach a specific threshold that you set, that’s when you can alert the user it’s time to recalibrate, it’s time to replace this part, whatever it might be. So, that’s how I would do it, you define the problem and then you can move forward with the solution by understanding what type of sensor would best work for you, understanding what type of data from that sensor is going to work best for you, and how to then move that data up the line, upstream into an analytics platform and into a user interface that can be easily testable and easily read and understood by the relevant parties who need to see that data.

Tom Jones: Very nice, ok, and my last question, again very open ended, from your experience what successful Quality 4.0 look like?

Chris Koch: So, I think successful Quality 4.0 is going to be a solution that will resolve issues on your factory floor. So better quality products, better or higher yields are two big things that, like I say, I’m seeing now. With working with a lot of contract manufacturers they also, it can be very detrimental if their lines go down. So, they want to understand ahead of time when their lines are going to go down, whether it’s periodically and better able to say “hey I know it’s going to go down after this many hours” now they can automate the hourly monitoring even better. You could
work with a drill press, and you can turn on the machine and you know the machine is running, but you might not know exactly how many times that lever is pulled to actually drill into the metal or whatever it is that you’re drilling into. So, with automation systems now you can monitor when it’s actually being drilled into and things like that. So, you can get a better understanding of when your drill bit is going bad compared to when the engine is dying, or something like that. So, the success is going to be monitored by how long you can keep your production line running before you need to change something out and how well, and quickly, you can define when something is about to go bad so that you can assign the appropriate downtime in order to replace it. So if you can get all of your parts and your labor in order ahead of time to replace parts or to swap things out, and then overall your uptime will be maximized at that point, because you’re now scheduling maintenance based on when you really need it, you’re not waiting for parts to fail, you’re not doing it too early, you’re not doing it too late, so that’s going to be a huge factor for success. One of the projects we worked on, when I was with my previous company, was pretty much exactly that. It was at a mining company and they had these pumps, and these pumps would run this slurry, this rocky mush, through these pumps and they had these big rubber casings that went inside the metal pump and over time the casing would wear down, and if it wore down too much the rock was coming in at such a fast pace it would just blow through the metal pump itself and it would ruin it. So, when that would happen, they would lose hundreds of thousands of dollars because they would have to shut a line down that they didn’t intend to shut down and they weren’t prepared to shift to a different line. So, by being able to monitor when these rubber casings would go down to a specific level they were able to keep the lines running longer. Because what they did after a few of those issues where they would blow through the metal housing of the pump itself, they decided they would set up a schedule when they would start to take these down, take these rubber casings down and out of there and replace with a new. And they found that they would often be replacing them way too early, and it would take a whole day, two people a whole day to replace this stuff because it was so heavy, it took so much work to undo these pumps. And so, in the end they wanted to find a system that would allow them to monitor how much damage is being done to these rubber casings, which you can’t see they’re all inside the enclosed pumps, and then to be able to extend the life of their system while also being able to better plan for when they would pull that down. Because when they planned for it, they could shift which line the ore was coming off of. And then they wouldn’t have any worries about unexpected downtime and losing all that money as they shifted from one line to the next. In the end I think that is going to be one of the biggest things for success for a lot of companies is having a longer on time, if you will, a longer production time and having less and less downtime, especially unexpected downtime.

**Tom Jones:** Nice, yeah for sure that all definitely tracks with everything. As far as the literature and the research so. That was my last structured interview question, before I stop the recording I want to ask if you have any questions or clarifications for me, or if there’s anything else generically that you’d just like to add?

**Chris Koch:** So generically to add I think you kind of covered all the big hitting points that I like to have in terms of the I4.0 stuff, so yeah, I think I’ve kind of covered all the main topics.

**Tom Jones:** Perfect.
Kevin Donaldson Interview 11.29.22

Tom Jones: Alright we should be good to go.
Kevin Donaldson: Alright, so, I’m Kevin Donaldson, I have been in the management consulting industry for a little over twenty some odd years. Primarily, almost twenty years with the IBM corporation in global business services. Certainly, have implemented a lot of IBMs technology as well as third party technologies, you know, throughout my career. We certainly have applied some of our, what I would say advanced analytics, to client problems and opportunities. To deliver what I would say are Industry 4.0 capabilities, Ok. So that’s basically my background, as we talk about technology. So let me talk about that in the context of Industry 4.0 but very specifically in the context of Aerospace and Defense.

Tom Jones: Ok.
Kevin Donaldson: Because that has been my focus here for the last, let’s say five to seven, maybe longer, years. You know, Covid we kind of missed two years. But as we look at the attempt to really, kind of the Digital twin capabilities and alike, I think it is confronted by each participant in the ecosystem wanting to monetize their own data. And let me explain that a little bit. You know, Boeing is a manufacturer, certainly they want to collect data from the aircraft via the design, via the shop floor, and then the qualifications as it goes to the FAA qualifications, you know they will collect all that data. Once that plane, that aircraft, is turned over to the airline they then own that asset, and they collect data on behalf of that entity. Whether that be American, united, or other. In doing so, what people, many people don’t realize is that the engine that is determined for that particular aircraft is really the decision between the airline in many cases and the engine manufacturer. The data from the engine is between those two parties in most cases, it’s not something that, you know, Boeing will get the full breadth of that data corpus as a part of their ability to evoke a digital twin. So now we’ve got three parties who have a piece of the data if you will, available to them and none of which are willing to share with the others because they’re looking to monetize the situation a bit, so and then it could be even as the plane gets older and flies in different locations. There’s a bit of other information that comes about with the sustainment capabilities right, so there’s third parties that will sustain the plane on behalf of the airline. So now we have four parties that have data that would enrich, you know, the data corpus required to do a digital twin, right. I will share this with you and this is kind of public knowledge. IBM acquired the weather company, I would say about six or seven years ago now, and the weather company has just enormous data corpus as it collects data globally, with the different weather patterns and information. And I have seen Boeing and other companies actually acquire the data corpus for purposes of really enhancing or having the ability to enhance their digital twin capabilities. So, as we talk about Industry 4.0 I think digital twin or the capability to do a digital twin is probably one of the ones that is top of mind for most of us. And the reason that is, is that you can then make some determination, make some predictions around quality, around the possibility of failure of any given component or aircraft or assembly. The richer the data the better off you’re doing around prediction. So, I’ll pause there and see if I’m hitting the mark as far as the list that you have in front of me?

Tom Jones: Oh yes absolutely.
Kevin Donaldson: Ok. So, if you want to talk about some of the methodologies, that you know certainly lean six sigma is a methodology that’s used, but really, I think as we talk about industry
4.0, to be able to scan, to be able to take a part and move from 2D to 3D I think is quite relevant to the overall Industry 4.0 capability, right? So, I think lean six sigma is something that I think we did in the 80s and 90s and we continue to do so, but I don’t think lean six sigma necessarily is the catalyst for Industry 4.0. I think the advent of video technologies, the advent of the scan and those kind of things are really going to move, I believe will move Industry 4.0 further. I talked a little bit about success factors, and I think I need to talk about these, both success factors and barriers, and it’s really the barriers of not getting the entire data corpus, right? To know under what conditions, and we’re going back to an aircraft right, what conditions did that plane fly under. I mean did it fly through a storm, did it fly through, at certain speeds, did it land faster than normal, what was the operation of the pilot. Those kind of things are going to be critical to really understanding the performance and the predictability of a quality incident if you will, as we would predict going further. How long can that plane fly on those particular tires, I’m using that as an example right, so having that complete data corpus is going to be critical for Industry 4.0 capabilities. As we talk about systems, I think that corporations are really going to have to look at the ability to do some of the things I’m describing. Data, data, data, and be able to, here’s a little bit of a nuance to the data discussion I’m having, is really to be able to predict on data streams, right? So, the ability to run analytics against a static data corpus, well you know I think those are table steaks, right, but to get to a data stream. So, to understand how the effect of certain situations would affect the stress that particular aircraft is under over a given period and be able to make some predictions even while the plane is flying. I mean as an example the 787 when it lands it has a terabyte of data.

**Tom Jones:** Oof wow.

**Kevin Donaldson:** To be able to take advantage of that, I mean, you’re going to have to have very large systems to do that. You’re going to have to evoke cloud capabilities. I mean, it’s one thing to be able to predict something based on a very small universe of data, but it’s certainly another effort to do it in a very holistic way. So, I think those are kind of the strategies that companies are going to have to really evoke to really bring quality or QMS processes to their capabilities. So, we talk about strategies for digital transformation. I’ll tell you one thing that as we talk about the capabilities, what we’re not talking about is really the human factor. Now as humans I think it’s part of our natural experience to challenge. Is not to accept what we see in front of us or to challenge what we see in front of us. I think to, a person on the shop floor or what I would say close to the processing, close to the manufacturing, close to whatever, is really to accept the information that they see. However, they also need to balance that with their experience. And let me give you a perfect example, and this is very unfortunate, but. The MCAS system that we all learned about with the 737 max, the reason that there weren’t any deaths or fatalities in the US is because the US pilots questioned what the computer was doing. And they actually unplugged the MCAS system, and then they took the planes under their own control. Unfortunately, in Ethiopia and in some other areas, and I hope no one hears this as a negative, but unfortunately there were some fatalities, they chose not to. And ultimately there was horrific crashes as a result of that. So, we’ve got to, we have to train the human factor as to how we’re going to integrate ourselves with these capabilities, or with all these capabilities, and at what point do we just completely rely on the machine to make the calculations. So, I’ll pause there and see if I’ve hit on some things, Thomas, that you think are relevant for the topic.
Tom Jones: Oh absolutely, I think the point of the interviews is to pull the specifics of real experience in against the literature review that I’ve already done. And I’m glad you paused there because I’d like to expand a little bit on the human system integration that you’re talking about, and then also have a follow up on, it seems like the most important factors that you’re highlighting are centered around data ownership, management, and creating a data system in which data shared equitably so that it can actually generate maximum value?

Kevin Donaldson: Correct.

Tom Jones: Ok, yeah if you could expand on both of those that would be great because those are fantastic topics for my research.

Kevin Donaldson: So, let’s, as we talk about the human factor, let’s think about the vehicles, right, that are coming about whether it be google or other, unmanned vehicles ok? Unmanned vehicles in the sky is fine, right, because we have something called traffic controllers, right? So, with that we make sure that they’re flying at certain altitudes, they’re flying at certain speeds, but more importantly they’re not running into one another. But if we use that same technology for vehicles on the surfaces of our streets, we don’t have the advent of traffic controllers. Yes, we have lights, but people tend to run through those lights, people tend to be distracted. So, when we talk about the human factor it’s fine if everybody had an unmanned vehicle, but as soon as we put the unmanned vehicle in with people who are driving and under control of their own vehicles, the risk, in my mind, accelerates significantly. Yes, the vehicle can predict, traditionally, what an individual may do in a certain situation, but that’s not always the case. And for that reason, I think unmanned vehicles, at least on surface streets, are going to be very difficult to manage going forward. However, unmanned vehicles, you know aircraft, I think is really the next generation for sure.

Tom Jones: So, would it be appropriate to take that line of thinking that you’re giving and expand it into the factory so, say instead of unmanned vehicles on the streets we’re talking about the automatic guided logistics systems. So, in that instance, to develop that system to work there has to be a level of separation so that all of the automation is contained?

Kevin Donaldson: So, let me give you this in my experience. It’s a little different, right? So, and I won’t tell you the particular client, but the client was building aircraft, and as you know aircraft, especially large aircraft, is really index build. You go to cell one, you know, certain things are assembled there, cell two, cell three, and then ultimately final assembly. And in this particular place this client allowed the scheduling to take place at each cell and then also there was a master schedule for which, that kind of managed the entire flow. What we found, and it wasn’t a very deep assessment, but what we found was that left to their own devices, to their own objectives per cell, that they sub optimized the overall capability of the manufacturing facility. Ok, because really what you have, you had conflicting objectives between the two. Certainly, the objectives would be to fully utilize the human resources. Well in cases where parts were not available, it doesn’t make sense to go on to the next step when the next step would require you to redo, repeat, once the part would arrive. It would make more sense to just sit there and wait for the part to arrive, assuming the part was imminent to arrive, right? But in a manufacturing facility you walk through, and management walks through and they see somebody sitting, that can’t be the case, get busy. Well, some of that busy work was really a detriment to the overall manufacturing capability, its efficiency, it’s cost to serve. So, I’ll use that as an example, as far as the human factor in understanding the flow of material, understanding that through the manufacturing process.
**Tom Jones:** Ok yeah, for sure, that makes sense. So, the data usage allows for better optimization of the system versus the local?

**Kevin Donaldson:** If you’re willing to accept the data. And that’s the human factor. If that data is against your norm, whatever your norm may be, it’s less likely that you will accept it.

**Tom Jones:** Yeah.

**Kevin Donaldson:** Ok, so you know along with this data capability, these analytics that we describe, we also need to change our objectives. We would need to change our aspirations about what good is, with this new data.

**Tom Jones:** Yes absolutely, yeah.

**Kevin Donaldson:** So that’s the human factor that I’m suggesting. And maybe it’s the process factor, maybe it’s the metrics factors, the KPIs, I think maybe additional KPIs should be attributed to what would be an advanced capability. What good looks like at that point.

**Tom Jones:** Yeah, for sure. I was just going to loop back to the data sharing challenge?

**Kevin Donaldson:** Yeah, so, every company believes that the ability to sell their data is a revenue channel, monetization, that comes to them with very little cost. The margins for potentially selling data as Dunn and Bradstreet does, and some of those other companies who are in the business for information sharing, or even software, are in the 70-80 percent range as far as margin. So, every manufacturing company who is creating this data corpus looks to benefit from that data and for that reason they’re not willing, necessarily, to share their data without the benefit of getting an equitable distribution from it.

**Tom Jones:** Yeah, yeah that makes sense.

**Kevin Donaldson:** So that’s some of the things, now let’s take a look, I’m going to migrate from A&D, aerospace and defense to automotive. Think about what GM has said, GM has said, “hey we want to be a service company, we don’t want to be a manufacturing company” and what I want to envision that means, and certainly there’s been some communications back and forth about this. But that vision is that you would sign up for a package, and it might be silver to platinum package. And the platinum package would give you the ability to access transportation. So, you may have access to a Cadillac, you may have access to a corvette, you may have access to a suburban, but you would have this access because you now have purchased this platinum package. But the asset is never yours. You only have bought a service. So, if something happens to it you just take it back. Now what that will do is, over the life of the particular asset, car, that if I’m only renting it I’m going to always take it back to the dealership. And I am not going to go to Jiffy Lube for oil changes, I’m not going to drive here, I’m going to always go back, because that’s part of my package, that’s part of my agreement. So what GM is looking at is really to try to get more control over their data ecosystem, and certainly drive more revenue back to the dealerships. But the attempt there is really to get control of the data ecosystem, by virtue of structuring the services differently, the capability differently. Just a thought.

**Tom Jones:** No, it’s, that’s intriguing, and I’ve been aware of the service model, so to build on that, Tesla has been kind of discussing or trialing a model where all of the vehicles are manufactured with every mechanical feature, but you pay for a service package that might turn the heated seats on or off if you’re not willing to pay for it. I had never looked at that through the lens of it’s about the data versus about the subscription versus ownership nature of revenue. So that’s very insightful and a new piece of.
Kevin Donaldson: But even today, and I mean listen, I’ve been in the workforce for a little while, but I’ll never forget I was working for General Motors, Thomas, years ago, I was, I would say in the early 80s. And I don’t know if you remember this company called Hughes Bechtel, do you remember that company? So, Hughes Bechtel was basically, at the time, was a satellite manufacturer. And General Motors acquired them, and having the opportunity to walk down the hallway with the engineer and he said, “you know, what we’re going to do, we’re going to launch satellites and we’re going to track vehicles all over the earth” and you’ve got to remember this is the 1980s, right? I’m thinking to myself “man this guy has really lost it”, well that’s exactly what OnStar is today.

Tom Jones: Yeah.

Kevin Donaldson: Right, that’s exactly what it is, it knows exactly where you are, what vehicle you’re in, you get notifications that this vehicle needs to be maintained, blah blah blah right? But they’re looking to expand that where that capability will follow you. So, your OnStar capability will follow you into a rental vehicle, it would follow you into an Uber vehicle. So, now they have the ability to say, I hate to say this, where this individual is going, what kind of things they like, what kind of vehicles they like, what city pairs are they going to. So now you’re starting to integrate with the rental car systems, or the rental car agencies, and then also other mass transportation, rail or air. So, there’s a confluence of this data corpus that will fit who you are into your desires and aspirations. That’s why General Motors is, and by the way you know General Motors owns a piece of, what’s the other one, not Uber but the other one?

Tom Jones: Lyft.

Kevin Donaldson: Lyft, you knew that right?

Tom Jones: I do now.

Kevin Donaldson: Yeah, that’s why.

Tom Jones: Yeah, no, that all makes sense.

Kevin Donaldson: Yeah, that’s why. So, I hope, we’ve kind of come to the bottom of the hour, I hope I’ve answered at least to the extent that you wanted me to Thomas.

Tom Jones: Yeah absolutely.
Dr. Alaa Elwany Interview 12.1.2022

Tom Jones: Ok we should be recording now, so my research focuses on the implementation of Industry 4.0 technologies to improve performance and quality within companies. So, for starters if you could just introduce yourself and your background with quality or Industry 4.0.

Dr. Alaa Elwany: My name is Alaa Elwany, I’m a faculty member at the department of industrial and systems engineering, Texas A&M university, and right now I’m on detail with the US federal government, serving with the department of energy advanced manufacturing office. My involvement with Industry 4.0 is mainly through my research work. I do work on additive manufacturing which is the technical term for 3D printing. And 3D printing is an integral part, or one of the building blocks of Industry 4.0. I also do a lot of work with using data and the tools of data analytics, machine learning, with advanced additive manufacturing processes which is also an element of Industry 4.0.

Tom Jones: Ok perfect, thank you, and again thank you for participating. So, with the constructs of the study being about Industry 4.0 and quality I’d like to start by asking about the technology landscape out there so if you could just describe from your experience kind of what the state of the art in data technologies looks like and what technologies do you see as the most impactful over the next five years.

Dr. Alaa Elwany: I can speak for Industry 4.0, I’m not entirely familiar with what you call Quality 4.0, but for Industry 4.0 I would say the most emerging technologies would be blockchain, 3D printing, cloud computing, machine learning and artificial intelligence. I already said 3D printing I believe. I would say these are the biggest ones that contribute to Industry 4.0. Now if we talk about quality then I would definitely put new types of sensors and sensing devices, the landscape of sensors keeps expanding and these are definitely essential towards ensuring quality in Industry 4.0 systems.

Tom Jones: Ok perfect, and yeah speaking from the Industry 4.0 perspective is perfect. One of the constructs of my study is the fact that quality is defined uniquely by different companies and a quality focused strategy isn’t necessarily the appropriate 4.0 strategy for every company so its fine to stay within the realm of your Industry 4.0 experience there’s no worries there.

Dr. Alaa Elwany: Yeah, and I’ve worked on quality and other constructs, so I’ll allude to it whenever relevant.

Tom Jones: Sounds good, so technology is the simple part obviously, implementation is where challenges come into play. From your experience do you see a relationship between lean manufacturing and Industry 4.0?

Dr. Alaa Elwany: Yes, Industry 4.0 is, I see them as pretty much the same. If we talk about lean manufacturing, six sigma, agile manufacturing, all of these are the terms that emerged a decade ago and all of these evolved to what we call Industry 4.0 today. So I see Industry 4.0 as a natural extension of these concepts that takes advantage of new technologies like cloud computing and sensors and the ones that I just mentioned. So I actually see them as complimentary at least, but a lot of people see them as pretty much the same. If I had to define it I would just say Industry 4.0, I would say lean manufacturing is Industry 4.0 minus the cloud computing and artificial intelligence technologies.
Tom Jones: Alright, thank you that’s a good description I think of the relationship. And then as a follow up do you see a relationship with Industry 4.0 and the applications there and the Total Quality Management methodology?

Dr. Alaa Elwany: Not quite, and I will say that I’m not fully familiar with TQM, of course I hear of it, and I’ve seen, I’ve read textbooks and I’ve heard of it but its not my area of expertise. But I do not see a direct connection, but that might be due to my lack of familiarity with TQM.

Tom Jones: Ok that’s fine, I can define the TQM construct. Essentially, the short explanation of Total Quality Management is that quality is no longer the responsibility of a quality department but needs to be architected into everyone’s job.

Dr. Alaa Elwany: Oh, then it’s definitely, it’s related because that’s what Industry 4.0 is all about. Industry 4.0 and quality in Industry 4.0 is about having possibly physically disconnected entities that are connected through the virtual space, and then the responsibility of meeting quality requirements is distributed. It’s like a distributed quality system so based on that description you just said I think that they are very much related.

Tom Jones: Perfect, thank you for that answer. Ok, so the next ones are kind of more probably relevant to expanding into your experience of using the technologies. The previous questions were more of just kind of a baseline. So, from your experience with any Industry 4.0 implementation especially I’d like to focus in on what major success factors or barriers you’ve encountered and how they may impact successful implementation of industry 4.0 technologies?

Dr. Alaa Elwany: I don’t think I understand the question.

Tom Jones: Ok, so, we’ll start with barriers then, I’ll specify. When doing an Industry 4.0 implementation, can you think of any key barriers that an organization will have to work through that may either prevent them from moving forward with implementation or lead to failure?

Dr. Alaa Elwany: Yeah, the barriers I could think of and that I saw for myself if I were to even rank them. Number one would be the talent, the availability of a trained workforce equipped with the necessary knowledge and tools and training on all these technologies. So that’s number one, the talent and workforce. And number two would be resistance to change, because many companies just want to follow the “we’ve been doing it like this successfully, why do we need to adopt these new technologies”. Number three is the, that’s a very practical constraint, is much of the adoption of these new technologies often happens at small and medium enterprises, as opposed to large companies. Large companies do not prefer to work with these emerging technologies that have not been proven yet, and small and medium enterprises have all sorts of finance and economic constraints. So I would say these are the three top barriers I can think of. So, the barriers really are not technological, the barriers are talent, resistant to change due the need of large companies to de-risk technologies before they use them or adopt them or implement them, and the challenges that the small and medium enterprises have been facing over the past decade or two.

Tom Jones: For sure, yeah, those line up really well with the constructs from the model that I’m working to validate through interviews, so I appreciate that. Could you recommend any key strategies or methods to approach those barriers?

Dr. Alaa Elwany: Public-private partnerships. No one will be able to do this on their own. This has to be models of partnerships where the private industry, both large and small, and the federal government, and the research institutes and academia have to work together in convening spaces where they work together on defining the obstacles and collaboratively de-risking and implementing these technologies. So, I’m a believer in public-private partnerships. You can think
of models like the Fraunhofer model in Germany, you can think of models like the Manufacturing USA model in the US, and so on. I think these are very good models. Another model is, oh you know what, that other model is also a public-private partnership, which is the manufacturing extension partnership program, MEP. So it all boils down to public-private partnerships to push the boundaries of technologies beyond the valley of death, the technology valley of death.

**Tom Jones:** Very nice, now, so ok, technology valley of death is not a term I’ve ever heard of. I have an assumption in my head of what it means but could you define that one for me real quick?

**Dr. Alaa Elwany:** Yes, sure, so you know there are levels, there are what you’d call technology readiness levels, TRLs, where these range from 0 to 9, from 1 to 9, where 1 represents basic research that is done in universities and research institutes, lab research, and 9 is fully commercialized product that’s being sold to customers. So going from one to nine, how do you do the technology transfer and the commercialization to take a new technology from the basic lab research level all the way up to a commercial product that is sold to people. That is called the technology valley of death, and these are typically technology readiness levels four to seven. So that’s a brief description of the valley of death.

**Tom Jones:** Ok that makes sense, thank you. So then my last question about your experience is if you had to define what a successful implementation of Industry 4.0 technologies looks like what would, how would you define that.

**Dr. Alaa Elwany:** That would be a system. Ok that’s a very philosophical question, let me think. I would regard it as a system where, that is characterized by being autonomous, decisions are autonomous based on sensor data collected from the physical assets in the system, and seamlessly transferred and sent to central processing systems in the cloud. And then decisions going back with an effective feedback loop such that, and a system that has clearly defined metrics. How do I define whether I have met my objective or not, so if I were to recap or summarize what I just said: that would be a system that’s characterized by being autonomous, having a feedback capability, and well-defined metrics to measure their performance and impact.

**Tom Jones:** Ok, I appreciate the clarity, it’s very, your answers are very tangible. Some of the people I’ve interviewed have lived much more in the philosophical, and I think it’s good data to layer into my study to have a slightly different nature of response.

**Dr. Alaa Elwany:** I have been a PhD student so I know how difficult it is to just hear people go on and on about abstract concepts, so I’ve learned to just try and be concise to help others when I can.
Seshu Akella Interview 12.7.2022

Tom Jones: So we should be recording, like I said, already introduced the research it centers on your knowledge and expertise on the topic of implementing industry 4.0 technologies so if we could start with if you could introduce yourself and your background with these technologies and what makes you a subject matter expert.

Seshu Akella: Definitely, my name is Seshu Akella. I am part of Deloitte’s applied AI group and I specialize primarily in helping enterprises adopt AI and analytics. So having said that, I have been focused primarily in the smart factory and the smart operations of Deloitte, and helping companies evolve into Industry 4.0 using AI and analytics. As AI and analytics is all driven by data, so the foundation is what we start looking into and my specialization has been primarily in the lines of ensuring, building solutions that will help clients and enterprises, especially in the manufacturing space, take advantage of the technology in the most efficient and effective way.

Tom Jones: Ok, perfect I think that you’re exactly the subject matter expert that I’m looking for then because it’s that actual application beyond the theory. Ok, so dive right in, my questions span a handful of high level topics so we’ll start with the technology topic because it’s the most straightforward really. So you’re probably a great person to answer this first question, but from your experience with the technologies that you are working with can you describe the state of the art in data collection and data analysis?

Seshu Akella: For data collection and data analysis, if you are looking at tools and techniques the market is filled with them honestly, but then if you’re looking from basic to advanced there are different stages in what you want to bring to the table. The basics, anybody and everybody’s favorite would be still an excel file, most of the time the data starts collecting in an excel file, but then as you increase the volume of data then we start seeing the transition from excel into more structured databases and even if you are trying to tap into some more unstructured, and anything like that, then you’re looking at a much more advanced and higher volume scenarios like building data lakes and all that. So, the technologies primarily I focus on are in the lines of from a data collection and ingestion point of view very much like cloud-based solutions, such as AWS or Snowflake and Azure, are the key foundational elements I would say on the cloud side. On the other, on prem, if there are customer limitations on using any of the cloud-based technologies or cloud infrastructure then you’re looking at classic tradition RDBMS’s like Oracle and these are all, once again, for the analysis part of it it’s all purely part of SQL in combination of reporting on top of that

Tom Jones: Ok perfect

Seshu Akella: Does that answer, did I miss anything, or do you want?

Tom Jones: No, I think that’s a great answer and I’m not looking for anything specific in the answers so I have a model that’s build from the literature on what Implementation might look like in theory and so I’m not seeking a specific answer because I’m weighting the experience of subject matter experts against the theory to see where the gaps exist basically.

Seshu Akella: Perfect, more than happy to help.

Tom Jones: So, as a follow up to that one, can you describe how with the data collection and analysis step in industry 4.0 how automation can be applied.

Seshu Akella: This is something I am tracking very closely and one of the favorite topics of mine. As we’re seeing the variety and the volume of data flowing into classic data lakes that I mentioned
earlier it becomes imperative that you no longer need ingestion, or you don’t have to babysit that process anymore quote unquote. What we are looking at is more and more there is a Kafka topics kind of, if I may, Kafka topics are very familiar and quite popular these days where you can build
in streams and push data, or ingest data, in very seamless scenarios where you can get data in near real time. So having said that, so to get the data populated and made available, automation is something that everybody is leaning on so there is tons of opportunities there in automation, especially ingestion of the data, putting triggers on top of it to inform people on notification. If I’m looking at any governance scenarios, automation also is one of the best things that we’re looking at to identify any data quality issues, so on and so forth. So, plenty of scope in that space.

**Tom Jones:** Nice, very nice, and my last question about technologies is: so over the next five-year threshold which specific technologies do you think will be the most impactful? For industry 4.0 sorry.

**Seshu Akella:** So interestingly I made a note very recently on this topic. Le me pull that out and share with you. There are six different technologies I’m tracking very closely, and as a matter of fact I will be presenting for a panel for my LMI this weekend also on the same exact topics so.

**Tom Jones:** Very nice congratulations

**Seshu Akella:** Thank you, so I’m looking forward to it. It’s actually after 25 years I’ll be meeting all my professors and I have been literally away for a long time from the university. But give me one second, I’m pulling the note here and I’ll share with you in a minute.

**Seshu Akella:** So, I’m going to break it down to two core pieces of it. The first one is more the lines of what are the core technologies that is going to build the fabric and I’ll also go deep dive into the AI/ML piece which is one of the key foundations here, ok? First part, is purely this transition of the data so essentially what that translates into is build the foundation layer, which is the one of the things that we are calling it is “data is the new oil”. So having a foundation and building the right infrastructure and pipelines to bring in data to the various hubs, data hubs, to make it available for various uses in the ecosystem is one of the key imperatives and key requirements I’ve been tracking from a technology standpoint of view. In addition to that what we also are looking at is IoT, the internet of things, devices that produce and share data become very important especially in manufacturing. Think of it like you are at a plant and you need to understand how efficiently your machines are performing and/or various aspects about machine health, diagnostics, and all of that. IoT is the best solution for that. Using RFIDs and a combination of different sensors you can collate and collect all the information and pass it along through the other systems which can talk to each other. Next one is something very core, which is becoming, which is actually is taking us like a storm, is cloud computing. We talked about AWS, Azure being the hyper scalers. These are the ones which we are seeing a lot of traction as a technology component to take advantage of cloud computing. The key benefit of cloud computing is primarily being scalable and extensible in the very logic construct. And also, the biggest benefit that you get is storage and compute power that is unlimited literally, sky’s the limit. And last two topics are AI and ML, I’ll go deeper on AI and ML in a bit, but also the same note are the networks, the 4g and 5g networks are another piece of technology that’s currently definitely making a big difference. A deep dive into AI/ML, the classic, the impact of AI/ML is primarily seen in three different ways. The first one is the classical ML technologies which is predictive analytics, preventive maintenance, anomaly detection etc. Unsupervised learning and optimizations. Deep learning scenarios where you are looking at reinforcement learning, typically
from industrial robots, computer vision, and autonomous machines like the classic examples that we’re seeing are spot, the Boston Dynamics dog. So, there are use cases and scenarios that people are tapping into and this is for real, these are all happening, not only in academia but also in the real world where we are seeing the use cases and impact on the floor of the factories. Last but not least on the AI/ML side is the generative AI where we are using a combination of mixed reality, AR, VR, metaverses and 3D printing taking strides here. Any additional questions on that? I think from technology I think I spoke.

Tom Jones: Yeah, I think that’s a very thorough answer I appreciate that. My next couple questions are Industry 4.0 and how it relates to other methodologies. So if you’re unfamiliar with either of these methodologies, let me know, I’ll define them.

Seshu Akella: Please it will be helpful to get a perspective on methodologies and the way you’re saying it.

Tom Jones: Before I define them though I definitely would like your answer if they’re methods you’re familiar with. So the first one, if you’re familiar with lean manufacturing, can you describe any relationship you see between lean and industry 4.0.

Seshu Akella: Lean manufacturing, can you share more details as to what exactly is your definition of lean manufacturing so that I don’t, for me lean manufacturing is being more efficient and more, so once again, minimal input and maximal output would be the core construct of lean manufacturing for me. In other words using the least amount of material to build maximum number of products.

Tom Jones: Yeah that’s a good definition of lean yeah.

Seshu Akella: Ok, if that aligns then lean manufacturing is what I think we are seeing a lot of especially whenever we talked about anomaly detection and predictive scenarios. This is where the whole, from the quality standpoint of view, as less from an overall production line capacity standpoint of view. People are, the manufacturing floors and the managers of the floor, are looking at optimizing these processes in the most efficient way. Once again, what covid has taught us is supply chain is going to be pretty unpredictable, come what may. So given that, with the material at hand how efficiently and how best you can build your parts in production becomes very important. So how do you do that? And this is where the technology and the AI pieces are coming into play and people are looking at it from a logistical point of view, so definitely lean manufacturing is imperative. Actually, the way I’m seeing it in industry and the way it is being applied it is very much correlated and with the newer ways of doing things. I would say “uberrification”, like reengineering the processes that you want to do and seeing with a fresh set of eyes is something that is commonly done in Industry 4.0. This all gives us the backbone for industry 4.0 in my opinion.

Tom Jones: Awesome, thank you. And then the other methodology if you’re aware of it is Total Quality Management. So could you describe if you see any relationship between Total Quality Management and Industry 4.0.

Seshu Akella: Ok this actually is a segue from the previous topic that we talked about for lean manufacturing and total quality, they go hand in hand in my opinion. As simple as this, the quality of product and preventing any kind of defect in the product is, and has been, the key challenge for most of the manufacturers for a long, long time. With computer vision and a combination of algorithms and even looking at the sensor data, putting into perspective it becomes easier and the quality control can be improved ten-fold in my opinion. And that’s something we are seeing is
very common. For our solution that we’ve built for improving smart operations this is one of the key tenants. Interestingly I can share a good story there, where for a manufacturing company which is building hoses, the algorithm or the thing, the solution that we had built up was taking into consideration the amount of the time the material was sitting in the warehouse because temperature their material is very sensitive to the temperature variations and we have taken into consideration, various outlier features which need to be factored for the final quality of the hose that is getting built. And by the way, we are talking about these regular hoses that we use for watering out plants. Interestingly there are six or seven different layers that need to go in for the manufacturing of the hose. The first one being the regular rubber or the polymer core and then on top of it a wire, a thin wire mesh, and so on and so forth. So the whole combination of manufacturing a hose, if it has a defect then you’re thinking of yards and yards of material going to waste just because of one little bump in the quality feature. So, all said and done the algorithm that we have put together is a combination of understanding the issues of the run using a camera and their technology together and to identify up front so that quality checks are much contained, and you are preventing the issues up front.

**Tom Jones:** Absolutely, yeah. I like the insight that the two that the methods flow together as well, that’s, I appreciate that. So, the next few questions are about factors that enable successful Industry 4.0 and barriers that prevent implementation of Industry 4.0. So, they kind of flow together. A barrier can be mirrored by a success factor so that’s kind of why these questions mush together. But I’ll start with success factors. Are there any key factors that are really important to enabling a company to successfully move forward to industry 4.0 and what are the impacts of those factors if you’ve identified any?

**Seshu Akella:** So, for success of any Industry 4.0 I would say the way we look at it is defined by three pillars. First is your process, second is your technology, and the third one is your people, or the change management workforce scenario. It’s, think of it like three different circles put together and the intersection of these three makes the biggest impact on the Industry 4.0. You need the processes to be aligned to the ways of doing things in a much more different way, the traditional ways of doing it might not be efficient, we talked about it in the earlier example. A traditional way of doing things might not be super-efficient long term basis, there are good things in that but in the same time from a long term benefits and from with all the interesting scenarios that we are running into from supply chain and available material, logistics, everything. And also with the demand also going up and down it becomes a lot more complex than any other time of in the whole intersection of all time. So given that, processes are the key component the way we need to look at it. To be successful you need to have the right set of processes, update and upgrade your processes to the most relevant and most current, that’s one of the key aspects. From a technology standpoint of view having the right set of technology is also an enabler. I cannot load volumes of data on a very limited set of storage and also the computing needs to be upgraded. This is where the whole cloud computing comes into picture. But once again security becomes one of the key barriers, we will talk about it in a minute, but more important is the technology needs to be upgraded and to be brought up to the same levels that you are looking at to operate at the data you want to play with. Same thing you had to invest in, computer vision related technologies, cameras, IoT devices. This is where the investment needs to be done, and this is where you start looking from a logical point of things. Last but not least the people who are taking care of all the business do need to be upgraded and do need to be having all the tools and techniques that they can play
with to be more efficient. That’s where the people come into picture, the right training, right awareness, the whole nine yards around change management and the digital workforce is definitely required on that space to be successful.

**Tom Jones:** Absolutely, yeah. And so you’ve already started to touch on to it, so my next question is exactly the same just, what are the barriers and how do they prevent success?

**Seshu Akella:** Totally, so this is this is where it becomes, cost is one of the key things right. We are talking about new technology, where do we get the funding here. The CapEx and OpEx is a constantly the battle that you’re looking at. How much do you really want to invest into it and how is your operating cost. This is where I think everyone wants to reduce the OpEx and how do you do that? That’s where the big bucks are, that’s where the whole optimization things come into the picture. But once again, it is all comes down to planning and investing in the right way in my opinion, a solution for that. But it is one of the key barriers that we see typically in this space. Another one is the generation where we are talking about the generational gap from expectations and are taken to the next level, the right amount of trainings and sharing the vision becomes very important. And many times what you see is the vision is not commonly accepted or shared across Gen X, and Millennials are 3 times ahead of how to adopt the new technology, but at the same time having the view and vision into how its going to play out after five to six years becomes a key challenge because technology is evolving, technology is changing. You cannot have one algorithm sitting there by itself and learning, for it to learn it needs more data, the whole thing needs to be planned and done diligently around. So, these are the key learnings that we have seen and the implementations. Key barriers are the key at least that I can think of which are pretty big and large that need to be taken into consideration.

**Tom Jones:** Nice, very good, thank you for that answer. It’s the barriers and the success factors are interesting because they merge together.

**Seshu Akella:** Very true, very true, what makes you successful will also bring you down.

**Tom Jones:** Yeah you touched on the security and it’s interesting because the constructs don’t seem to indicate that having good cybersecurity is an enabler, however that’s the number one barrier that comes up is not being confident in cybersecurity will prevent the company from moving forward.

**Seshu Akella:** I again talked good stories around that, if you look back about eight years ago when Amazons and Azures were taking strides, even IBMs were taking strides. I used to work for IBM by the way I forgot to mention in my introduction, I used to work for IBM Watson group and that’s where I have kind of sharpened my AI analytics skills on that space. But, then one of the key things that we saw from adoption was exactly the same thing, I had one client who was super paranoid learning that Watson can learn. They, guess what, they had us use a, we were building a solution using Watson and they were so paranoid about that, they said if your system can be on a network and it can suck up all my data, I will do one thing, whenever you’re running the system I will shut down the network and I will unplug your machine to run in isolation. It was funny but that was the level of paranoid we were looking at from a security standpoint. If we are protective about their data and that becomes a huge concern. I wouldn’t train if I am unplugged, if I am completely offline, its not going to work, so.

**Tom Jones:** Yeah, yeah and that’s a common narrative. So the more repetition of the same narrative I get from expert experience the stronger it lays the foundation for the model I’m building. So, it’s just, that one always jumps out at me. Ok a couple more questions. I’ve got one
question about systems, so this one’s a bit broader. So, in implementing an Industry 4.0 application of any scale really, what do you think the impact of the way a company’s overall hierarchy and work systems are designed is?

Seshu Akella: In the implementation, sorry can you please repeat the question again?

Tom Jones: Yeah, so and this one’s kind of more vague so it’s been a stumbling block in my interviews. But I’m trying to identify if there’s a relationship between how a company organizes it’s overall structure, it’s management hierarchies, it’s workflows, and whether that has an influence on success with implementing Industry 4.0 technologies.

Seshu Akella: Oh totally, this was this is something that I touched upon earlier, is the change management for the digital workforce, right. So, with new teams coming in and new way of doing things, what we are seeing is the traditional org structures are breaking down, and we are looking at more agile, more smaller teams with a product mentality that building a product and driving through that is becoming a very common scenario. Especially in the IT world if you reflect back 20 years ago, we had one application which was ordered by hundreds of people to get. Now those hundred people are kind of distributed and focused on multiple products. Classic example is how Googles and Facebooks are operating today. That is a construct which is kind of helping move faster, it is like the fail fast and learn with your failures kind of scenario which is what everybody is adopting. And those are the changes that you are seeing from an organizational standpoint of view. Your leadership is broken down into multiple silos, not silos, multiple different divisions, and each one of them is operating independently and cohesively on a single platform. That’s the beauty of it. So, technology is a pattern that’s connecting everybody, but when you’re looking at the intelligence or the knowledge is kind of coming from multiple sources together in a small team instead of the team working isolation. It’s a new way of collaborating.

Tom Jones: Awesome, yeah that makes sense. Appreciate that answer. So the last two questions are the ones that are the most open ended and your opinions, your experience. So, the first one is if you were to recommend a strategy to successfully implement Industry 4.0 technologies what would that strategy look like?

Seshu Akella: Strategy to implement 4.0. It will be as follows: first and foremost, understand what are your, what’s your vision and where do you want to see yourself tomorrow. That’s tomorrow as in as a future that you can visualize right, because that’s very important. And also put into perspective what is happening in the industry. So that’s where my strategy is going to be starting, is to understand what is happening in industry today. How this kind of extrapolates to the next five years six years, how these technologies, how these processes are going to evolve, and what is the need for that. So that is the groundwork on the foundation side to start looking at. Once that is established, I start looking into what are my needs and what would it take for me to get there. Once again, the three P’s that I talked of, technology, processes and people are the three grounding principles that I’ll be leaning on, and I typically build on those lines. Do I have the right processes in place, do I have the right technology in place and do I have the right people in place. So, I will start evaluating and doing assessments around that and get a quantitative view around what is to be done, if there are any gaps. Based on those gaps I start building out what are the things I need to focus on, build those initiatives in, and start working towards end state.

Tom Jones: Perfect.

Seshu Akella: Does that help, or do you need more detail I think I kind of briefed it and kind of went with an abridged version of it.
**Tom Jones:** No, no I think that’s an appropriate level of detail for a strategy question. And this last one, ok, totally open ended. What does Industry 4.0 success look like from your perspective? **Seshu Akella:** From my perspective it is a good from a larger scope of things and from what I have seen it is, it has started the journey has started, for me it is a journey, and the journey has started, and it is going to be remarkable to see how it is shaping up different industries. The key aspect is the foundation of the key pillars of the industry 4.0 are your network and the evolution of that is definitely going to drive it like we are talking about we are moving from 4g to 5g networks and the speed and the bandwidth we are going to get. To start streaming the data and moving the data at lightning speed is going to make enormous difference as opposed to what we are seeing earlier, so this is not only going to add to the ways of doing things but also the way is going to shape the future. So, long story short but the way I am seeing it is quite promising is quite going to be quite rewarding investing in this. So to be successful in Industry 4.0 definitely it is time to start looking at the bigger picture and investing in the largest group of things as to what is going to be helping the folks and enterprises to get to the next level. **Tom Jones:** Gotcha, I like that definition for success as well, very macro view. That’s a slightly different perspective in looking at the development of industry 4.0 overall I like that. I, those are all the prepared questions I had. I think you gave really good elaborations and descriptions which will definitely contribute to the body of knowledge that I’m compiling. If there are any questions for clarification or just anything in general that you’d like to add you can go ahead and do that. **Seshu Akella:** I’m just curious, who all have you been speaking with, any, mostly Deloitte or are you looking at across industry folks and academia also? **Tom Jones:** I’ve been looking across industry and academia, the smart factory at Wichita was a really good connection for me because a lot of people were interested, and I think that the Deloitte folks that I’ve talked to have been a great resource because all of you guys have different backgrounds and don’t just do Deloitte industry 4.0 but work with clients as well. But let’s see, I’ve talked with someone from Amazon, I talked with a college professor who was tasked with creating an Industry 4.0 preparation type curriculum for grad students, and I’ve got several more interviews to go still and they kind of just span industry and academics. **Seshu Akella:** Perfect that’s interesting. I like the topic, it’s one of my favorite topics honestly so I have been tracking it very closely. We have been helping with the Wichita project that we did, and you heard about it, the smart factory kind of came out of that. It is one of the key marquee solutions that we have built and that we talk about at Spirit Aero. You have seen the videos I believe, which Emily might have shared with you also, so that is the work and that is the reality for me when people ask me if it’s hype or is it reality, it’s not hype for me anymore it’s the reality that we are living. So that’s really what I’m seeing. As success for me is people embracing it in the right way than looking at it in the way of Automation and machines taking over the planet and we all are becoming slaves of machines, all those are Hollywood stories. I won’t even subscribe to it so even if people talk about it and there is so much media about it, it’s not going to happen any point of time.
Dr. Tahany El-Wardany Interview 12.14.2022

Tom Jones: Ok so we’re recording now, I just introduced the Quality 4.0 topic, so we can go ahead I think and jump right into the questions. I, one of the keys with my interviews is not to bias any answers, so if there’s any concepts in my questions that you’re not familiar with at all I can clarify and define them, but if you have familiarity go from your own experience and knowledge if you would.

Dr. Tahany El-Wardany: Ok.

Tom Jones: So, for starters just to establish your experience could you give me your background as it relates to quality and Industry 4.0?

Dr. Tahany El-Wardany: Ok, my background in general is advanced manufacturing. I look for all the modeling, optimization, for any new manufacturing technologies, available manufacturing technologies and also what we can say, like the, I don’t want to say old manufacturing technology, I can say that for example well developed manufacturing technology like machining, like casting, like forging. So, in general all my area of expertise is really focused on manufacturing, modeling, and simulation of manufacturing processes. In addition to that I have built models for tribology, and I have worked on tribology too.

Tom Jones: Ok perfect thank you.

Dr. Tahany El-Wardany: Yeah, and if you look at industry 4.0 it is really related to what we are doing for manufacturing, how we are developing the manufacturing processes.

Tom Jones: Perfect, yeah, I think a focus on advanced manufacturing definitely makes you a subject matter expert for my study so that is a perfect background.

Dr. Tahany El-Wardany: When we talk about advanced manufacturing I am talking generally, not only additive manufacturing. I’m talking about all new manufacturing technologies that are being investigated or used. Including, also a new area about electrification of the manufacturing processes.

Tom Jones: Perfect, yeah definitely the target expert that I’m looking to interview. Ok so I’ve established that you’re a subject matter expert. My questions flow through a few different topics and the first topic is on technologies, which I think is definitely going to be right in your experience. So for starters from a technology standpoint, with the technologies that you work with, can you describe what you see as the state of the art when it comes to data collection and data analysis?

Dr. Tahany El-Wardany: Oh sure, we actually utilize some of the standard data analysis software, but at the same time we’re also building, ourselves in the research center, we are building many data collection software or codes in addition, of course, to the analysis. When you talk about analysis in manufacturing we’re talking about either a finite element or analytical models, so we are covering in our industry, we’re covering a wide range of these analytical software. We’re also building a lot of machine learning applications for manufacturing. Let me try to get for you, do you want me to specifically talk about specific software or just in general?

Tom Jones: No specific software aren’t necessary.

Dr. Tahany El-Wardany: Yeah, and also lately most of our work now, artificial intelligence is a part of the developed manufacturing technology too.

Tom Jones: Very nice. Ok perfect, so with the state of the art in our data collection and analysis can you describe what parts of data collection and analysis are typically automated?
Dr. Tahany El-Wardany: OK. For the data collection and analysis, I mean, for example let's talk about that we are doing some experimentation. You know when you go for digital thread or for process optimization. So in these cases, in manufacturing at least, we always have a lot of sensing that we are using even with additive manufacturing, which is advanced manufacturing, or other processes. We are always using sensors either to collect forces, collect dynamics, vibration, collect temperature, using some thermocouples or other sensors available. Sometimes we need to collect, if we want to look at the quality, want to see how the part as we are fabricating it, gets distorted or dimensions are not the correct ones. So, there is a wide variety of parameters or data we are collecting for analysis. And after that since we're already collecting the data and going through some of the codes we developed, so you're analyzing the data sometimes online, you know, as you are for the digital thread, for example. You're collecting the data, it's analyzed in sequence, and after that a decision or something occurs to maybe readjust the process or readjust some of the parameters. So, this is one of the analyses we are using. The other analysis is, we are looking for example if the part is distorted. We’re looking to know, as we are moving the part, how much distortion exists so right away we can start running other software or codes to try to do distortion compensation. Surface finish, for example, it’s another quality parameter which we are looking for most of the time. And there are some laser assisted or laser probes that can give us an idea about what is going on, and again if we are applying digital thread in this case, we will be able to right away compare this data with what we’re supposed to have. And if there is a difference we directly need to go back and see the depth of cut, or there was some vibration, or some dynamics, or a thermal heating in the part when we are additively manufacturing it, so we have to try to compensate for the next part. Distortion or like adjusting surface finish or eliminating distortion of the part. Is this something you are looking for?

Tom Jones: Absolutely yes.

Dr. Tahany El-Wardany: So, regarding the application of this digital thread this is part of Industry 4.0 and in most of, I think, in a lot of cases our machines, even if they are old machines, they do have something now, some sensing that is used. For example, I can measure forces as I am cutting and if the forces start to increase because of the tool wear we have to stop the process and change the tool. So, there is a lot of automation now in our industry for the Industry 4.0 and the quality too.

Tom Jones: Perfect that answer is exactly on topic. Awesome I have one more technology question and I think that you were just speaking about this so it should be an easy one, but with the recent technology changes which technologies, from your experience, have had the greatest impact on quality?

Dr. Tahany El-Wardany: For example, additive manufacturing, when we are building parts with additive manufacturing we also knew that we will have rough surface at the end, we also knew that although additive manufacturing is a great technology but sometimes some defects happen and it does affect the material properties. So although these facts we know about, but also we see that something usually started to happen like, for example, application of hybrid manufacturing where they know that the surface finish is going to be rough but at the same time the machine now for additive manufacturing became a combined additive and also subtractive which is machining. So you can control the surface finish, the quality of the surface finish for example. There are also some heating processes that follow the additive manufacturing to reduce some of the defects that exist in the part. There are also a lot of models lots of models now actually not only models, I
mean even if you look at all the big names like Anses, Abacus, all these finite models, software I mean, started to include a module about additive manufacturing. So, for the defects, for example, you can run pre depositing the part, you can run and see the effect of the process parameter you selected. The scanning strategy you selected, on the origination of defects and in this case before you start depositing you can change some of the process parameters to ensure that you are having a good quality part. So, there is a lot, maybe not everything is automatically or done online or in sequence. Some cases we have models and we run these models until we identify the optimal process parameters that we can use with our defects.

Tom Jones: I gotcha, that makes sense. Ok perfect so those are all my questions about technologies, the next few are about different methodologies and implementation of the Industry 4.0 tech. So, the first one about methodologies is with Industry 4.0 technologies do you see a relationship between Industry 4.0 and lean manufacturing?

Dr. Tahany El-Wardany: Of course. Isn’t one of the Industry 4.0, no, no, I’m sorry, yes there is a relation between the lean manufacturing and Industry 4.0, that’s for sure.

Tom Jones: Can you expand on the nature of the relationship as you see it?

Dr. Tahany El-Wardany: Ok, when you’re talking about Industry 4.0, you’re looking for time savings, you’re looking for scalability, you’re looking for control of the process itself. So, when we talk about lean manufacturing, we’re talking about that you are producing parts with, actually, minimum scrap and minimum, avoiding all the associated problems with environment. So, I think there is a very close relationship between Industry 4.0 and lean manufacturing.

Tom Jones: Perfect, and I have one more question about methodologies, so same question really, do you see a relationship with Industry 4.0 and Total Quality Management?

Dr. Tahany El-Wardany: I think if we looked at Industry 4.0 and we talked about digital thread it is one of the main pillars of Industry 4.0. Ok when we do digital thread, which means that we are sensing whatever we are producing and correlate whatever we sense with a problem that exists in the part, and we go, we collect all this data, we analyze it within the controller, and we come up with a decision-making tool eliminating any of these issues or problems associated with manufacturing of a part. Why are you doing that? Because you want to ensure that the quality of the part produced, the total quality of the part produced, is within the specification.

Tom Jones: Absolutely.

Dr. Tahany El-Wardany: So I think total quality of parts or total quality of manufacturing is actually, if I look at it from outside, it is the main target for Industry 4.0, right, because you’re not producing the first part right but also you’re ensuring that it is cost effective and you are optimizing the process to reduce production. So you’re doing a good, you’re producing a part with a good surface finish, geometrical wise it’s correct, any fine features you are inducing is also within the specs, and the whole part is within the specs. Sometimes even you can go further and ensure that the microstructure of the top layer of the surface is what you are looking for, is having the residual stress profile that you need to increase the life of the part. So there is a lot of things, each element of it is a part of Industry 4.0.

Tom Jones: Perfect. Yeah, I would agree with that as well. So, my next two questions are about how to succeed when implementing these technologies. So, and I think your experience is perfect for these questions, so first question is about success factors. So, what factors have the most positive impact on implementing Industry 4.0 technologies and how do those factors play a role?

Dr. Tahany El-Wardany: Can you repeat the question please?
Tom Jones: Yes, which factors help enable an organization to implement Industry 4.0 technologies and how do those factors affect implementation?

Dr. Tahany El-Wardany: Ok.

Tom Jones: And this question is inclusive of any types of factors, organizational factors such as like the size of the organization, the industry that they’re in, their leadership styles, et cetera.

Dr. Tahany El-Wardany: Ok. First of all, you need to start looking for smart manufacturing or smart factories. Where you give, you are willing to add some measurement technology, data acquisition technologies. Or what we call Industry 4.0 is digital transformation for industry right?

Tom Jones: Yes.

Dr. Tahany El-Wardany: So definitely there are factories, you need to hire, or your team has to have different knowledge, you know. Every, the people are working, they need to be, some of them are very good in digitization of any process in industry. The second one is the implementation, you know, the implementation in Industry 4.0 it is not something, when you want to adopt Industry 4.0 technologies you need to have several changes in the way you approach or you plan your process. In the way you are transferring the machines you have to be some smart machines and the most important also is that you have the people who believe the need and they want to apply it.

Tom Jones: Absolutely.

Dr. Tahany El-Wardany: This is very important, honestly, because I worked with people for example, they’ve been working for forty years fifty years doing the same thing, and they are doing a great job, a really great job. Very successful, they produce parts the way they like to produce it, very good, and you want to come and say ok let’s make it a little bit smarter and instead of using this tool try to use this tool because it will reduce production time by 90%. Some people are willing to look at that, some people think we’ve been doing it for a long, long time correct and we have really good quality, why do we need to make this transformation. So, this is another factor that’s very important, that people are willing to implement all these new technologies on the machining cell or manufacturing cell to make it faster, to make it more correct, to make it with high quality, to make it cost effective. To collect the data and analyze it online, in sequence, and change things. So human resources and the competitiveness is an important factor for implementing Industry 4.0. The strategy, how are you going to implement it, when are you going to implement it, which parts you are going to implement the technology, is another factor. Of course, the organizational fit, I’m not talking about upper management, I’m talking about the whole organization. The whole organization needs to be a big believer of data collection and analysis in sequence and decision-making applications and the changes and the installation of the, all the sensing technologies, to make your factory or your machine smart.

Tom Jones: Yeah. Those factors all make sense for sure.

Dr. Tahany El-Wardany: Yeah, I’m just saying this is what I think, whenever you want to implement 4.0 you have to make sure that all these factories are working in harmony together.

Tom Jones: Absolutely, perfect I love that answer, very thorough.

Dr. Tahany El-Wardany: Ok one more thing please, when you talk about digitization of manufacturing, you also need to talk about automation and interconnection. Because for digital thread, for example, you’ve been working with the digitization even by building these new technologies and models. Now the two things you need to make sure of, for example, when I talk about automation I’m talking, for example, you have the machine, it is working to build an
aerospace part. You need to have, also, inside the machine while it is building, in certain frequency you need to automatically collect data that you will be analyzing to ensure that your system, or the part you’re building is within the quality required. So, the digitization and the automation, automation is part of smart manufacturing, smart machines, and interconnection between the two. Because automation could be collecting data, automatically, you’re not interfering in it, and you’re sending this data for analysis, and there is some interconnection to get the results or the decision making to change the speed and feed, for example, without any interference from the engineer or without any interference from the technical people or technicians.

**Tom Jones:** That also makes total sense, so architecting the system to be able to utilize the technologies and actually realize value.

**Dr. Tahany El-Wardany:** Yes, this has to be the end usage.

**Tom Jones:** Yeah, I think you’re right. Yeah, I really like that answer. The next question mirrors the last one. So, there’s the factors that enable success but then there’s also barriers that cause companies to either not move forward or fail in their implementation. Can you identify any significant barriers to the Industry 4.0?

**Dr. Tahany El-Wardany:** Yes, first one is how good is the digitized, or the models you are developing or using. How well calibrated they are for different areas. How well, how smooth the integration of these different technologies on your machine. My advice in general, I don’t come with an idea, and I just think about it and I say OK tomorrow I’m implementing it this way, it will not work this way. You have to make sure that you already, thoroughly, planned the technology you are implementing. And thoroughly planned the methods you are going to develop for the digitization. And you have to try it and validate it completely before you do that. Before using any of this technology you have to validate it otherwise you are really, really going towards failing the implementation of the process. And I think this is, if you talk to anyone in industry, we spend lots of effort and funds to make sure whatever we are implementing is great, is correct, is working better. You’re gaining out of it something. I can’t spend ten million dollars in developing process. At the end I will get 5% advancement, there has to be enough planning to whatever manufacturing process you want to implement. And the verification, and the testing, otherwise I don’t think things will go successfully.

**Tom Jones:** That makes sense especially with new innovative systems where we don’t have just a road map to follow.

**Dr. Tahany El-Wardany:** Yeah.

**Tom Jones:** Perfect, ok I only have a couple of questions left. So, the next question is about companies quality management systems or work management systems. So, when it comes to implementing Industry 4.0, implementing the technologies, how does the organizations work management and the design of the organization impact success?

**Dr. Tahany El-Wardany:** Well, I think I won’t be exaggerating if I said you need, first, to get the confidence and approval of the management that this process is good. You know, when you do any research, you start first writing the idea, explaining it, and planning it. Planning it towards success, right, if you don’t have that how do you expect the managers who are going to say yes, we’re going to go implement Industry 4.0 and yes we’ll allocate a set amount of money for it? How will you get that if you don’t plan properly to make them see the possible benefits? And the willingness to support and fund the implementation.

**Tom Jones:** Yeah absolutely.
Dr. Tahany El-Wardany: And this is happening in everything. You can’t just go and say oh I decided to do that, and you don’t have any experiments to prove it works, the concept is ok. You don’t have any publication from other people, it doesn’t need to be your publication, that proves that smart factory is the way to go. So, you have to be making the proper plan. That people can find beneficiary to the industry, and they will support the implementation of it.

Tom Jones: Yeah, that makes total sense. Ok two questions left. These last two are very open, just purely your opinions and experience, more than the last ones even. So, second to last question is about what strategy would you use to, from the ground up, develop and implement a smart factory system?

Dr. Tahany El-Wardany: If I was going to use it. The first thing, if I’m transferring my factory or my lab to a smart factory technology. So, first thing, I have to study what is needed to make this place a smart factory. What is the target. You have to have an objective. When you’re talking about smart factory technology, what do you need? Do you need to reduce the energy used for manufacturing? Or do you need to enhance the quality of the part? Do you need to apply automation in a way that you reduce the production time, and you reduce the cost? So, this is a very important thing. For every smart factory you want to implement the smart factory to, you need to first study the factory, to study the people, and to start after that to look at the gaps that exist now in this factory. These gaps are the ones which are delaying or increasing the cost because we have increased scrapping, for example. So this is the first thing to do, you need to define you’re objective to have a smart factory. After that, right away this will direct you to what you need to make to have a smart factory. And after you studied very well you start to implement and while you are implementing it you need to do verification and validation of any new technology you are incorporating.

Tom Jones: Perfect. I like that answer as well. Ok so the last question I have is how would you describe success when it comes to digital transformation?

Dr. Tahany El-Wardany: Success for digital transformation, it could be obtaining the proper geometry correct, every time. Making first part and every part correct from first time. Reducing scrapping, reducing production time, reducing energy consumption, reducing tooling. If you increase the life of tools this means that you are reducing the cost and reducing the tooling that you are buying. Having a system which works, this is very important because you try it once you try it twice you try it three times it works, you come to the fifth time, something happens. When it happens after you start implementing it completely this means that you did not do a good planning and validation to the process before. So my success, I consider it a success if I promised my management that if we use this smart factory or Industry 4.0 on this process, we will never have scrap, we will always have high repeatability, we will always have the part geometry and surface within the spec. If I fulfil all these, of course I’m successful.

Tom Jones: Yeah that’s, that makes sense to me.

Dr. Tahany El-Wardany: Sometimes also success includes that your transformation from ordinary factory to smart factory is not going to be dragged and dragged and dragged and dragged. You will make all these transformations within a year. And after that it should give you what you want exactly, or within two years, and after that you will get what you want. In the same time, also, this success will never happen if you don’t train the people on the new technology.

Tom Jones: Oh yeah absolutely.
Dr. Tahany El-Wardany: So, this is what I think or consider success, I might be wrong but I think it should be this way.

Tom Jones: No, I like that answer as well. So that is all of my questions, so before I wrap up the interview portion, if there’s any important topic that you think I missed or just anything you’d like to add, or any clarifying questions you have for me, feel free, open floor.

Dr. Tahany El-Wardany: Well, I think you asked all the questions I’m thinking of, so if you have something else I can answer it.

Tom Jones: I’m glad to hear that I’ve got everything covered. So again, I really appreciate you contributing to my research with this interview.
Tom Jones: Again, I’ve introduced the research and the topic. So, on the topic of Quality 4.0 or the implementation of Industry 4.0 technologies if you’ve never worked with that specific quality 4.0 terminology. For my first question if we could just kick it off if you want to introduce yourself and give your background and your subject matter expertise on the topic?

Rick Burke: Sure, I’m Rick Burke, I’m a managing director at Deloitte in our smart factory offering. Been with Deloitte coming up on six years now. My background I’m an electrical engineer with a minor in computer science so I’ve always worked pretty much at the intersection of manufacturing and technology. Started out as a PLC programmer man machine interface developer back in the late 80s early 90s. Had an opportunity to get into SAP and SAP consulting so I’m moving kind of up the tech stack to the enterprise level. With a vision in the 90s of being able to connect the shop floor to the top floor, however in the 90s most companies were just focused on getting ERP in for Y2K and the technologies and the politics I would say, of around doing that were very strong headwinds. So, I did a lot of SAP manufacturing consulting work both for clients or working in internal roles. And then joined Deloitte to help them really think through their strategy around digitizing supply chain and one of our first big Industry 4 dot 0 projects I sold and led for a plastic packaging company. And a lot of that involved quality sensing as a very sensitive plastic thermoforming extrusion process, very sensitive. And so, deploying various quality analytic capabilities in order to increase their OEE and their yield. So, I’ve been in and around this space for pretty much my whole career, but some at the plant floor level and some at the enterprise level. And what I do now is work with clients to really think about their Industry 4 dot 0 journey, how to get started, where to hunt for value, what sort of technologies they need to be thinking about or acquiring. And really just help them shape their strategy, vision, roadmap, business case around the problems they’re trying to solve.

Tom Jones: Yeah, very nice I think that pretty much establishes you as exactly the type of background experience that I’m looking for with the subject. Again, I appreciate you participating, it’s definitely going to be a valuable contribution to my dissertation and my research.

Rick Burke: Glad to help.

Tom Jones: So, with that we can jump into topical questions. So I run through, I’ve got some high level topics and some guiding questions, if in any of my questions we hit a concept that you’re unfamiliar with I can define it for you, but again to not bias anything if you’ve got any familiarity at all with the topic I’d rather lean into your experience and your interpretation, because there’s no right or wrong answers it’s just your experience. So first up is the easy ones, technology. So, if we could start from your experience could you describe where the state of the art is with data collection and data analysis?

Rick Burke: Ok, wow, ok, it is kind of a broad question. Let me think about how to structure the response so. I would say first you’ve got to look at the level of maturity of the company right, we work with some companies that have zero operational technology infrastructure in place and we have to think about then what use cases are going to drive the most value and then what types of data needs to be collected in order to drive that outcome. In some cases, it’s having to put in a plant historian and “sensorizing” key aspects of their process in order to collect that data. And then be able to decide what sort of analytics you want to run on that data, what are the outcomes you’re trying to seek. And then really the most important thing is if you’re not doing closed loop
feedback is what’s that user experience for say the operator on the line to utilize that insight and take the appropriate corrective action in order to, you know, address a potential quality issue hopefully before it even occurs. So, but some clients already are well established; they’ve been collecting a lot of data. Obviously, there’s advantages for those companies. A lot of companies also have just tons of data, and they don’t know what to do with it so helping them think through, again, what data points are going to be most meaningful to drive the quality outcome they’re looking for and really decomposing their process to do that. And then, kind of the same story then right, what is that user experience. Is it a push notification to a cell phone, is it a tablet it, is it a high visibility display in the plant. You have to think through all those kinds of human form factors. Because at the end of the day it still pretty much requires a human intervention. What we can do is give them much better, earlier, warnings or insights to solving a quality issue. As far as the technologies that I’m seeing out there, I mean video analytics has come a very long way. It’s really quick value from an infrastructure standpoint when you don’t have to necessarily get into cybersecurity issues or adding, you know, new instrumentation on a production line. Running power, conduit, connectivity, and all that can be very expensive and very slow. What we’ve found is vision analytics, even if it’s disconnected and you’re doing offline, you know, non-real time analyses on certain quality datasets, can be very impactful. It at least helps you prove hypotheses to then justify making the investments in say the industrialized solution. And what we see is using video analytics, we’ve done it for like temperature control to make sure that the thermoform plastic sheets were coming out uniformly. All the oven temperatures, we’ve detected sensors being bad therefore it was skewing the quality. We’ve used video analytics to look at human performance and our operators or assembly technicians following the work instructions properly and being able to notify when the algorithms detect a misstep or an incorrect step. So, that I would say video analytics is kind of the hot area right now for a lot of the quality sensing and detection.

**Tom Jones:** Very nice, I’d like to pull a thread there. So, ok, this is a semi-structured interview, I didn’t super-specify that, but basically, I have guiding questions and then am supposed to act more like an auditor where I might follow up. But you hit an interesting topic with the video monitoring of the workmanship, is there any tricks to implementing something like that with the potential hesitancy or resistance for employees to maybe want to be on camera.

**Rick Burke:** Ha ha, yes and as you can imagine, unionized plants are even more challenging. But what we’re seeing is everyone is getting used to being surveilled, good or bad, right. It’s tough to walk down a street and not notice a camera. And so, I think we’re getting to a point where even with Covid, right, with social distancing and wearing monitors to make sure, you know, in a plant the people weren’t exposed, and then being able to trace that. I think that’s kind of helped get over some of that phobia. You know, and some of the video analytics have facial blurring, you know, capability. So, you may know who the operator is, but their facial, face and everything can be blurred out. And so, you know it is a fine area and I’m about to address this with one of my clients. We think there’s a strong use case for some video analytics to address a pretty significant quality issue they have in a manual assembly process. And that’s a conversation we’re going to have with them, right. Is it going to cause people to be less motivated to work and don’t want to be in a work environment that’s being surveilled, or do they not care and just want to, you know, get whatever improvement that they can through better training of how they’ve been taught may not be the best way because they may not have been taught to the work instruction. So that is an area that we have to navigate very carefully with HR, you know the HR departments, the cybersecurity
departments. But I think even if you’re an operators and you’re not on camera, your performance is still being monitored, right? How many units did you produce, how many of them made it through the next quality inspection. Now you’re just doing it through video, so its like is it really that different from a surveillance perspective?

**Tom Jones:** Yeah, that makes sense. Perfect, thank you. So, expanding on technology a little bit, the, one of the hot button topics is obviously automation, so with the data collection and analysis, what, where are the biggest opportunities for automation? What does the state-of-the-art look like specifically on the automation piece?

**Rick Burke:** Physical automation?

**Tom Jones:** Data automation, sorry.

**Rick Burke:** Can you define what you mean by data automation?

**Tom Jones:** So, let’s see, an example might be…

**Rick Burke:** Are you talking about like edge vs cloud or?

**Tom Jones:** No, I mean, so, gosh. If I went to the gym and a heartrate monitor estimated my calories instead of me manually tracking how long I worked out for. Does that clarify?

**Rick Burke:** I believe so. So, you know, what we often find in, really, I kind of have to think about it between process and discrete manufacturing. Process has been collecting a lot of just raw data for decades. And the data automation there is pretty mature I would say. Discrete is different, you know, some companies have a manufacturing execution system, many may have some home-grown systems. I’m finding that they’re playing a bit of catch up in terms of that use of data to drive outcomes. And so, if I think about it, I’m trying to give you a clear answer because it’s a bit of a difficult question. I mean, right now a lot of, there’s two philosophies I would say, one is just collect everything and either keep it on prem or push it to the cloud. And then what I think we’ve been finding is that’s not the best answer, like data lakes were a huge thing, now you don’t really hear people talk about data lakes anymore. That was just an idea, throw everything in and then magic was going to happen, value was going to fall out of the sky. Now people are realizing that it has to be much more targeted and some things you need to be able to process at the edge, due to real time decision-making resiliency, things like that. Others are what you could push, less time sensitive information into the cloud and run your analytics up there and then push the insight, you know, back down to the edge. That’s really getting into a lot of real architecture questions and use case specific solutions for those, so it’s a little bit difficult to answer in that regard, but like one of the video analytics partners we work with, you know, it’s a cloud based platform so using 5g we can set up a camera quickly and start pushing the video images to the cloud and then training the models on what good looks like and what bad looks like. And start doing pattern detection. So that’s just like one example of, kind of, data automation that we’re seeing, especially around the quality space.

**Tom Jones:** Awesome, and just to clarify real quick. With the models behind the video systems that you’re talking about, machine learning models?

**Rick Burke:** Yes

**Tom Jones:** Ok I thought so, but I didn’t want to…

**Rick Burke:** But not unsupervised, right, there is a supervised training required of those models.

**Tom Jones:** Ok perfect, yes, I didn’t want to make that inference without clarifying it when I analyzed your responses. My last technology question is: if you had to pick which technology or
maybe a couple technologies have singularly been the most impactful on quality over the last five years which ones would you pick?

**Rick Burke:** I think it’s going to be your traditional historian, or MES, that’s collecting process and operator data. It’s not really something over the last five years, it’s been around, but we’ve seen tons of power in that. Certainly, evolution of edge and cloud has been instrumental. And I think a focus on, I keep getting back to it, is the user experience, and making sure that whatever the medium is that you’re interfacing with an operator or a quality supervisor, what have you, that they want to use it, right? And we’ve just seen so many companies try to implement things without really addressing, and this is not, maybe this is part of the future discussion but, you know, really focusing on the human and the change management aspects of these capabilities, versus a traditional IT project or OT project gets screwed in and then no one wants to use it. So, I would say edge/cloud architectures and process historians and obviously just the advancement of machine learning, AI/ML capabilities are, a lot of R, Python being used out there, a lot of open source. I think that’s the other kind of cool thing is just the amount of open-source data or algorithms that are out there. I kind of find it interesting, everyone thought we were going to have a shortage of data scientists, but now we see that the data scientists aren’t really needed because of other advanced process capabilities are coming out by different startups and, you know, it’s kind of interesting that I haven’t seen clients scrambling now to get data scientists.

**Tom Jones:** That is interesting, awesome. Ok so that wraps up my technology’s questions. The next two dabble into a couple of other Quality/IE concepts so this is where if you need anything defined just let me know. So, the first one is: do you see a relationship between Industry 4.0 and the digital transformations and Lean manufacturing.

**Rick Burke:** Oh 100%. Yeah, I mean our perspective is that the traditional lean six sigma capabilities are still pretty essential for a manufacturer to lean out waste in their processes, but we find that that’s kind of incremental returns over time, whereas when you start introducing Industry 4 dot 0 capabilities you really start getting step change performance improvements that, quite frankly, shouldn’t plateau. If there’s a good strategy and vision on what a company’s trying to achieve. So, as they kind of evolve their maturity with using these technologies, the value creation should continue to go up where a lot of our clients that have been doing lean been on a lean journey for years, it’s a fifty-thousand-dollar improvement here or a hundred-thousand-dollar improvement there. Where another client we’re trying, we were able to move their overall equipment effectiveness up 9%, which gave them fifty million in incremental revenue. You know, so that’s kind of our perspective on how Industry 4 dot 0 and lean they need to coexist together. Layering in tech, Industry 4 dot 0, on sub-optimized processes is usually a bad recipe, and when we see clients that have failed, we often see that they think there’s an easy button with Industry 4 dot 0 that makes it that they don’t have to go fix all their broken mess. So, and that just doesn’t exist.

**Tom Jones:** Yeah, no that makes sense. Ok, perfect, great answer nothing to elaborate on there. Next question is same question if there is a relationship between the 4.0 and total quality management?

**Rick Burke:** Yeah, I mean again I think TQM can be great, can be improved using Industry 4 dot 0 techniques. You know if I look the automotive industry, right. They’ve been doing a lot of work around Industry 4 dot 0 and TQM that, you know, arguably has raised the quality of US car manufacturing over the last couple of decades. So, much like lean I kind of see them as
inextricably linked. A lot of our clients honestly don’t really have solid TQM programs. They may have a quality department, but they may not actually be a very mature TQM organization. And I don’t know I’m not the deepest expert on TQM, but I would say with my clients I’m starting to see them, if they have the lens they want to be able to start integrating, you know, real time insights into the lens as opposed of being an after the fact quality inspection. And that’s kind of one thing that I’m seeing more and more of right now is, one needing a lens and two, getting it connected with real time, near real time, data and actually start doing a bit more prediction versus offline testing.

**Tom Jones:** Gotcha, yeah that makes sense. Ok so those were my two questions about related methodologies. The next few are a bit more open ended and definitely lean into your experience the most. So next when it comes to, I want to focus on the, when a company goes to implement an industry 4.0 strategy, what are the biggest factors that lead to success in implementation and how do they have an impact?

**Rick Burke:** Ok, so first is a culture of being willing to experiment and be more of an agile based organization, so the idea of failing fast, learning fast, is important. I think a culture of embracing data and analytics versus human intuition is critical. I think having IT and OT alignment, and I think just a foundation of technology, you know whether it’s in the plants whether it’s WIFI or its connected. Making sure that you’ve got that backbone to build this on and a company willing to invest in that infrastructure without actually a business case, right. Because you can’t bake some of these investments on a single use case in a single plant. You have to think more broadly about what are those enabling technologies that you’re going to need to support really any Industry 4 dot 0 use case. And then having a plant that is willing to be a leader within their organization and invest the time and the people and even the production capacity if you need to run, take some downtime, or run experiments on a line. Those are many of the things that I’ve seen. Usually what doesn’t work well, or I would say it pops down ownership, so if you start with, whether it’s the CEO, CFO, CTO kind of championing the program versus it being an innovative electrical engineer working in a plant on a single use case that’s not attached to any real strategy or vision and it’s not scalable. You know, there’s a lot of great ideas that emanate from the plants, but they often don’t get adopted broadly because it’s just disconnected from kind of the enterprise vision.

**Tom Jones:** Gotcha. Ok perfect, sorry about the dogs barking there, I think they thought someone was at the door. The next question kind of mirrors that one, but I think it helps to frame it from both directions. But what are the biggest, when a company wants to implement but either chooses not to move forward or tries to implement but fails, what are the biggest barriers that cause those two situations?

**Rick Burke:** Yeah, I mean it truly is the converse of what I just described. You know, I would say what we’ve seen a lot of clients do is what we call random acts of digital. Very, people obviously are very interested in working with these technologies and, you know, leading it in their organizations, but if it’s not really driven with an enterprise vision, strategy, and roadmap, it just, like I said, becomes just random acts of digital. Doesn’t get the right sort of budgeting, doesn’t get the right prioritization amongst all the different things that an enterprise could be doing. You know plants already have their plans so how do you fit this into to something that they may not have seen coming. User adoption is a huge one, I’ve mentioned that a few times, just really thinking about that user experience and that interaction model that, you know, is going to drive the most value. Not being able to manage or, identify and manage, an ecosystem because Industry 4
dot 0 is really about an ecosystem play. Whether that’s service providers or technology providers
a lot of clients just aren’t very sophisticated in having to manage that, that’s fairly new to them.
And there’s such, just a wide variety of capabilities and startups that, for them, how do they
constantly scan and monitor, you know, the capabilities that are out there. I think that’s another
reason why they tend to fail is just poor ecosystem management. And then lacking of a value case
or a business case, right. In being able to measure value over time to show that these are actually
making, contributing real value to the organization.

Tom Jones: Yeah, that all definitely makes a lot of sense. So, from success factors and barriers
my next question is: if you were architecting a general strategy, because I know you already
touched on the fact that there’s a case-by-case element that depends a lot on the context of the
specific business, but a general implementation strategy for industry 4.0 technologies, what would
that look like?

Rick Burke: Well usually what we would do is, first we wouldn’t necessarily go in with an
Industry 4 dot 0 strategy, right? We would really start and look at what are the business problems
and the business outcomes that they’re trying to achieve. Those will often be solved through both,
what I like to say, analog and digital capabilities. Analog being, you know, just human interaction,
kind of process improvement type things. And so we’ll start really from the beginning of what a
client’s trying to achieve, and depending again on where they are in their maturity journey we’ll
figure out where they are today from across all the ten to twelve business functions within
manufacturing. Kind of also looking at the in bounds and out bounds, so the hand offs from
engineering to manufacturing, manufacturing then to distribution, planning, scheduling, quality,
maintenance, people, IT, OT, technologies. So that’s kind of like at a plant level, kind of just
understanding where they are today and where they aspire to be and what are those kind of analog
and digital capabilities that align to that journey map. The other is working very early with the
executive team to really even understand what their, in their minds what definition of Industry 4
dot 0 or digital is, because it means so many things to so many different people that it’s often
helpful for us to interview the stakeholders individually and get a perspective. And then from that
help shape a draft vision for the organization, and that’s usually done through like a workshop
process. And then from there we start laying out, once we understand kind of where their value
drivers are and where they are from a maturity perspective across those different business
functions, and we start laying out what are the, you know, the best opportunities based on a kind
of value and effort perspective. Like a two-by-two matrix oftentimes. And just saying look, I
mean this may be a really hard one to tackle, maybe you’re not mature enough yet for it so why
don’t we start with something that’s a quick win, right? Well client’s love quick wins and so, we’ll
prioritize from that and get agreement on that and then flesh out what the roadmap is including all
of the enablers required, whether it’s people or infrastructure, things like that. Kind of like mini
project charters I would say. That’s kind of our kind of approach to things. Kind of a classic
strategy approach, it’s just now it’s the opportunities that we generate from those analyses could
be more of an Industry 4 dot 0 play than others.

Tom Jones: Nice, I like that answer. The overall, the macro viewpoint there of where Industry
4.0 fits in with business strategies is much appreciated.

Rick Burke: Yeah, no I mean, I think clients get in trouble when, again, I think they think that
digital is an easy solve for bad business practices. And often we find, well you know what you
really do need to go on a lean journey before you go screw in these capabilities, right? Because
then you’re building on quicksand. And we as a firm, we usually get a little bit nervous, and I get nervous, when a client wants to only talk about advanced capabilities or Industry 4.0 because often, we find that there’s a lot of low hanging fruit just through the analog work before they can really take advantage of the digital work.

**Tom Jones:** Yeah, for sure for sure. Definitely good insight for my dissertation. Very last research question: so, when you do work with a company and the situation does call for digital, what are the hallmarks of a successful industry 4.0 implementation? What does success look like?

**Rick Burke:** Yeah. One is obviously obtaining the business case, first and foremost, but that requires, you know, stable systems, easy usability. And then what we see is the next plant, or the next department, starts asking for it, right? A lot of this is done to plants, I think success to me is when everyone starts clamoring for that capability. And because they know that it’s going to help improve their operations. So I’d say those are probably the biggest, just employee satisfaction, employee experiences, achieving the value case, and generating a pull versus a push on the capabilities.

**Tom Jones:** Yeah, absolutely that makes sense. Nice, ok, so that wraps up all of my structured interview questions, but before I wrap up the actual data collection interview portion of our conversation, I’ll just open up the floor if there’s anything topically that you think I didn’t ask about that’s worth saying or if just anything you’d like to add, feel free.

**Rick Burke:** Nothing comes to mind. To be honest I think one thing to point out though, now that I think about it around kind of technology, one challenge we’re seeing with our clients is what we call OEM lock up. Which is basically, you know, they are unwilling to expose the data in their PLC or HMI to allow us to extract that data and use it in a meaningful way. And sometimes they often are trying to monetize that, which creates complexity obviously and can delay things pretty substantially if those risks aren’t addressed before starting one of these projects. So, it’s kind of an important thing and some reasons why we use alternatives like video that are non-invasive and we don’t have to then go in and muck with a PLC program or an HMI database to get that information.

**Tom Jones:** Yeah that’s, the data landscape out there definitely, I think will be a huge topic moving forward so that’s a good addition.
Dr. Elizabeth Cudney Interview 12.19.2022

Tom Jones: There we go, should be recording. So again, I’ve introduced the study purpose, I’ll introduce the topic of Quality 4.0, which is the application of digital Industry 4.0 technologies towards achieving quality goals, as I’ve got it defined for my study. Those quality goals can be process based, not just quality of a product. So really whatever a company would scope their quality performance goals into is an appropriate application for my Quality 4.0 definition. So, with that we can jump right into the questions I’ve go. First one being; if you could introduce yourself with your background in quality and related to Industry 4.0 technologies.

Dr. Elizabeth Cudney: Awesome, my name is Beth Cudney. I’m a professor of data analytics. From a six sigma standpoint I went through the six sigma black training in 1998 so I’ve been a six sigma black belt since 1998, and then a master black belt since, that’s a really good question, probably at least fifteen years now. So, I was in industry for ten years, in automotive mainly manufacturing, then went on for my doctorate and I’ve done six sigma, lean and six sigma projects in healthcare, service industry, automotive, aerospace, just about any industry pretty much. And then my research heavily relies on six sigma but, I don’t know what else to kind of add about that but, so over about twenty-five years, over twenty-five years of experience in the area.

Tom Jones: Very nice, definitely I think a valuable perspective for the study then. Ok, perfect, so my first few questions I kind of have high level themes that I flow through. The first few are technology focused, very Industry 4.0 questions. So, if you could, questions one and two are pretty similar. From the work that you’ve done can you describe the state of the art as it comes to data collection and data analytics?

Dr. Elizabeth Cudney: Good question. So, the first part was data collection, correct? Yeah so, I think now, especially with big data, one of the key things we’re seeing is there is so much data available. And so, we’re really switching from more of the, well some industries still do it, the paper and pencil, writing things down, to all the automatic upload. And so, from a data collection standpoint it’s almost an, to some extent, overload of data that we’re dealing with in some instances. And so, I don’t want to kind of jump ahead in case you have this question later, but, tons of data, but what I’m seeing is it’s very easy to get the data but not everybody now understands where the data’s coming from with data analytics, and kind of everything being automatic, the upload, and collected for us. So am I getting ahead or is that kind of still where you’re going?

Tom Jones: No, you’re great, if you answer a future question I’ll just adjust.

Dr. Elizabeth Cudney: Ok perfect. So what I’m seeing now is because there’s so much, in kind of the state of the art everything’s being collected for us, that we’re losing key aspects of six sigma to some extent. One is because I don’t think people are as familiar with the data because they’re not out there having to collect it and be so personally involved within the process. And that ties into the data analytics side as well too, because data analysts are often given data and told to kind of go analyze it, go look for trends. But what’s happening in the Gemba, on the shop floor, wherever the data’s being collected, to where it’s being analyzed and scrubbed for trends and everything else, there’s kind of a disconnect in my mind that I’m seeing more and more. Yeah. So that’s kind of the big thing from more of the data collection side of it. From the data analytics part of it, we’re starting to get more and more away from a lot of the software packages that we’ve been able to use in the past because of the massive amounts of data that we have. So from the data analytics perspective six sigma black belts are having to use coding more and more, whether its
writing SQL code, to they’re pulling information from various databases and tables so they can really pull that data together. And then more and more with writing code whether its in R or Python so that they can analyze the code a lot better, and getting away from, whether it’s Minitab, SPSS, whatever software package they might be using. So, I think trends are going more and more, and going to continue going more and more, into the coding side of it.

**Tom Jones:** Very nice, that’s, I like that answer, I kind of want to circle back to the data collection part where you hit the Gemba concept. That follow up question about Gemba had already popped into my head before you said Gemba. So essentially with that there’s a challenge that you’re seeing where being further away from the Gemba is driving different organizational understanding and behaviors around process management?

**Dr. Elizabeth Cudney:** Yes, and for example last week I was in a company where they did all the prototyping in one site and all their manufacturing other places, and so they’re getting data, whether it’s from the prototyping processes that they have and they’re hoping it’s going to match what’s out, actually, in their factories, or they’re getting information from they’re factories where they’re not at. And there’s just something so valuable about still going to the Gemba, seeing what’s happening in the process, and you’re, they’re missing that, right. So when you’re looking for root cause analysis, what all could be happening, and I don’t have any data whatsoever to prove this at this point, but my feeling is from little bits of information that I’ve seen, is that if you were to have created a cause and effect diagram six years ago even, or five ten years ago, it would be very different than what we’re creating now, because we’re not out there actually seeing it we’re trying to do this in so many remote locations that we’re not really living and seeing the process. And that’s really impacting the process improvements that we could be implementing. I mean just the cultural side, working with people, everything else.

**Tom Jones:** For sure, I like that insight. Ok, so, data collection and analytics, my next question technologies wise is what are the trends that you’re seeing with automation, from the digital automation specifically?

**Dr. Elizabeth Cudney:** So, I’m seeing a lot more with machine learning that’s being implemented within the systems in terms of process controls. I’m not seeing much in terms of issues with that, which has been nice. However, what I have seen more and more is there’s still a lack of understanding of how that works. There might be one or two people within the organization that kind of know and understand it but the rest are still novices in terms of it and they don’t understand the nuances of machine learning, what it’s really doing, how it works, and so there’s kind of that buzzword that’s out there without much understanding whatsoever. And I think, in some instances, it will probably cause, that confusion, will cause more issues and also since only a handful of people, or a couple of people within the facility that truly understand it, it’s kind of like that tribal knowledge to some extent that if something happens within those individuals, systems that have been set up will go away if those people leave the company.

**Tom Jones:** Gotcha, yeah that makes total sense. The tribal knowledge there, you’re the first person to hit that buzzword, but it’s an insightful answer I think.

**Dr. Elizabeth Cudney:** And I think part of that as well goes to, it’s almost like a black box, and the good thing about having, if we’re talking about neural networks or anything else, it’s kind of like a black box, that calculations and people don’t understand how neural networks work. Many of the six sigma black belts I’ve seen at companies have come up through so many different areas, and even people out there giving training on six sigma, so their backgrounds not necessarily in...
engineering or anything technical. So, there was already a struggle sometimes with understanding some of the advanced calculations, or the statistical analysis when you’re getting into hypothesis testing or design of experiments. Now you’re adding in tools like machine learning and predictive analysis that is going to require people going through those programs to have a whole nother set. So when you’re trained on the DMAIC methodology, you’re not coding typically, so now with big data you’re really going to have to still pick up all those skills in SQL, R, Python, data visualization so there’s Tableau, Power BI, and so there needs to be some sort of boot camps or something to go along with that to make sure that people can understand that data and how to represent it in a meaningful way. And I think that doesn’t happen, meanwhile there’s so many free resources out there that you can go to. Stack overflow, whatever that it may be, lots of blogs and websites out there and it becomes another black box if you’re pulling down somebody else’s code trying to make it work for your data, and you don’t really understand what random forests are, or whatever type of statistical tool that you’re going to be using. So it’s junk in junk out.

Tom Jones: Absolutely, yeah. No that makes total sense. So, I think that, what you’re talking about there, we’ll expand on in one of my next round of questions. My last technology question, to close off that topic, is from the work that you’ve been doing, which Industry 4.0 technology or technologies do you think have had the greatest impact on quality over the last five years?

Dr. Elizabeth Cudney: That’s a really good question. I’d almost say, and I don’t know specifically how I would put this in a bucket, but something around data accessibility and data visualization, where we’ve got our dashboards and our monitoring that we can track and see what’s happening no matter where we are. So, I think just the visibility from that perspective has been tremendously helpful. Where we can have our key performance indicators and our KPI boards somewhere else that we can see them and track them and whether I’m at a facility, whatever state, wherever in the world, I can see what’s happening. And so, I think that made a huge difference just in the accessibility standpoint.

Tom Jones: Nice absolutely. I, yeah you’re the first person to give that answer, but I think I know what you mean, trying to distill which technologies that falls into, but that’s kind of the nature of the fourth industrial revolution more than the previous ones is that this is a death by a thousand cuts stack up of technologies that’s led to revolutionary change whereas steam power, electricity, and programmable logic were one major thing. So I think this is a difference and that answer makes sense with the nature of it.

Dr. Elizabeth Cudney: Yeah, and to me thinking back to twenty years ago, when I was still in industry. If I wasn’t in the facility, I didn’t know what was happening unless somebody called me. Now I can be working from home, and I know exactly what’s happening with all production lines. I can see everything. And it’s probably, the internet helped with that, but there’s just better data visualization aspects of it as well too, and real time data.

Tom Jones: That makes sense. Ok, perfect. Next two questions, I’m excited with your expertise because I’ve had to clarify some stuff on these ones for other people, I don’t think I will have to with you, first one is; can you describe any relationship between the Industry 4.0 digital transformation and lean manufacturing?

Dr. Elizabeth Cudney: So, Industry 4.0 and lean manufacturing? I mean absolutely, so we’ve got all this data and we can use it all for creating our value stream maps. Gosh I mean just the flow of information, so coming over the value stream map I would still want to go out and watch the flow and make sure I’m seeing things but the type of data that I would have would be much
more accurate and representative, versus what I was doing before which was going out and timing ten parts in a row. Gosh, I mean SMED I’d have all that data. Just from the data perspective, absolutely there’s so much more that could be done, and with all the sensors on my equipment, from the timing perspective is as an industrial and mechanical engineer, that would make my life so much easier in terms of doing the lean process improvements. Having that data readily available, so there’s absolutely. And then back to data visualization, even with how things are happening within the processes and machine learning, when something goes wrong from a lean perspective there’s still waste, which are defects. So I know exactly what’s happening. All the sensors when it comes to total productive maintenance, taking care of my equipment, knowing when it’s time to change the oil, or vibrations on belts. Just from the sensor technology alone I can, my maintenance is going to be so much better. Yeah, I mean, I could probably give you an example for every one, but yeah there’s definitely a clear linkage.

Tom Jones: So with the, you hit a few different tools and the defects waste there, would be it accurate to say that Industry 4.0 makes it easier to measure what we have to observe experientially from lean?

Dr. Elizabeth Cudney: Absolutely.

Tom Jones: Ok that’s kind of what I was pulling out of there as a theme.

Dr. Elizabeth Cudney: You said that much better than me.

Tom Jones: No, you articulated it really well and I was just hearing you can measure Gemba, you can measure TPM, you can measure, so that makes sense.

Dr. Elizabeth Cudney: Absolutely, yeah, and visual management I should have all my visuals on everything. Bells and whistles telling me what’s happening. 5S I might struggle a little bit more with but, I mean you have everything there so everything else comes together you just have to worry about a nice clean environment, having everything organized and clearly labeled.

Tom Jones: Yeah, next questions really similar to that one; do you see a relationship with Industry 4.0 and total quality management?

Dr. Elizabeth Cudney: I do. From a total quality management perspective, it’s more about how do you manage and focus on what’s important right. So using that information, your pareto charts are always updated with what’s happening, you know even down to tracking production, understanding what’s happening within your processes for process improvement, yeah absolutely. You know I might, when I hear TQM, often times go to Deming’s fourteen points. And I, so in my head I kind of keep thinking about how empowering employees, understanding what’s happening within their processes, it’s much easier for them to understand what’s happening as well and take action. Yeah, so absolutely.

Tom Jones: Very nice. Ok perfect, so my next questions are more, definitely they start to get more subjective, so no right or wrong answers for sure. Next up is success factors and so; could you describe what factors have the biggest influence on whether or not a company can successfully implement Industry 4.0 technologies, go through a digital transformation, and how they make a difference.

Dr. Elizabeth Cudney: I think the biggest one is probably going to be something around training. Making sure people have the right training. And probably even before that, honestly, looking at what type of systems that they have and what systems need to be set up. So, hiring the right personnel, the right people that can come in and say based on the type of data that they have how are we going to store it, how are we going to systematically kind of link all of our systems so that
we have that data that’s easily accessible. So oftentimes that’s going to start with more of the IT, somebody that’s a nice conduit between manufacturing and IT from that data perspective, because we’re going to be creating a lot of data lakes with all of the data that’s being collected, and then more of the data science people and someone from the, I think it’s going to be the six sigma, lean six sigma black belt, is going to have to be more of the data analyst that’s still going to have to be able to pull that code, I’m sorry pull that data by writing whatever code they need to get the information that they need. So, management is going to have to have enough of a foresight to understand that this is not going to happen overnight whatsoever. It’s going to be a fairly large investment, not only from understanding and the amount of sensors that are going to be needed, putting the systems in place, but then also training people. So I feel like in some instances it’s almost like what a lot of organizations went through in the early mid late nineties, in terms of the waves of black belts that they sent through training to get that basic understanding and knowledge of six sigma. We’re going to need that but also from the data analytics side, where they understand how to pull the information, use it, and then run the analysis that they need.

**Tom Jones:** For sure. Yeah and this was where I was referencing in the interview with the employee skill as a topic that would fit in with this question pretty well.

**Dr. Elizabeth Cudney:** Absolutely because I don’t think this is anything that, with current academic programs, I don’t know that there are many, if any, that are graduating say with an undergrad, that would be able to do this. They’d have some basic coding skills, all engineers take some, they might have a basic understanding of six sigma or just quality in general, they might have a good statistics knowledge, but this isn’t somebody that comes out of any program right now, I think, ready to hit the ground running. It’s a combination of skills from different places.

**Tom Jones:** Yeah, I would agree with that 100%.

**Dr. Elizabeth Cudney:** So, it’s going to be interesting, and I think management sometimes, and leadership, just think there’s a quick fix to it. And we can send people through training, but if we still don’t have the right people in IT, so there’s going to be a lot of work that goes into this.

**Tom Jones:** For sure. My next question mirrors that last one, so my next question is; what are the biggest barriers to a successful digital transformation, and it’s, it mirrors the last question but there tends to be some things that we think of as we need to do this to succeed and some things that we think of as this is a huge road block.

**Dr. Elizabeth Cudney:** I, and I don’t think this is quite the answer that you’re after but I’m going to say it and then we can go from there. I think we’re going to find that there are a lot of people, six sigma professionals out there right now, that with where we’re going with Industry 4.0, Quality 4.0, that are not prepared whatsoever to work in this new space. And I think there’s going to be a lot of quality professionals that will struggle because they came up through varied backgrounds. I see a lot of people that are master black belts that have been working in industry, in training, but they focus more on the cultural side, they don’t really even get into statistics, much less the coding side. So, I think one of the big barriers is going to be that we might have a much smaller workforce, and I’m trying not to be too biased as an engineer, but as an engineer most degreed engineers have enough of a statistics background, a mathematical background, and a coding background, that this isn’t a huge hurdle for them. But individuals coming up from the softer side and from humanities that have been able to be very successful in the lean and six sigma world now, from the cultural side, I think will struggle to really, to make that transition. Unless they really go back and do some pretty advanced training on statistics and software and coding.
**Tom Jones:** No that makes sense.

**Dr. Elizabeth Cudney:** Yeah, so I unfortunately think it’s going to make a big difference in how many people are out there and available to do it.

**Tom Jones:** So essentially, there’s a, we’ve got a huge focus on that the workforce needs to adapt and, I think you touched a little bit on the leadership commitment so there should be some facilitation of that adaptation?

**Dr. Elizabeth Cudney:** Yeah absolutely, yes. So barriers, cost, the people side not having the proper backgrounds, absolutely so leaderships going to have to make another kind of big commitment like they did with six sigma. That wasn’t cheap training at that point, and now, meanwhile the cost of a lot of things have gone down, and actually R and SQL, well R and so many things are free, Power BI is free. So there’s a way to do a lot of this with open source which is good, but then we also have to be careful of how much it’s going to cost to have the training for people to bring people up to speed. And then the cybersecurity aspect of it of making sure that when we’re pulling things down from wherever we’re finding code that it’s doing, there aren’t any bugs.

**Tom Jones:** Absolutely. That’s a good answer as well the cybersecurity. So, my last two questions are the ones that are the most heavily your experience, subjective. If you had to recommend a digital transformation strategy for a manufacturing company, high level what steps would that entail?

**Dr. Elizabeth Cudney:** And this would be like an overarching if I had so a two-to-three-year strategy I could roll out?

**Tom Jones:** Yeah, I think you could set whatever timeframe you think would be appropriate to advise.

**Dr. Elizabeth Cudney:** That’s a really good question. So with anything I usually like to start with kind of baby steps so things aren’t that intimidating. And probably have things happening in parallel. So one of the first things I would probably do would be to get people on board with software such as power BI for data visualization just because it’s a nice stepping stone in terms of learning new software, getting people comfortable with learning new software, that ties in very nicely with different software packages. I would have my IT group kind of in parallel, starting to look and working with the six sigma black belts who are at a facility, on how to start getting some data upload if it wasn’t there already. Most organizations are in pretty good shape already, where I see a lot of organizations struggle is where they’ve got these data lakes, but they haven’t put the thought into how the information is collected, how it’s stored, how to make it user friendly. So I would probably have some sort of team, for lack of a better word, that would start looking at data storage to make sure that it’s secure but that we’re also collecting data in a way that’s very useful so that we could use it for any sort of process quality improvement aspect. And if there were any gaping holes in terms of that, getting IT on board to make sure that we’ve got the appropriate systems in place. While there’s the sensors available there’s still so much that’s been missing, so trying to figure out with that kind of effort and that team to see how to best support six sigma projects in terms of data collection and so that the IT people are on board, and then start some training for those individuals that, they get the power BI training they’ve gotten their feet wet with that, but then start rolling out something such as SQL to how they can pull data for their reports. Building their own databases, tables, whatever they need for their data and kind of start that route. Then I might get into probably R or Python, whichever, so we could start using different, and
probably Python is more industry friendly in terms of the coding. Kind of rolling that out as the next wave again, so that it’s not so much of a struggle. But I would have some sort of overarching plan as well, too. So, what companies did, you know the master black belt, the black belts, the green belts, how would I get everybody, to start getting everybody on board with the data and data usage. So, getting people and being very intentional in terms of selection so that we’re permeating all the different business units so I have someone in each one that can really help people with getting the data that they need.

Tom Jones: Gotcha, so iterative upscaling while laying a cultural foundation.

Dr. Elizabeth Cudney: Yeah. And then people are going to be afraid of learning how to code so that’s going to be something that we have to slowly roll out in waves so that it’s not overwhelming.

Tom Jones: For sure. That makes a ton of sense. And there’s the culture and the skills pieces there that you’re balancing, and I think, so from that answer it sounds like you’ve also recognized that a lot of companies maybe don’t have the data use culture in place already?

Dr. Elizabeth Cudney: No, I mean certainly companies have gotten a lot better, but not everyone within the organization has access to the same amount of data and there’s going to have to be some level of data transparency when you’re running this or else there’s a lack of trust with how people are seeing this new transition. And the culture part of it also is, it depends on everybody, but there will be people, regardless of age within an organization, that will see this and be not accepting. Within any initiative you’ve got people that are going to jump on board, people you can pull along, that goes back to, I’m forgetting his name, he's a Harvard psychologist, I think.

Tom Jones: I know what rule you’re talking about, and I also don’t know his name.

Dr. Elizabeth Cudney: Yeah, you’ve got those people that are just going to be, I’m out what can I still do where I don’t have to write in code, I don’t have to do anything. And there’s going to have to be a strategy on how to do that. And it might be just to let them leave, but there might be also to kind of reinvention the workforce. And their roles.

Tom Jones: Yeah, for sure. Ok nice, I like that answer, it’s very thorough. I have one final pre-planned question, which is so digital transformation strategy, at the end of that what does Industry 4.0 success look like?

Dr. Elizabeth Cudney: That’s a great question. Everybody has access to all the data they need to do their job effectively. It’s right there at their fingertips. It’s a transparent organization, you know what’s happening. The metrics tell you; you’ve got your metrics that are linked to the strategic goals, and you know exactly how everything’s running and what needs to be done. You’re not searching for data and information.

Tom Jones: Very nice. And to clarify when you say that people can use the data effectively?

Dr. Elizabeth Cudney: Hopefully that’s where they would be, everybody would be well versed in the software, and they would make data driven decisions.

Tom Jones: Ok that’s what I was getting to, data to drive behavior.

Dr. Elizabeth Cudney: Right, yes.

Tom Jones: Perfect, I like that answer as well, granted, whether I like it or not that’s my bias. So that’s all of my planned questions, but if there’s anything big with the Quality 4.0 or Industry 4.0 topics that you think I’ve missed or just anything that you’d like to add, open floor.

Dr. Elizabeth Cudney: I can’t really think of anything else.
APPENDIX B:

IRB APPROVAL LETTER
NOT HUMAN RESEARCH DETERMINATION

October 19, 2022

Dear Thomas Jones:

On 10/19/2022, the IRB reviewed the following protocol:

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<tr>
<th>Type of Review:</th>
<th>Initial Study</th>
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<tr>
<td>Title of Study:</td>
<td>A Conceptual Model for Quality 4.0 Deployment in US Based Manufacturing Firms</td>
</tr>
<tr>
<td>Investigator:</td>
<td>Thomas Jones</td>
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<tr>
<td>IRB ID:</td>
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<td>Funding:</td>
<td>None</td>
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<td>Grant ID:</td>
<td>None</td>
</tr>
<tr>
<td>Documents Reviewed:</td>
<td>• HRP-250-FORM- Request for NHSR.docx, Category: IRB Protocol; • interview questions.docx, Category: Interview / Focus Questions;</td>
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The IRB determined that the proposed activity is not research involving human subjects as defined by DHHS and FDA regulations.

IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities are research involving human in which the organization is engaged, please submit a new request to the IRB for a determination. You can create a modification by clicking Create Modification / CR within the study.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Kristin Badillo
UCF IRB
REFERENCES


Jacob, D. (2017b). What is Quality 4.0.


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