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The Change Management Process for Automation Implementations

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THE CHANGE MANAGEMENT PROCESS FOR AUTOMATION IMPLEMENTATIONS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Mechanical Engineering

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by
Nicole K. Zero
May 2020

Accepted by:
Dr. Joshua D. Summers, Committee Chair
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ABSTRACT

The objective of this thesis is to identify change management processes in manufacturing and, if they exist, identify challenges and opportunities for improvement. There are many changes encountered in manufacturing as the advances of automation are integrated within production. For this reason, a change management process is required to effectively and efficiently implement these changes.

To research this, a case study was conducted at a large manufacturing firm (more than ten-thousand employees). The facility studied produces low volume (~one per week), high complexity (~million components) products. The case study spanned six months, in which sixteen interviews were conducted with nine people from three different functional groups. The case study focused on a change to production, which was an automated machine that was implemented in the facility. This was not a change to the product, but a newly configured production station resulting in a decrease in automation level (bringing more manual activity into the task). The previous manufacturing method was fully automated but was not robust. Therefore, the change was to increase the human-robot cooperation in the robotic system. This study investigated the change process for this newly implemented automation.

This was identified as a good case example to study due to several reasons. First, this was implemented within the past five years, which meant that people involved in the change process were still present. In addition to this, since the machine was still in operation it meant the propagation effects were stable and the changes were kept. Another reason this was a good example, was because this was a large-scale investment (~million dollars). This meant the return on investment (ROI) was high, leading to more attention to detail and higher resource allocation. From a research perspective, these reasons ensure the process was a critical case for study.

Many change management processes align with the following high-level process: identify opportunity, gather approval to find a solution, form teams to solve, discover a solution, review, deploy a solution, and measure the solution. The change management process identified through the interviews followed this general pattern. In this model, thirty-four tasks were identified. Through a series of follow-up interviews, the process model was validated. However, obstacles were identified throughout some of the tasks in the process that encountered many changes. To explore this, a collaborative design resistance model was applied to see whether the model could accurately identify the tasks of highest resistance. The resistances were applied to the objective data from the interviews, such as team size and communication, and then compared to the subjective obstacles. From this, it was determined that the resistance model accurately predicted the challenges throughout the process.

This research resulted in a mapped change management process for typical automation implementations. It additionally helped discover opportunities for making these implementations more efficient by mitigating the resistances. Motivated from this study, the following are some opportunities that were discovered for future work: conducting workshops to have participants build the change process model, studying the process at a small-medium enterprise, studying the process at a company with product change (high volume, low complexity).

DEDICATION

This thesis is dedicated to my family for instilling in me the ability to achieve anything I put my mind to and supporting me throughout this journey of graduate school. This would not have been possible without their endless love and encouragement. For this, I am forever grateful.

ACKNOWLEDGEMENTS

To start, I would like to thank Dr. Summers for his guidance throughout this research. His continual support and collaboration helped me navigate through this experience. Additionally, I would like to thank him for accepting me as his student and seeing the potential in me even as the math undergrad pursuing an engineering grad degree. His dedication to his students and their learning was apparent day in and day out. Dr. Summers made me a better researcher and provided me the opportunity to study and follow my passion in manufacturing. This made my graduate experience one I will never forget.

My graduate experience would not have been complete without the collaboration with my committee Dr. Kurz and Dr. Mocko. Through classes and industrial projects, I carry with me the experiences that I had and thank them for their additional guidance.

This research would not have been the same without the partnership of the company I interacted with. To all my mentors and participants of this study, I am very thankful for their time and help. I learned a lot through this study and appreciate all those that took the time to help me learn and grow throughout this experience.

I would also like to thank members of the CEDAR Lab for their support and feedback throughout this process. We truly were all in this together! Big thank you for the support from the following individuals: Chase Wentzky, Caroline Buck, Vijay Sarthy, Nicholas Spivey, Maria Vittoria Elena, Apurva Patel, and so many more! Special shout out to Chase Wentzky for being my automation colleague throughout this process. This would not have been as fun without collaborating with you!

To conclude, an unconditional thanks to my friends and family for always pushing me to achieve greatness. Through the ups and downs, they motivated me and ensured I never gave up.

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CHAPTER 1.
SMART MANUFACTURING

As industry looks to adopt more advanced technologies and synchronize their IT networks with their manufacturing processes, there has been a dramatic shift towards smart manufacturing [1]. With the concepts of smart manufacturing continually developing, the way it is defined amongst production and engineering literature varies [2]. However, a common theme is the integration of technology and data to connect manufacturing processes and propel manufacturing forward into the next revolution [1,3–5]. For purposes of this paper, smart manufacturing will be defined as the integration of technology within human and machine processes to increase reliability, agility, and productivity, leading to a revolution among human-machine interaction in manufacturing.

To help guide the advances of manufacturing, in the United States of America an organization was formed, called the Smart Manufacturing Leadership Coalition (SMLC). The purpose of this coalition is to define some of the terminology and best practices related to smart manufacturing, although they too are in the development phase [1,3]. Being made up of industry partners, universities, and laboratories, provides them the resources to research and expand on these ideas [3].

In Europe, specific research organizations called the European Factories of the Future Research Association (EFFRA[1]) stem from 'Factories of the Future [2].' Like the SMLC, this is a combination of a range of small to large companies, academia, and research labs.

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[1] https://www.effra.eu/effra ; Accessed February 11, 2020.
[2] https://www.effra.eu/factories-future ; Accessed: February 11, 2020.

Their goal is to increase the competitiveness of European manufacturing by supporting research and implementation of these technologies at companies [6].

As shown in Figure 1.1, smart manufacturing is part of the larger progression towards Industry 4.0. The premise of this chapter is to introduce some of these key topics that have helped promote the advancement of manufacturing into the future.

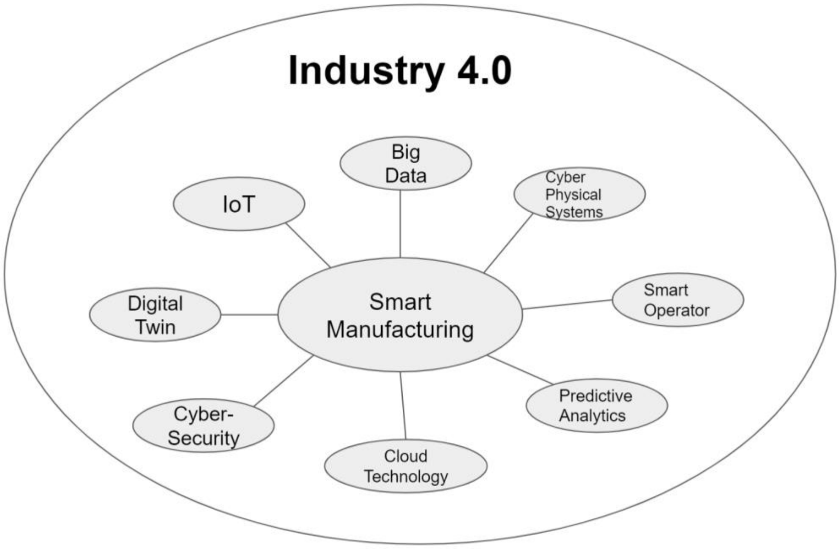

Figure 1.1. Industry 4.0 Key Concepts

1.1 Defining Industry 4.0

With industry's shift toward the fourth industrial revolution, research is helping advance the adoption of Industry 4.0 concepts in manufacturing. Similar to smart manufacturing, the definition of Industry 4.0 is not well defined and varies amongst literature [7]. However, the constructs of Industry 4.0 began in Germany [8]. The concept of Industry 4.0 was a platform for increased flexibility through the use of technology to connect production processes and increase the adaptability of cyber-physical systems based on collected data [4,9]. As one of the leaders in manufacturing, Germany used this initiative to gain a competitive edge in the manufacturing market [8,9]. Since this topic became public in 2011, research initiatives have expanded tremendously in the field and look for practical application of these methods in industry [8,10].

What distinguishes Industry 4.0 from the previous revolutions seen throughout history are the technologies to connect automated machinery and computer systems found from Industry 3.0 [11]. Figure 1.2 (from footnote 3) shows the progression of industry throughout the ages and highlights the connectivity of the future Industry.

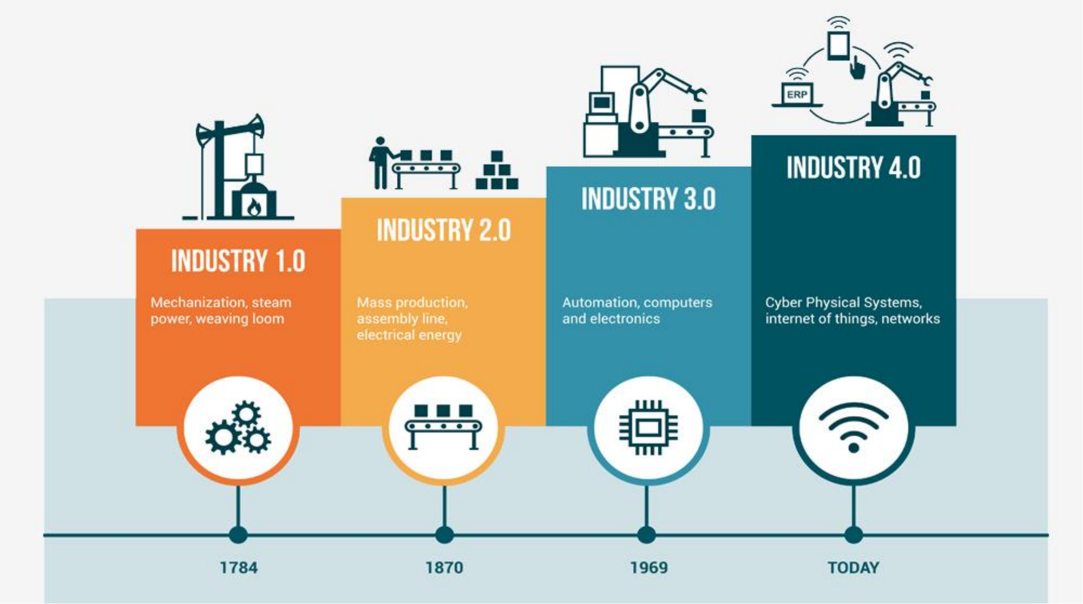

Figure 1.2 Industrial Revolutions [3]

While there have been major advances towards this next revolution, industry has not fully adopted these methods and technologies [4,7]. Therefore industry is progressing towards, but has not yet achieved Industry 4.0 [12]. As additional research helps define many of these concepts, future research can help identify how best to implement them.

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[3] Momentum: https://www.seekmomentum.com/blog/manufacturing/the-evolution-of-industry-from-1-to-4 ; Accessed: February 15, 2020.

1.2 Defining Industrial Internet of Things

To integrate all aspects within a manufacturing environment as proposed with Industry 4.0, the use of sensors, RFID, software systems, cloud platforms, and other digital technologies are needed more than ever [8,10]. These IT technologies bring to fruition a fundamental concept of Industry 4.0 called the Industrial Internet of Things (IIoT), most commonly known as the Internet of Things (IoT) [13]. IoT is a collection of physical items that are connected to the internet and use electronics, such as sensors and software, to collect data and status on these items [4,13]. Through this network, these physical items are connected throughout the factory and real-time data can be collected on the status of these items, identifying maintenance opportunities and even energy consumption [4].

The implementation of these advanced technologies to assist in the growth of IoT is best set up by the support of IT teams in companies. Based on their education and general competencies, these capabilities help ensure that the technology follows the requirements of cyber-security, as well as standardizations prior to the implementation.

Currently, companies such as IBM[4], known for their leadership in technological hardware and software, have leveraged their technological capabilities in manufacturing, thus moving towards Industry 4.0. IBM[4] claims that their platform of using artificial intelligence (AI) and IoT can help mitigate downtime through predictive analytics.

Through the connectivity of the IoT, manufacturing is said to have increased agility and flexibility [13]. With increased communication amongst systems and humans, there is a deeper understanding of the process. This opens up the ability to make more informed

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[4] IBM: https://www.ibm.com/industries/industrial/industry-4-0 ; Accessed February 15, 2020.

decisions based on the environmental data [4,13]. Alongside this, IoT has great benefits for a more fluid value chain process through its communication and tracking capabilities [8].

1.3 Defining Operator 4.0

As there is further adoption of technology in manufacturing facilities, the training that will be required of the operators will drastically change. With increased interactions with advanced automated systems, the responsibilities of the operator are evolving. This future operator is what is known as Operator 4.0 [14,15]. The goal of the Operator 4.0 is to build trust between the human and machine in order to leverage both the skills of the machine and human [14]. This introduces several human factors such as trust and situation awareness that will be discussed later in CHAPTER 2.

In addition to this, the shift in manufacturing technology is also to be developed such that it assists the human and makes the processes more efficient for them [15]. Figure 1.3 shows the change in operators' responsibilities throughout time. The evolution from Operator 3.0 to Operator 4.0 shows the change in human machine collaboration and the transition towards machine aiding the operator's needs [15]. For this to be possible, the machine would need to be able to process the needs of the operator, which is referred to as adaptive automation [16].

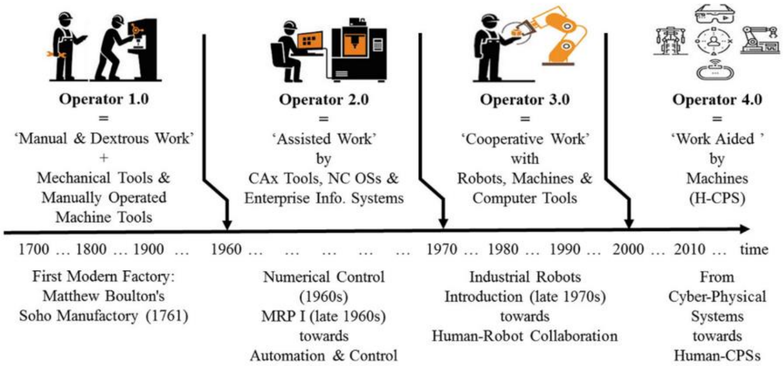

Figure 1.3. Operator Transformations [15]

However, there are challenges that present themselves as industry shifts towards an Operator 4.0. One challenge being how to best prepare and train the current operators for this transformation. Since everyone has different skills and experiences the most effective method to train these future operators is not trivial [14]. While research mentions that training will be required, it does not go into details to what that training should consist of [14]. Future work would benefit from identifying affective methods of training of these advanced technological systems.

1.4 Automation in Manufacturing

The focus in manufacturing has always been, and will be, to increase the productivity, reliability, and quality of production systems [17]. To achieve this, years of data from production will help to optimize the use of tools, personnel, and now technology [12]. During this time, automation has transformed from mechanized tools to now complex combinations of machines and computers [18]. As previously discussed, with the increase of 'smart technology' being embedded in automated systems, automation will shift towards aiding the physical and cognitive needs of the operator [15]. Through the connectiveness of the IoT, this adaptive automation will have the ability to communicate between not only machine-machine, but also between human-machine more effectively [15].

1.4.1 The Role of Human Operators

While there are many advantages to the use of automation, the acceptance of it in manufacturing has not always been positive. The fear has been that automation will take jobs and replace humans [19]. However, in most cases automation does not take away work, rather it changes the human's role in the process [19,20]. As automation takes over some of the manual and repetitive operations within the process, the human's role is then to monitor the task or system [19,20]. Since humans are more flexible in their decision-making capabilities, they act as better supervisors to the mechanical operations [20]. However, as will be discussed in CHAPTER 2, there are specific human factors that need to be considered for human's to be successful in their role.

Even though technology is advancing rapidly and is being implemented in larger degrees in production, automation will not completely take over manufacturing or replace humans in the near future [21]. Automation does not have the flexibility like humans to make judgement [19]. Many automated systems are programmed to the desired specifications and that's precisely what they follow [19]. Therefore, the process will require humans ability to adapt and their cognitive capabilities [19].

Chapter 1 - Takeaways

- Industry 4.0 is the next revolution that industry will encounter
- Training and preparation of operators for this industrial shift will lead to an Operator 4.0
- Automation is useful for repetitive, manual labor
    - Automation does not remove work, it changes the human responsibilities

CHAPTER 2.
DRIVE FOR AUTOMATION RESEARCH

To become more competitive in industry, manufacturing has looked to automation to help increase the efficiency and productivity of systems and processes [22]. However, there are many elements to consider when using automation. This chapter will address these trends in automation research. To conclude this chapter, the gaps within literature will propose the research questions for this study.

2.1 Research Trends

Within automation research, there are many different trends being studied from the machine capabilities to the human relationship with automation. Nonetheless, human and machine are affected by the continual changes being made in manufacturing. Having some level of awareness to these research trends helps understand the implications of changes in production and what factors need to be considered.

2.1.1 Human Factors

As automation grows in manufacturing, technology should not be the only element of focus, there are many factors that must be considered from the human perspective [23]. These considerations are related to human capabilities when interacting with different elements, which are referred to as human factors[5]. Incorporating these human factors into the design of the automated system can ensure that the machine will support the human needs.

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[5] Human Factors and Ergonomics Society: https://www.hfes.org/about-hfes/what-is-human-factorsergonomics ; Accessed on February 28, 2020.

While automation assists in many physical aspects of manufacturing, it also accounts for some cognitive aspects, all of which impact the human's physical and cognitive capabilities [24]. However, the focus of automation has primarily been on the physical factors, and it is unclear how, if at all, the cognitive human factors are evaluated when automation is implemented [25]. Some of these cognitive factors include trust and situational awareness [23–28]. The trust operators have towards automation can be viewed in a variety of ways. From a 'systems' perspective, operators perceive trust from its dependability, consistency, robustness, and more [26,27]. From an 'individual' perspective, an operators personality, adaptability, and openness can affect the trust they have towards automation [26,27]. Lastly, from a 'situational' perspective, the designated restrictions on time, work, task balance, etc. also contribute to trust [26]. This total level of trust plays a critical role in the relationship between human and machine [27].

Situational awareness is another human factor influenced by automation that is defined as a person's perception of a given situation and their understanding throughout a task [29]. When a human collaborates with an automated system through supervision, the human's situational awareness will be affected based on the complexity of the task [26,29]. The benefits of high situational awareness leads to the operator performing better and making more informed decisions [29,30]. However, the levels of automation affect the situational awareness of the operators, leading to the operator out-of-the-loop dilemma [24,26,29]. By designing the automated systems with operators situational awareness in mind can prevent any mishap with placing the operators out-of-the-loop and ensure the operators are working at peak performance [24,29,30].

Through the case study that will be discussed in depth in later chapters, parts of the design process were explored providing greater detail into the operator involvement for the automation implementation. This helped provide context to the design considerations, as well as the current state of operations from the operator's perspective.

2.1.2 Human-Machine Interaction

The previously discussed human factors that accompany automation can provide a better understanding of the human and machine relationship [23]. To mitigate any failures in the system, the human must be considered while designing the automation [23]. This relationship between human and machine is affected by the levels of automation, which will be discussed later [28].

As the role of automation and operators change, the relationship between the two will evolve [31]. Automation will be viewed less as stand-alone machines and more as collaborators with operators [31]. This can be achieved through improved communication [31]. For the human and machine to communicate efficiently, the right information needs to be provided to the operator [32]. This is done through different systems and interfaces [32]. Research on human factors has looked into responses between human and different interfaces [32].

In the case study, which will be discussed in further detail in CHAPTER 4, human-machine interaction is prevalent between the operators and the automated system being implemented. This interaction and relationship between human and machine help to better understand some of the human factors addressed earlier, such as levels of trust and situational awareness throughout the task.

2.1.3 Human-Cyber-Physical Systems

With the role of automation evolving to assist the needs of the operator, human-machine interaction will lead to stronger socio-cyber-physical systems, most commonly known as human-cyber-physical systems (HCPS) [15,33]. As previously discussed, these new systems will make the engagement between human and machine more efficient [15].

Previous research focused efforts into developing this concept of cyber-physical systems (CPS), which is the integration of the physical and software elements [34,35]. When looking to integrate these systems engineers focus heavily on the production process and operations [35]. However, this excludes the most critical element to all automated systems, the human. Without the human element, these systems are just tools [31,33]. By incorporating the human throughout the design process will help shift the machines capabilities to aid in the operators physical and cognitive tasks [15].

In this research, HCPS was discovered through the three functional teams that were identified: engineering, IT, and Operations. Operators are the human element, IT is the cyber element, and engineering is the physical element of the system. This relationship shows the importance of these functional teams for these implementations. However, as will be discussed later, the operators are involved at the end of the change process.

2.1.4 Level of Automation

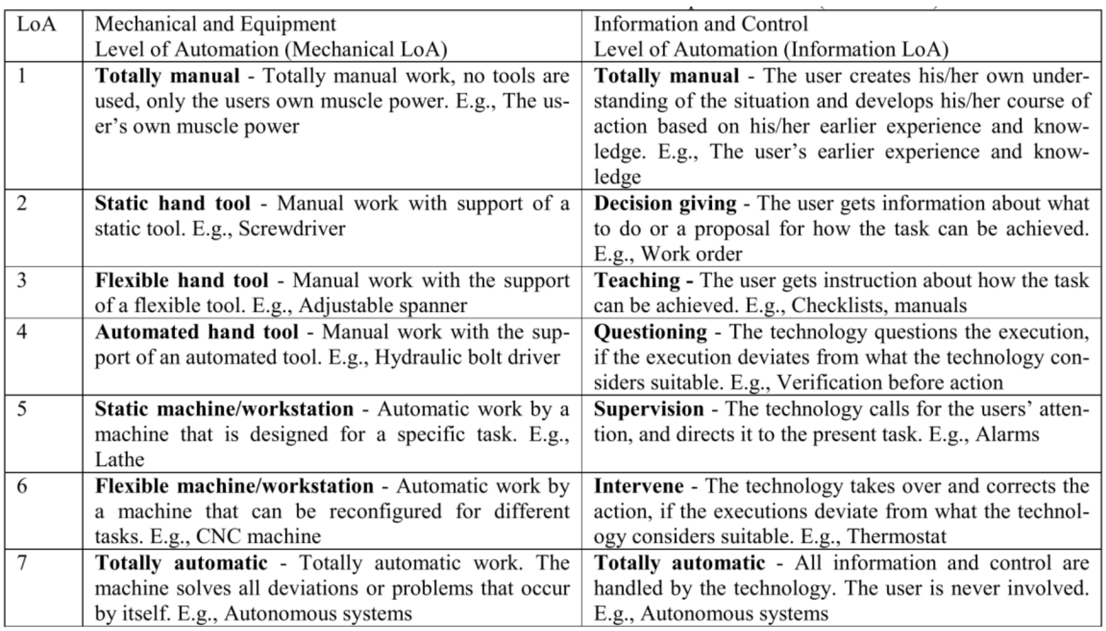
Even with the adoption of new technology in manufacturing, tasks are comprised of physical and cognitive elements [36]. Examining the physical and cognitive elements for each task can provide a better understanding of the entire manufacturing process and assist in proper task allocations [36]. This type of research is measuring the levels of automation

(LoA) [36]. This topic has an important role in this study as the change implemented reduces the LoA.

2.1.4.1 Cognitive and Physical Levels of Automation

To analyze these physical and cognitive elements within a task a method called DYNAMO++ was created [36]. This method evaluates the physical and cognitive elements on a seven-level scale [36]. Table 2.1 shows the 7 levels used to evaluate the LoA for each task, where physical elements are represented as Mechanical LoA and cognitive elements as Information LoA [37]. It should be noted that the higher the LoA does not mean that the process is any more efficient than one with a lower LoA, it is all dependent on the needs and requirements of the process [38].

Table 2.1 Physical and Cognitive Levels of Automation [37]



LoA	Mechanical and Equipment Level of Automation (Mechanical LoA)	Information and Control Level of Automation (Information LoA)
1	**Totally manual** - Totally manual work, no tools are used, only the users own muscle power. E.g., The user's own muscle power	**Totally manual** - The user creates his/her own understanding of the situation and develops his/her course of action based on his/her earlier experience and knowledge. E.g., The user's earlier experience and knowledge
2	**Static hand tool** - Manual work with support of a static tool. E.g., Screwdriver	**Decision giving** - The user gets information about what to do or a proposal for how the task can be achieved. E.g., Work order
3	**Flexible hand tool** - Manual work with the support of a flexible tool. E.g., Adjustable spanner	**Teaching -** The user gets instruction about how the task can be achieved. E.g., Checklists, manuals
4	**Automated hand tool** - Manual work with the support of an automated tool. E.g., Hydraulic bolt driver	**Questioning** - The technology questions the execution, if the execution deviates from what the technology considers suitable. E.g., Verification before action
5	**Static machine/workstation** - Automatic work by a machine that is designed for a specific task. E.g., Lathe	**Supervision** - The technology calls for the users' attention, and directs it to the present task. E.g., Alarms
6	**Flexible machine/workstation** - Automatic work by a machine that can be reconfigured for different tasks. E.g., CNC machine	**Intervene** - The technology takes over and corrects the action, if the executions deviate from what the technology considers suitable. E.g., Thermostat
7	**Totally automatic** - Totally automatic work. The machine solves all deviations or problems that occur by itself. E.g., Autonomous systems	**Totally automatic** - All information and control are handled by the technology. The user is never involved. E.g., Autonomous systems

2.1.4.2 Levels of Automation Matrix

Upon evaluating both the cognitive and physical level for each task, a matrix is used to plot and tally the LoA [39]. Figure 2.1 shows the matrix used to mark the cognitive (x-axis) and physical (y-axis) level for each task [39]. The matrix is made up of three core quadrants: "human assembling and monitoring," "machine/technique monitoring," and "machine assembling" [39–41]. The "human assembling and monitoring" would be when an operator is completing the task and monitoring the work [39]. The "machine/technique monitoring" would be when a machine monitors the work done by a human or machine [39]. Lastly, the "machine assembling" would be when a machine is completing the task and the human is monitoring the work done, or not involved in the process at all [39].

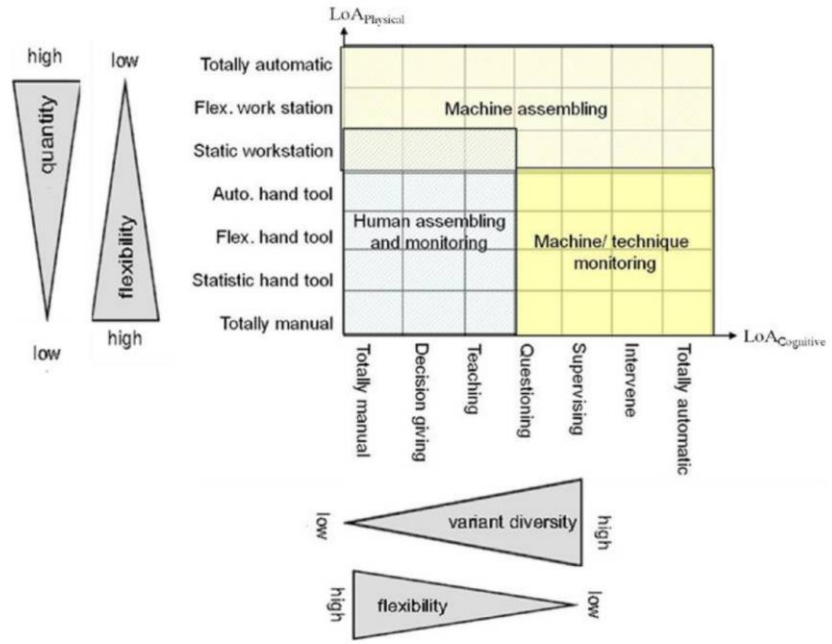


Figure 2.1. Level of Automation Matrix [39]

The matrix also shows an interesting relationship between flexibility and the levels of cognitive/physical LoA [39]. According to Figure 2.1, flexibility in the process is highest when the cognitive and physical LoA are totally manual [39]. As both the cognitive and physical LoA increase in automation, the flexibility decreases [39]. With many continual changes occurring in manufacturing, flexibility is an element that helps streamline these change in the process [42]. As was previously discussed, automation is only as flexible as the program that was written for it. Therefore, it makes sense that the more flexibility comes from more manual tasks.

Once all of the tasks have been evaluated and added to the LoA matrix, the area in the matrix that has the highest concentration of tasks can be further analyzed for opportunities. If most of the tasks are totally manual for both cognitive and physical LoA, then an opportunity might be to find where more automation can be added.

2.1.4.3 Example Using Dynamo++ Method

To understand how this method works, some examples will be shown in the proceeding screenshots from an automotive manufacturing video[6]. These screenshots illustrate different manual and automated tasks in an automotive manufacturing facility and will be evaluated for the cognitive and physical LoA following the definitions provided in Table 2.1 Physical and Cognitive Levels of Automation [37] Table 2.1. Figure 2.2 has been considered physical level 4 as they are using an automated hand tool, and cognitive level 1 because the operator gathers or already understands the task based on experience.

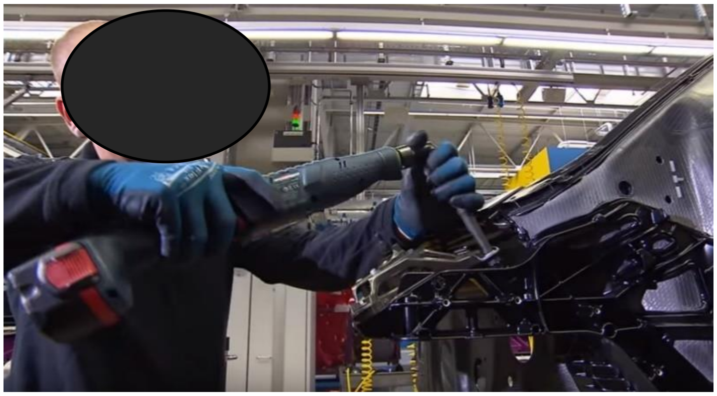


Figure 2.2. Operator Places Bolts and Tightens with a Hydraulic Bolt Driver

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[6] Retrieved from https://www.youtube.com/watch?v=adB8xIUTLDI; Accessed *February 13, 2019.*

Figure 2.3 is considered a physical level 7 and cognitive level 7, because the machine is in complete control of the task. The automated machine is in control of gluing the adhesive, as well as processing all of the information on its own. This would be considered a fully automated machine.

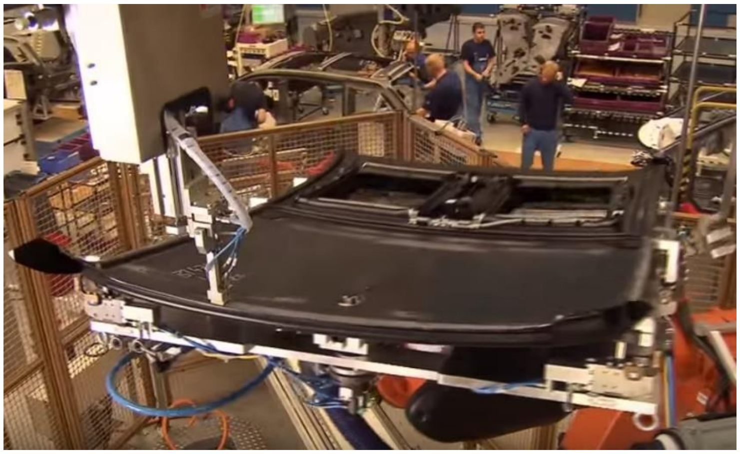


Figure 2.3. Machine Applies Adhesive to Roof

Figure 2.4 was considered to have a physical level 5, as the lift assist is a static workstation aiding the operators to install the roof. The cognitive LoA was determined to be a level 3 as the operators most likely follow a procedure in the installation manual to ensure the roof has been assembled correctly.

Figure 2.4. Lift Assist to Install Roof

Figure 2.5 was considered to have a physical level of 2, since there is a static hand tool used, which is circled red. The cognitive level for this task was considered a level 1 as the operator is completing the task without any assistance and using prior experience to connect the cables.

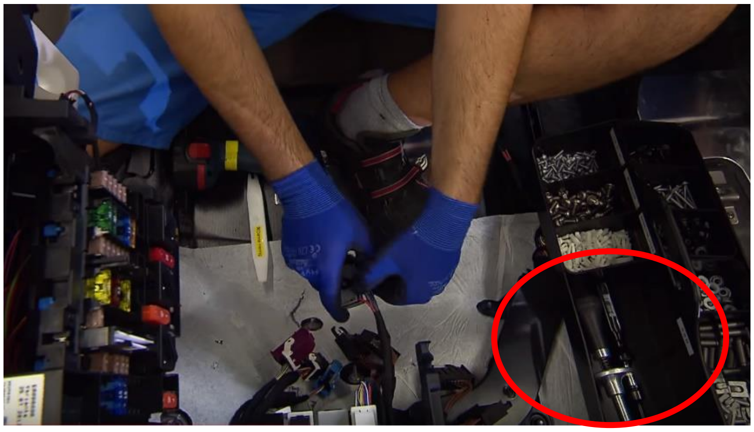
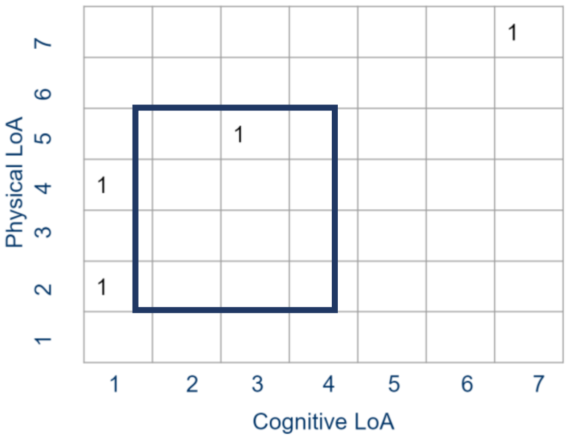


Figure 2.5. Operator Installing Electrical Cables

More task pictures and analysis can be found in APPENDIX A: DYNAMO++ LOA EXAMPLES. All of the physical and cognitive LoA for each task is then tallied. Like plotting points on a graph, the cognitive LoA represents the x-axis and the physical LoA represents the y-axis. Table 2.2 shows the plotted LoA for all of the tasks evaluated. If there were several tasks with the same LoA, they were be summed together. The box around the three LoA tasks represent the "concentrated" area in the manufacturing process and is called the "Square of Possible Improvements," or SoPI [40]. This would identify an opportunity area to evaluate these tasks in deeper detail. Perhaps through the analysis there is an opportunity to increase the LoA.

Table 2.2. LoA for Example Tasks



Physical LoA	1	2	3	4	5	6	7
7							1
6							
5			1				
4	1						
3							
2	1						
1							

By using the DYNAMO++ method, manufacturers can find the appropriate balance of manual and automated systems [39]. The premise is to evaluate the entire system and ensure that each process is running at its optimal level [39]. This method also helps determine the human-automation interaction in the process [41]. This involves understanding the task allocation and should evaluate the human and machine tasks together [40].

The advantage of using this method is to increase the understanding of task allocation between human and machine throughout the process. However, it does not tell the user where and when to automate. This is a challenge that has identified itself throughout industry. Additionally, this model does not provide the user with the appropriate ratio of automation to manual labor. The challenge stems from processes being customizable, so no process is the same. Therefore, there is no standard ratio between automation and manual task, even though it would be helpful. Alongside this, it is not clear how much automation is too much. Currently levels of automation are at the discretion of the company to decide whether automating is worth the return on investment (ROI).

Through evaluating the LoA in a production process, opportunity areas are identified. Opportunities lead to the changes seen within manufacturing. This introduces an important area of research to understand changes to *processes*, this research will look to cover this topic.

2.1.5 Change Management

Implementing a change in a production process requires a rigorous change management process for it to be fully accepted and to be successful [43]. Change management processes cover a range of elements to ensure a smooth transition and mitigate the amount of resistance to change. Further discussion on how resistance plays into the change management process will be discussed later in CHAPTER 5. Ideally change management heavily evaluates upstream and downstream processes to ensure no issues can be introduced into the system with the desired changes [44]. Proper analysis helps prevent increased cost and delays in the schedule [44].

Table 2.3 briefly summarizes several change management processes found in the change management literature. While the principle goal of all the models is to aid in the process towards implementing a change, no method was found to be the same.

Table 2.3. Change Models from Literature

Change Models	**Type**	**Defined Goal**	**Structured Team**	**Awareness of Change**	**Project Debrief**
McKinsey 7S [45-47]	Organizational		**Yes**		
Kotter's 8 Stage Process [47-49]	Organizational	**Yes**	**Yes**	**Yes**	
Kurt Lewin's Change [47,50-52]	Organizational	**Yes**		**Yes**	
ADKAR [47,53]	Organizational			**Yes**	
Bridges Transition [54,55]	Behavioral			**Yes**	**Yes**
Nudge Theory [56-58]	Behavioral	**Yes**		**Yes**	**Yes**
Engineering Change [59-63]	Part/Product	**Yes**	**Yes**		

The McKinsey 7S model is made up of seven components: Strategy, Structure, System, Style, Staff, Shared Values, and Skills [45–47]. The model does not follow a sequential order, rather each component should be analyzed in parallel prior the change [45–47]. This model is presented as more of a high-level management approach in considering the impact of a proposed change.

The Kotter's Eight Stage Process is configured as a step by step process for implementing a change [47–49]. The eight steps are as follows:

1. Set the urgency,
2. Create a devoted team,
3. Formulate the goal and create plan,
4. Communicate goal and plan,
5. Empower individuals to act on the change,
6. Set short-term milestones,
7. Initiate more change, and
8. Make the changes concrete [47–49].

This model provides guidance on the overall process. Some of the steps require subjective considerations, such as setting the urgency. These subjective aspects of the model can be best addressed through collaborative decision making.

The Kurt Lewin's Change model is a simple three step process that is considered to be the foundation for many other change management models [47,50–52]. The process involves:

- Unfreeze (preparing for change),
- Change (executing the change),

- Re-Freeze (solidifying the change) [47,50–52].

This model provides a general description of a state change model (before, during, after), without significant guidance on how each of these phases interact.

The ADKAR model is a made up of five elements that focus on how people acclimate to change [47]. The elements are Awareness (towards the change), Desire (to contribute to the change/empowerment of employees), Knowledge (of the change process), Ability (resources and skills available to implement in the change), and Reinforcement (method to enforce the change) [47,53]. This model is more focused on the culture of change rather than the implementation of the change in a manufacturing environment.

Bridges transition focuses on the levels in change processes [54,55]. The transition comprises of three phases: “Endings” (leaving behind the old method) , the ‘neutral zone’ (establishing new processes, becoming more familiar with transition), and “New Beginnings” (culture shift to accept change) [54,55]. This model essentially is a combination of the state change model of Lewin’s and the ADKAR model focused on culture adaption.

The Nudge Theory provides an opportunity for feedback throughout the change process [56–58]. The Nudge Theory defines parameters regarding the change, gathering feedback from those impacted by the change, and presenting back the new change as the preferred ‘choice’ based on the feedback [56–58]. This feedback loop is central to monitoring the implementation of the change so that it does not have detrimental impacts on other aspects of the system.

As seen in Table 2.3, each change model focuses on different key elements. However, some elements appear to be shared across multiple models. First, there has to be a clearly defined goal and plan [43]. Without this the project does not have a foundation when proceeding with the project. Next it is important that there is a structured team that is preparing and implementing the change, with the addition of a designated leader [43]. Having a standard team (with little variance in representatives) will help increase the efficiency of the collaboration and communication [64]. Typically the most effective teams range in size from six to fifteen [65]. Alongside this, it is critical that all individuals impacted by this implementation are made aware of the changes before proceeding with implementing the change [43]. This allows the individuals to be prepared and involved in the process, even though they may not be on the implementation team [43]. Lastly, upon completion of the implementation, it is helpful for future implementation projects to evaluate the process used and identify opportunities [43].

Throughout the proposed processes, it can be inferred that change management is human-centric. Not only does each step require input from people, but change impacts individuals [66]. Since change processes involve people this results in different levels of collaboration, which is discussed further later. While Table 2.3 shows many examples of behaviorally and organizationally focused change models, there has been research done on product change management [59–63]. This can be viewed as design changes after the product has already been integrated with production [60]. Among the engineering change literature studied, a standard process for product changes was not identified. However, one commonality between the processes studied is the reason for change, whether that be external or internal pressures, such as safety, quality, or cost [60,67].

To summarize Table 2.3 shows example models, from literature and industry, for how people and products are affected by change. Although there are processes changes that need to be considered as well. In change management research, the gap discovered is with the process. Therefore, this research looks to understand change management for production processes.

2.1.6 Design Processes

While many similarities were found in this research between change management and design, this section will review different design processes in literature. To start, engineering design focuses on understanding the ‘what’ and ‘how’ to a problem [68]. The ‘what’ phase focuses on discovery, defining the problem, and generating requirements based on the needs of the stakeholder [68]. The output of this is called functional requirements [68]. The ‘how’ phase focuses on devising a plan for executing those functional requirements [68]. The output of this is called design parameters [68].

In engineering there are many different design processes and methods that can be used. Depending on the objective, one method may work better than the other. Some methods follow sequential tasks, others can be iterative. If the project is more adaptive versus structured, an iterative process would accommodate a higher degree of flexibility. Table 2.4 shows different design processes and methods found in literature.

Table 2.4. Design Processes/Methods in Literature

Design Processes/Methods	Description
Traditional Design Process[7] [69]	Discovery, Planning, Defining, Designing, Testing, Improving
Spiral Model [69–71]	Requirements, Prototypes, Evaluation, Planning Next Phase… (Repeat as needed)
Waterfall Model [69,70,72]	Requirement gathering, Designing, Prototyping, Testing, Supporting
Verification and Validation [72–75]	"Constructing the model correctly to constructing the correct model"
Axiomatic Design [68,76]	Stakeholder needs, Functional requirements, Design parameters, Process variables

2.1.6.1 Traditional Design Process

The traditional design process follows a cycle from beginning to end, for example the start of a project to the end of a project. This design process is made up of typically 6 sequential steps, which can be seen in Figure 2.6 [69]. The process starts with identifying and defining the problem [69]. Once there is context to the project, requirements are generated[7]. The product or solution is then constructed or implemented, then goes through testing[7]. Upon testing the product, there is an improvement period to support and aid in any additional changes that may be required[7]. As a result of the structure in the traditional design process, when there is an engineering change identified in any step, then there may be a need start the process from the beginning to ensure the new requirements are met.

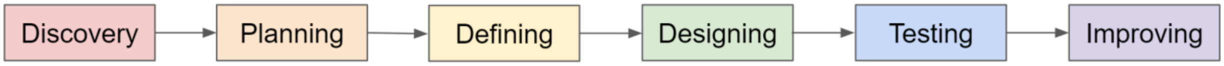


Figure 2.6. Traditional Design Process [69]

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[7] Retrieved from: https://www.nasa.gov/audience/foreducators/best/edp.html; Accessed February 25, 2020.

2.1.6.2 Spiral Model

The Spiral Model is another design process most often used in software development [69–71]. This is an iterative process that works closely with the stakeholder, similar to design reviews [69–71]. Figure 2.7 shows a spiral model as it relates to engineering development [69]. The phases involve gathering requirements, prototyping, evaluating with the stakeholder, and planning the next phase [69–71]. This process then repeats until accepted by the stakeholder [69–71]. What distinguishes this model from the others is the continual prototyping element [69–71]. For software developers, these prototypes can be completed much faster as opposed to a physical prototype [69]. But this user group is expanding with the growth of rapid prototyping [69]. As a result of the iterative nature of this process, when a change is introduced there are more opportunities to adapt and revisit these changes.

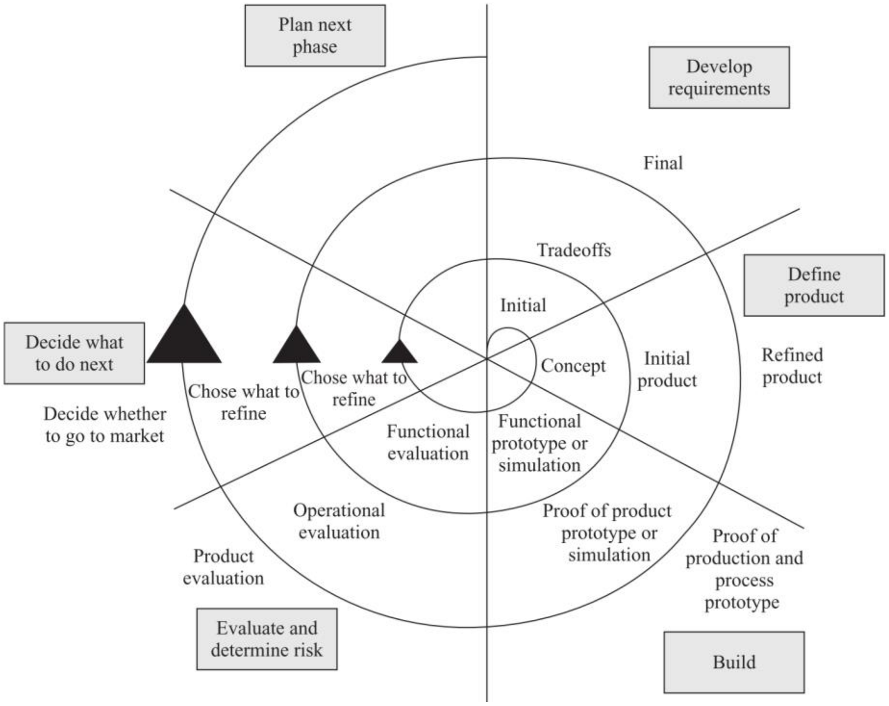

Figure 2.7. Spiral Model [69]

2.1.6.3 Waterfall Model

The Waterfall Model, also known as the stage-gate process, is a sequential phase model [69,70,72]. This means that to move on to the next phase requires the preceding to be finalized [70,72]. For this reason clear deadlines are critical for this method [72]. The general model follows the following steps: Requirement Gathering, Designing, Prototyping, Testing, and Supporting [70,72]. The most emphasized step in this model is the requirements gathering. Due to the strict sequential nature of this model, the requirements should be concrete and should not vary throughout the process [70,72]. Therefore, this model does not adapt well to change [70].

2.1.6.4 Verification and Validation Model

The Verification and Validation Model, also known as the V-Model, has been often used for coding, simulations, and system engineering processes [73–75]. Between the two elements, verification focuses on constructing the model correctly and validation seeks to construct the correct model [74]. Figure 2.8 shows a high-level V-model. While the tasks are sequential, this is an iterative process model [74]. With continual changes throughout the project lifecycle, the verification and validation is repeated to ensure it meets the requirements [74]. The V-Model has many similarities to the Waterfall method, however, the V-Model has a stronger emphasis on testing [72].

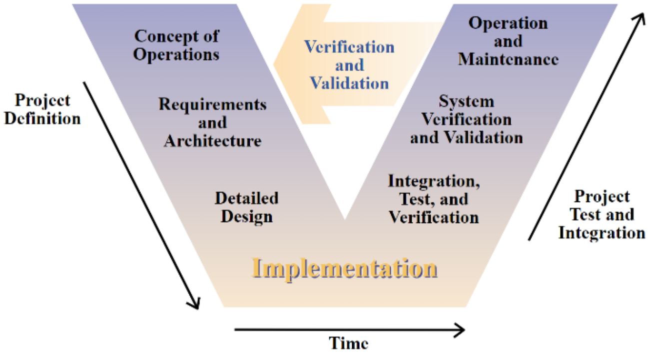

Figure 2.8. Verification and Validation Model [8]

2.1.6.5 Axiomatic Design

Axiomatic Design is another well-known design method. Figure 2.9 shows the design domains that are broken down in this method [68,76]. The design process starts in the 'customer domain,' which is gathering information and collating the needs of the stakeholder [68,76]. This information is then translated into functional requirements, within the 'functional domain' [68,76]. Mapping to the physical domain, these functional requirements are transformed into design parameters [68,76]. The last domain, 'process domain,' takes the design parameters and works towards a product, this is achieved through 'process variables' [68,76].

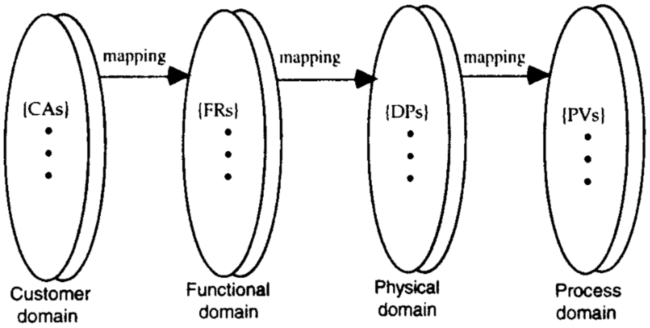

Figure 2.9. Design Domains [68,76]

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[8] Retrieved from: https://en.wikipedia.org/wiki/V-Model ; Accessed on February 26, 2020.

In this process, Axiomatic Design defines two axioms [68,76]. The first axiom is to keep the functional requirements independent of one another [68,76]. Thus, a change to one functional requirement will not affect other functional requirements [68]. The second axiom is to reduce the amount of information for the design [68,76]. This axiom is a measure to determine the best design based on the amount of information required to suffice the functional requirement [68,76]. Thus, functional requirements that are satisfied with the least amount of information is favorable [76].

Together, these axioms ideally result in functional requirements being individually linked to design parameters [68]. However, this does not mean that each design parameter results as a physical feature on the design [68]. By using a process like Axiomatic Design, designers have increased creativity [68]. Ultimately, due to the relationship between functional requirements and design parameters, the effect of change is locally controlled. This should make changes easier to accommodate, since there is less connectivity between elements [61].

2.2 Research Questions

As discovered, there are many topics highlighted in literature that are active research topics in automation and manufacturing. However, automation and smart manufacturing literature does not extend past rudimentary information. For example, smart manufacturing literature does not address how to implement these technologies and automation literature does not address how much automation is sufficient or where in particular to automate. All of these concepts relate back to *changes* being made in the production process. As such, in this research, the primary focus is understanding changes in manufacturing. Since technological changes are inevitable in this current era of manufacturing, the goal of following a change management process would hopefully provide insight to the meticulous decision making and better understand the collaboration element, whether that be human to human or human to machine.

2.2.1 Research Question 1

What is the change management process for large-scale automation implementations?

Stemming from the evolution of automation in manufacturing, understanding the reason for change and *how* these changes are made are of interest in this research. Figure 2.10 shows two assembly methods in the automotive industry, manual (left) and automated (right). These distinct differences in the manufacturing process was a key motivator for this research. This raises several questions such as how was it decided where to automate and how were these changes made?

With advances in technology, assembly tasks are becoming increasingly automated [77]. However, it is not well known how tasks are chosen to be automated or the process to how these automated systems are implemented. To fill this gap, this research looked to better understand the change management process for automation implementations.

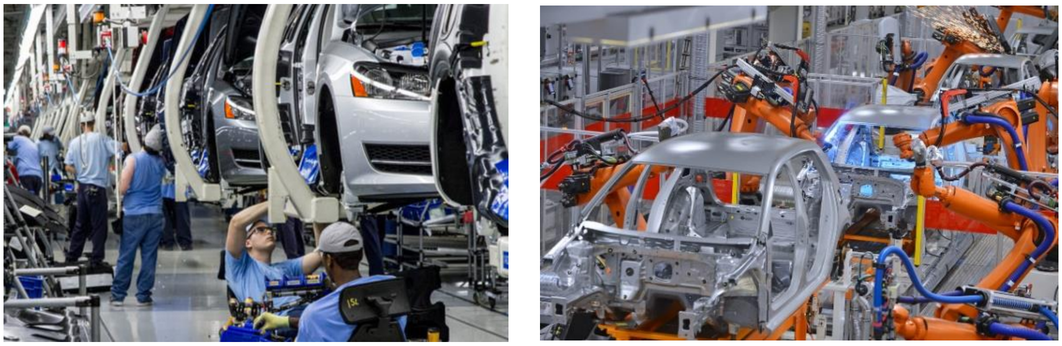

Figure 2.10. Manufacturing Evolution: Left(Manual)[9], Right (Automated)[10]

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[9] Image Retrieved from: https://www.magoda.com/industrial/recovering-auto-manufacturing-industry-boosts-global-demand-for-robotics/ ; Accessed on February 27, 2020

[10] Image Retrieved from: https://www.robotics.org/blog-article.cfm/The-History-of-Robotics-in-the-Automotive-Industry/24 ; Accessed on February 27, 2020

While literature addresses different change management processes, it is not clear which method is used in industry. Do companies follow change processes from literature, create their own process, or not have a process at all? Studying *how* these implementations are managed creates a better foundation for future automation implementations. For there to be improvements in the efficiency of these implementations, identifying the change management process and evaluating it will help find opportunities for improvement for future processes.

2.2.2 Research Question 2

How does the Change Management Process differ from the Design Process?

Through studying different change processes and conducting a case study on the change management process to automation implementations, similarities were found between the change process and design process. For this reason, it became of interest to study what makes the change management process different from the design process? Could it be that the change management process is that similar to the design process that they are used interchangeably? Or is the change management process embedded in the design process, or vice versa? Through studying this, it is intended to provide clarity and a better understanding of the differences between these two processes.

Chapter 2 - Takeaways

- There are many research trends regarding human and automation that play a critical role in this research (human factors, human-machine interaction, LoA, etc)
- Change management processes focus on organizational, behavioral, and product changes
    - Gap in research for process changes

CHAPTER 3.

CASE STUDY RESEARCH METHOD

Empirical studies collects data through the ‘current-state’ observations of practices in industry [78,79]. The use of empirical research can help develop the methods used for automation design [25]. Empirical studies are made up of quantitative and qualitative research [80]. Qualitative research can help to understand the process people take and the purpose of certain actions [81]. This research used qualitative methods through the use of a case study and conducting interviews [82]. This chapter will review case studies, as well as an overview of the interviewing method.

3.1 Case Study Methods

As previously mentioned, case studies are a qualitative research method [82]. They are particularly useful in answering research questions such as ‘how’ and ‘why’ certain phenomena occur [83,84]. With the motivations of this research to observe and identify a change management process, a case study was used. Case studies are a good method to use when looking to study a ‘current-state’ scenario in the field without modifying or controlling any elements in that scenario [85]. They are often useful in gathering data after changes have been made, this is what we were focusing on for this research [86].

Like many methods and processes, the case study method starts with identifying the problem [84]. A plan should then be put together to ensure that the data is collected properly [84]. Since case studies are often under scrutiny for reliability and validity, the data collection process is important to consider [84,86]. The case study can then be executed and general conclusions can be drawn [84].

Since case studies often focus on one phenomenon, the results are difficult to generalize [84,86]. This is the major criticism that case studies receive [86]. However, the data collected helps develop inferences and predictions for future work [86]. In this research, the motivation was exploratory, since these concepts in literature are not well defined. For this reason, the research was not focused on replication, rather gathering foundational information for future work.

3.2 Interview Method

Interviewing is a method that can be used to collect data in empirical research [86]. There are three different interview methods: structured, semi-structured, and unstructured [87]. Structured interviews have a list of specific questions that are asked in a set order for every interview [87]. Semi-structured interviews have set questions, however, they are more flexible allowing the interviewer to ask follow up questions or change the order of questions as needed [87]. Unstructured interviews is the most flexible interview method, by allowing the interviewer to ask any questions based on the context and not needing to prepare questions in advance [87]. In this study, semi-structured interviews were used. When preparing the questions for semi-structured interviews the researcher should triangulate the questions [88]. This means asking the same questions in different way to see if the interviewee will respond similarly, this helps to validate the question and answer [88,89].

To know how many interviews need to be conducted is found through ‘data saturation’ [90]. Depending on the research, the level of data saturation will change, which is what makes this a controversial topic in research [90]. However, for purposes of this research, data saturation is when interviews provide no new information leading to no new data being introduced [90].

Chapter 3 - Takeaways

- Case studies are a qualitative research method, good for observing the ‘current state’
  - Great for answering ‘how’ and ‘why’ questions
- Interviewing is a data collection method for empirical research
  - Three different kinds of interview methods: structured, semi-structured and unstructured
  - Number of interviews needed depends on data saturation

CHAPTER 4.

OVERVIEW OF CASE STUDY AT COMPANY

The case study that will be introduced in this section was conducted in industry at a manufacturing company. For purposes of this paper, the company will be referred to as TruAutomation. The company name will not be disclosed in respect to remaining anonymous. To provide more context to the study environment, TruAutomation is a lower volume, larger product manufacturing company. On a spectrum of company size, TruAutomation would be considered a large company with 50,000+ employees.

Due to the complexity of the product, the manufacturing processes consists primarily of manual work. This results in a slower movement of the product throughout the line. However, with the advantages of automation, there has been a shift towards further adoption of these advanced technologies in hopes to increase the speed of production, while maintaining quality and improving reliability.

The type of manufacturing process observed in this study was job-shop[11] style. This means that the manufacturing tasks were grouped based on their function and the flow of production is scattered throughout the facility[11]. While there was a final assembly process, this was not evaluated in this research.

During the duration of this study, the researcher interacted with members from different teams, including several different engineers, IT representatives, and operations support. This provided the researcher with a broader perspective of the environment. In addition to this, all members interviewed were co-located at the same facility.

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[11] Retrieved from: https://www.whatissixsigma.net/job-shop-manufacturing/ ; Accessed: April 14, 2020.

4.1 Investigation of Case Example

The automation example used for this case study was a machine where the human and machine were working cooperatively. However, as in many automation cases, the human was assisting the machine in completion of the task. The machine would start the task and only once the human completed its task could the machine move on to the next task. From this, different perceptions of automation were found. Some believed that the human was not as efficient as a fully automated system, but through observation the human was waiting on the machine in most instances. While the machine has the capability to make decisions on whether it can move on to the next step or not, the human still has override abilities since there is an operator that supervises the machine on different displays. It should be noted that only the manufacturing process needed to be studied as there was no change to the product.

The machine is made up of 4 automated systems working alongside a team of approximately 8 people. This is a 2:1 ratio of human to machine. During operations, the operator has limited vision capabilities of the machine. Therefore, what is displayed on the monitors for the operators is critical to the task and must provide the operator with the proper information for the task. This requires there to be a level of trust between the human and machine. As previously discussed, trust is an important human factor when looking at human-automated systems.

For this case study, it was important to find an automated machine where the implementation process could be followed. The goal was to be able to understand how changes were made through this process. After expressing the goal and objective of the research, the example case for the study was identified for analysis by the company. This machine had already been implemented prior to the start of this investigation on implementation process. However, it was a good case to study because it was only implemented several years prior, which meant people involved in the process were still available to be interviewed. Additionally, with this being a large-scale automation implementation there was a large investment at stake requiring a high return on investment. This meant that the process studied would be rigorous, there was a higher attention to detail, and a larger resource pool to observe.

This project stemmed from TruAutomation's initiative to enhance the manufacturing technology. Due to the complexity of the implementation, this project took several years to complete. It also required efforts from cross-functional teams to get the machine up and running. With that said, there was a heavy rotation amongst the team members throughout the entirety of the project. This led to several challenges, which will be discussed further in the proceeding sections.

To become more familiar with the machine, daily standups were attended. Standup meetings were small meetings (less than ten people) in front of the machine reviewing data on current state operations. This was a good opportunity to hear the current state of the machine and how changes were being made to improve the efficiency of the system. The standups used manufacturing improvement methods such as Kanban and Kaizens. Kanban is a Japanese method stemming from the Toyota Production System [91]. This method is traditionally done non-electronically and provides a visualization of updates regarding the machine, operators, and production/rate [91]. Similarly, Kaizen also originates from Japan, meaning "continuous improvement" [92]. These are often smaller, quick suggestions or improvements that can be implemented on the machine [92].

4.2 Interview Questions

To study this case example, interviews were used to collect the data. The interview questions for this case study were created and tested in a preliminary study for the ME 8730 – Research Methods class at Clemson University. The context and background of the study were similar to those of this case study. The questions were tested at two different medium sized companies (5,000+ employees). Both had distinct automation capabilities, with one company having older automated systems and the other implementing new automated systems. The preliminary study provided feedback on the most useful questions that pertained to the research question. The questions that were not useful were thrown out of the set. The finalized set of sixteen questions can be found in Table 4.1.

Table 4.1. Interview Questions Used for Case Study with Automation Stakeholders

Background Information	1	Name, Job Role/Organization
	2	Describe day in the life/daily activities (hours, tools used, etc.)
	3	How did you use/interact with the machine?
	4	How long have you been working with the machine?
	5	Have you worked with any other automated systems? If yes, how would you compare them?
	6	In your perspective, what is the manual effort?
	7	What's something you would keep and what's something you would change/improve?
Change Management	8	When did the process start changing?
	9	What were the changes? Were they good or bad?
	10	Was this change communicated to you? If so, in what way? Who told you?
	11	How involved were you throughout the implementation process? What did the training look like?
	12	Do you know how to suggest changes?
	13	Did people follow up?
Post-Implementation	14	Has there been improvements since the change was implemented?
	15	Why would you or would you not say you are prepared for another implementation?
	16	Who should I go talk to next?

The interview questions can be broken down into three categories: background information (orange), change management (blue), and post-implementation (yellow). Each section was created to target critical aspects of the research question. It was important to gather different perspectives on the contexts of the machine, how the change was executed, and evaluation after it was all completed.

4.2.1 Background Information Section

The background information provided more context to *who* the person was, *how* they were involved in the process, and their perception of the automated system. With the nature of industry, roles often change within a several year span, for this reason, it was important to understand the persons current role, as well as their role during the implementation.

This section also highlighted the individual's level of experience with the machine by asking how long the individual worked with it. By asking whether they ever worked with another automated system triangulates the question back to their experience level particularly with automation. If they had prior experience with another implementation, the comparison question was to find out more of what makes this automation unique as compared to the others. By asking what they believed the manual effort was not only provides their perspective of the automation level, but it also triangulates back to their experience with automation.

To help transition to the next section, each person was asked what they would keep and what is something they would change regarding the machine or implementation. This was an opportunity for identifying obstacles, as well as gathering more information on the process.

4.2.2 Change Management Section

The change management questions were crafted to specifically find out how the change was executed and what steps were required for their role in the process. Asking questions such as “when did the process start changing,” points to when the individual was first made aware of the project and helped distinguish where in the process they began to be involved. Following this with asking what the changes were, was to determine the awareness throughout the implementation and how roles may have changed the type of information that people receive. With this section focusing solely on change, it was an opportune moment to also ask whether they knew how to suggest changes. This would then open the discussion to discuss a change process if there was one put in place.

Throughout the change, it was of high interest to capture communication patterns. This would provide more context towards understanding the collaboration aspect during the implementation. For this reason, the question regarding whether the change was communicated and who was responsible for sharing the information was asked. This question was still helpful even if the person did not work directly with the implementation as it showed levels of awareness to changes made in the factory, triangulating back to understanding the communication patterns.

After discussing the change process and leading into the post implementation section, each person was asked whether people followed up on the changes. It was of interest to see whether those that made changes were also the ones to follow up on the success of the particular change.

4.2.3 Post Implementation Section

The last set of questions in the interview was on the post-implementation to understand the current state and what the change process looked like after the machine was set up. By discussing the improvements since the machine was stood up was to gauge the size of changes post implementation. The last question in this section was towards the interviewee's opinion on the readiness for another implementation. The goal with this question was to extract what methods went well and what could be improved for future implementations.

To conclude the interview, each person was asked who should be interviewed next. This not only was a referral, but also provided more context to who this person worked with on the project.

4.3 Overview of Interviews

With their being an advanced technologies team in IT focused on automation, this was an ideal team to start the study with. This research was of interest to this team to better understand the standardization process and identify opportunities throughout the implementation. With their own objective, the individuals in IT were more familiar with the study. They were also more available throughout the course of the study for any help or questions that arose. For this reason, the interview responses from IT were more honest and identified more challenges, which will be discussed later.

With a starting team, the rest of the interviews could be set up through referrals, following the "snowball interview method" [93]. Snowball sampling relies on recommendations to people that are related to the particular topic of study [94]. This was particularly helpful considering the entire network for this change process was not known

[95]. Therefore, this method helped identify different individuals involved throughout the process, as well as understand the collaboration between the individuals.

4.3.1 Interview Process

Since many of the interviewees were referred, in most cases the introduction was conducted via email. The email consisted of a personal introduction, brief explanation of the study, and request to meet to ask some questions. While many of the interviewees were met in person, a couple were conducted virtually to accommodate schedules. In several cases, the interviewee was not met in person and the relationship only developed virtually. Figure 4.1. Interview Process shows a high-level flow for how the interviews were conducted.

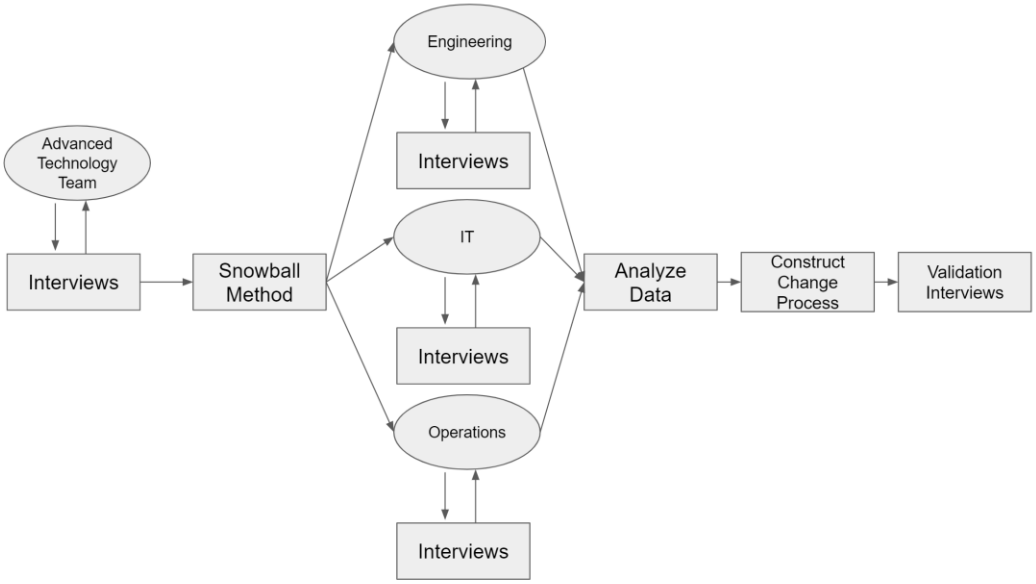


Figure 4.1. Interview Process

As was mentioned, the project started with the Advanced Technology Team. Several interviews were conducted on this team and referrals were made for who to talk to next. More interviews were done with individuals from different teams and roles providing a diverse perspective. With this data, the objective was to create a process model to understand how the automation was implemented. The recap of all interviews can be found in Table 4.2. It should be noted that the interviews could not be recorded due to the nature of the information discussed. In this case, only handwritten notes could be used.

Table 4.2. Interview Recaps

Name	Position	Type of Interview	Day of Research	Duration (minutes)	Location
Isabella	Technology Integrator	1 Formal	21	50	Conference room near desk
		1 Validation	163	45	Virtual
		1 Gemba Walk	15	60	Factory Floor
Emma	Engineering Programmer	1 Formal	28	35	Virtual
Ivy	IT Business Partner	1 Formal	29	35	Conference room near desk
		1 Validation	183	45	Virtual
		1 Gemba Walk	17	60	Factory Floor
Olivia	Operations Business Partner	1 Formal	48	40	Conference room near machine
Opal	Research	1 Formal	55	30 minutes	Virtual
Ingrid	IT Architect	1 Formal	70	60 Minutes	Conference room near desk
		1 Formal	72	60 Minutes	Conference room near desk
		1 Validation	147	50 minutes	Virtual
		1 Gemba Walk	76	60	Factory Floor
Ellie	Maintenance/ Tooling Engineer	1 Gemba Walk	41	45	Factory Floor
Irene	IT Business Partner	1 Informal	22	90	Conference room near desk
Olga	Operator	Gemba Walk	49	360	Factory Floor

The day of research shows when in the study the interview was conducted and how far apart each interview was from one another. The study started with Isabella, who was a technology integrator, in the Advanced Technology team. Through the snowballing method the interviews spread to different teams and individuals in various roles. The time in between interviews allowed for processing the previous interview information as well as begin the introduction and set up of the proceeding individuals interviews. From the table it can also be observed that one Gemba walk was done with the operators. This was done earlier in the project to better understand the machine and process, in addition to providing more context for the rest of the interviews. ‘Gemba’ is another Japanese word meaning ‘real place’ [96]. In manufacturing, the ‘real place’ is the shop floor at the station being evaluated. These walks are an opportunity to be immersed in the process and to gain the perspective of the person involved [96].

4.3.2 Overview of Roles Interviewed

To better understand the interview data, a brief description of each position will be provided. From the IT team, there were three individuals that were interviewed. One was a technology integrator, which focuses on the technology being brought in and standing it up to the specified requirements. Another was the IT business partner, whose responsibility was to interact with other departments and support the development of the department’s strategies. The person interviewed was in the role during the implementation, but had since changed roles, which is why another IT business partner, who was currently in the role was interviewed informally. The third was an IT architect. This role’s responsibilities were often to map out the networks of different technologies. On this project the IT architect helped breakdown the engineering requirements and illustrated it in such a way that made it easier to process.

From engineering, a programmer was interviewed. This individual worked with the research team to help develop the technology for the automated machine. Additionally, an informal interview was conducted with the tooling/maintenance engineer. This individual was responsible for making sure the machine was running properly and assessing downtown. This person was often at the standups sharing updates on the machine.

From the operations team there was a range of people interviewed. One was the operations business partner. This role's main function is to support different parts of the factory to ensure the resources are available to minimize downtime. This person had a large role in the implementation from starting to then supervising the project. Another person interviewed was on the operations research team. This team focused on helping integrate improvements to the machines that were already stood up in the factory. Lastly were the operators, who were the end users interacting with the machine.

4.3.3 Interview Recap

Reviewing Table 4.2, everyone was given an alias for anonymity purposes. The location of the interviews was also heavily considered to ensure a familiar environment, which is why the conference rooms were chosen near the interviewees desk or on the factory floor. Also, some interviewees offered to do a walkthrough of the factory. This ended up showing how the perspective of the factory changes based on the role of the individual. Not surprisingly, the individuals in IT focused more on the technology during the walkthrough, while those in engineering focused more on the machines and production processes.

4.3.3.1 Overview of Interviews

In total, there were 7 formal interviews, 3 informal interviews, and 3 validation interviews. The informal interviews were primarily focused on general information regarding the machine and current process, as the interviewees were not directly involved in the implementation but worked with the machine in its current state. The formal interviews followed the semi-structured interview approach and each interviewee was asked the questions in Table 4.1. The semi-structured interview approach allowed the flexibility to ask clarification questions as they were needed throughout the interview, which was particularly helpful for company specific acronyms.

Once the data had been aggregated and the process model was created, the validation interviews were to review the information gathered in the formal interviews, as well as validate and gather feedback for the process model found in Figure 4.6. The key feedback received was the process model would represent more of a “perfect-state” implementation. It also reinforced some of the challenges that were identified during the interviews.

4.3.4 Common Words in Interviews

Based on the six people of which formal interviews were conducted, there were several common words identified. These words were totaled and then aggregated in Figure 4.2. The one word that was highlighted in all interviews was ‘standardization.’ While the context varied based on the interviewee, several pointed out the lack in standardization of individuals on the team. Since this was a multi-year project, people rotated in and out of positions frequently. This caused challenges with team familiarity, which in turn can affect the performance of collaboration and knowledge sharing [64]. From the interviews, it also became apparent that there was not a standard process for requirements tracking. For those involved in the implementation there was mention of requirements being the responsibility of each team and providing those at the weekly project meetings and then uploaded to a file-share. However, after a certain point in the project, there was so much information and nobody was identified to be tracked requirements this way. This introduces an opportunity which will be discussed later in this paper.

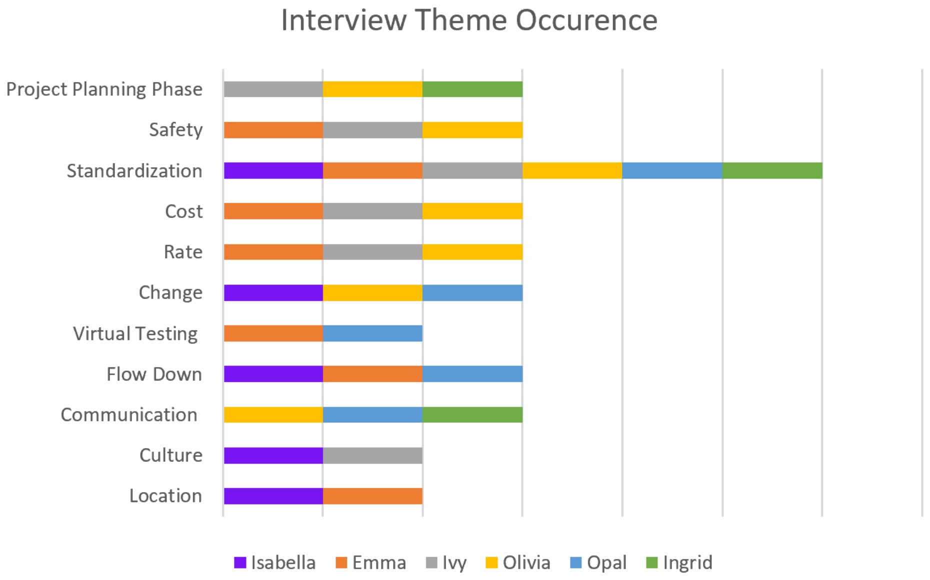


Figure 4.2. Interview Theme Occurrence

Many of the other words were referenced in half of the formal interviews conducted. These include project planning phase, safety, cost, rate, change, flow down, and communication. All terminology that is prevalent in manufacturing.

Another interesting point is that interviewees from IT addressed culture. One interview focused on how change is culture influenced and for there to be adoption individuals need a “change in behavior.” However, the question that results from this is how to effectively change a culture? The other interview addressed culture from the project team phase. With representatives from different departments each has their own culture. This can be seen through the different focuses and requirements that the teams had during the weekly meetings.

4.3.5 Interview Observations

Additionally, from the interviews, it became apparent that IT felt they were repeatedly being made aware of certain decisions after the fact, because the engineers wanted primary ownership of the project. It was mentioned that on several other automation implementations, an automated system would already be in the facility when IT would be made aware of it. During the interview, Isabella mentioned to fix this it requires a 'change in behavior' to accept a 'standard process,' but there is 'resistance to do something in a new and different way.' Enforcing a standard process would ensure that future technologies are following the specified requirements and can be stood up faster knowing it meets the requirements.

However, this is not the only instance where there seemed to be siloed teaming. Once the requirements would be brought back from managers after the weekly meetings, individuals would go about executing the job without much cross-reference with other departments. This "siloed teaming" is quite common amongst larger teams as they are more comfortable working with those that they know and relate to. Figure 4.3 shows interactions between roles during the implementation and illustrates some of the "siloed teaming" that was found from the interviews.

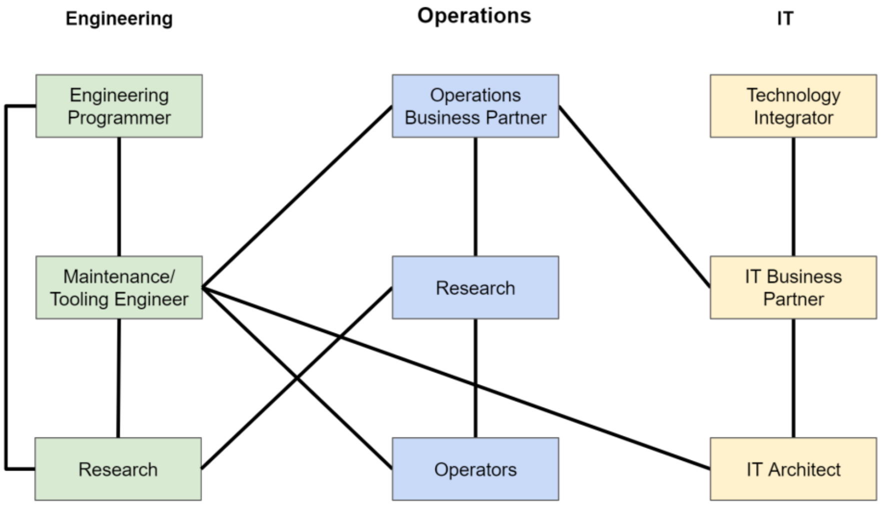


Figure 4.3. Collaboration Map

The collaboration map shows the individuals interviewed and the interactions mentioned in the interviews. If someone said that they had worked with someone else that was interviewed they would become connected on the map. However, it should be noted that this map does not identify all the interactions that each role had. This only identifies the people mentioned in the interviews.

One observation from this map is that few people mentioned interacting with the operators. With this being an automated solution that entails a close human-automation interaction, ideally the operator should have been involved in the implementation. In their interview, the operators mentioned that when the change was made, they were told what to do and how to do it. Following concepts of human-centered design, with the operators being the end user, they have superior experience that could improve the overall product before it is implemented in the factory. When asked about future implementations, Ingrid (IT Architect) did acknowledge the need to leverage the knowledge from the operator's experience. This reinforces a major opportunity for future automation implementations.

Upon aggregating all interactions identified in the interviews, the three core teams of engineering, IT, and operations became quite apparent. As previously mentioned, while all core teams are interreacting with one another to some capacity, there are opportunities to increase the communication and collaboration. This also highlighted an interesting relationship between the studied Human-Cyber-Physical systems (HCPS) from literature and the core teams, Operator-IT-Engineering. Figure 4.4 illustrates this relationship.

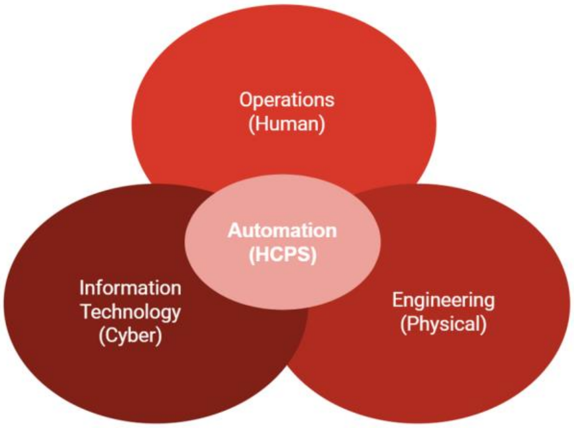


Figure 4.4 Relationship between functions and HCPS

Recall that HCPS focuses on the person interacting with the machine, which in this case are the operators working with the automation. The cyber aspect is the technology that goes into the machine, which IT helps implement those capabilities, and the physical system is the machine which is owned by the engineering team to maintain and sustain the operations. Therefore, these three core teams can be more deeply investigated to help further research on HCPS. From this relationship, perhaps a better understanding can be developed in how each elements of HCPS tie in with one another.

4.3.6 Process Obstacles

As was mentioned, during the interviews several obstacles were identified within the process. In varied capacities, all roles encountered obstacles. However, due to the relationship with certain interviews, not all obstacles were expressed explicitly. The hurdles that will be highlighted in this section were all discussed in the interviews.

4.3.6.1 Changes in Project Team

Within the multi-year development there were several critical obstacles identified. For the two roles interviewed that were a part of the Project Team (Ivy and Olivia), there was an emphasis on the challenge with a changing team. Each week the project team would meet, there would be a new representative from different departments. Through mention of losing expertise with people leaving this was identified as a hurdle. In the other interview, ‘large teams’ and ‘not fully standard teams,’ was repeated several times. This lack of a standard team creates a challenge of team awareness and furthermore, responsibility.

4.3.6.2 Requirements Tracking

Additionally, during this phase the only individual identified that was tracking requirements was a person in IT (Ingrid). Ingrid mentioned that when she came on the project nobody seemed to be tracking requirements. This meant that only the requirements that Ingrid was made aware of would be tracked, all others ‘lost’. Ingrid also mentioned the data being free floating. The challenge created by this was a lack in proper documentation. Hence, if the documentation was not updated, there runs the risk that individuals are working off of wrong or outdated information which could lead to change propagation later in the project [59]. Alongside this, since the changes were not communicated very well, the documentation did not change either. This effects the repeatability for future implementations, such as a “digital twin” reference.

4.3.6.3 Communication and Recommending Suggestions

Obstacles were also identified in interviews with the machine’s operation support team. From the research team, Opal used the word ‘disorganized’ when referring to the process and little communication when changes were being made to the machine. Similar to IT, the interviewee felt they were made aware of changes once it was already implemented.

However, the most obstacles came from the operators working on the machine. When asked whether they knew how to suggest changes, this became a major frustration from their limited ability to make suggestions. The operator mentioned ‘lost communication’ and this was repeated in several scenarios. While the Kaizen cards were the method of submitting improvements, they felt that nobody followed up on them because the appropriate changes were never made. In addition to this, there was not anyone they felt that they could follow up with except Opal in Research.

4.3.6.4 User Interface

Another challenge was regarding some of the user-interfaces between the operator and machine. They had expressed that they were not able to see some information that would be helpful for their tasks, but due to not being able to successfully suggest changes, they work with what they have. As was previously discussed, this is an opportunity with the human factor’s aspect of the human-machine interaction. The operators also mentioned the challenge of not having a step by step process written out for them. This becomes a challenge when operators are brought in and they are trained on the process at the machine versus with standard work instructions.

4.3.7 Use of Obstacles

With the goal of mapping the process model based on the interview data, as more obstacles were highlighted, they became opportunities for improving future implementations. The most challenges were found at the beginning and end of the process, which will be discussed later in CHAPTER 5. Further discussion on these process opportunities will be in Section 5.4.

4.4 Process Model

As was previously mentioned, the interviews helped map out the process model. Recall the goal was to understand *how* this machine was implemented. By interviewing individuals in different roles, information on the process was gathered, such as when people were brought into the project, their level of awareness, who they collaborated with, and their perspective on the implementation. Figure 4.5 shows a condensed form of the process model. Similar to the detailed process model, the colors represent different teams and gives a basic idea of the flow of tasks throughout the implementation.

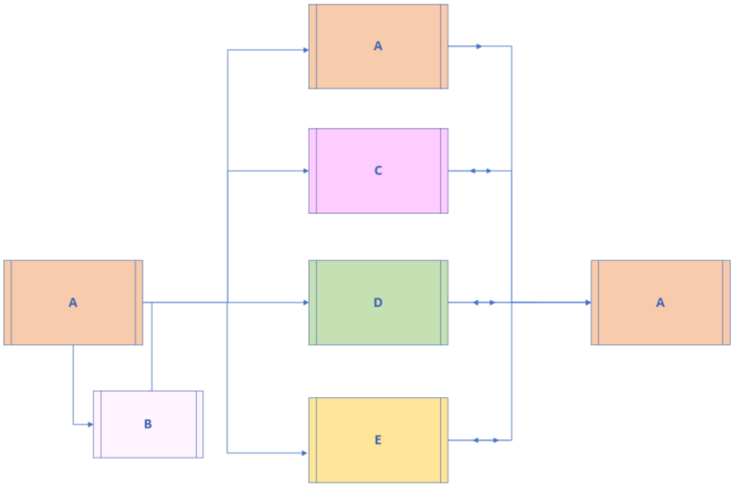


Figure 4.5. Condensed Process Model

The detailed process model that was built can be seen in Figure 4.6. Depending on the task, the shapes of the boxes represents whether it was an action (To Do), a formed team, or communication. Note that the different colored boxes represent different teams/roles. However, not all individuals that were a part of the implementation were interviewed. This was due to several factors, such as people no longer at the company and interviewees not remembering certain individuals due to the multi-year span. This detailed process model was also created at the high-level and kept general for future research on additional processes.

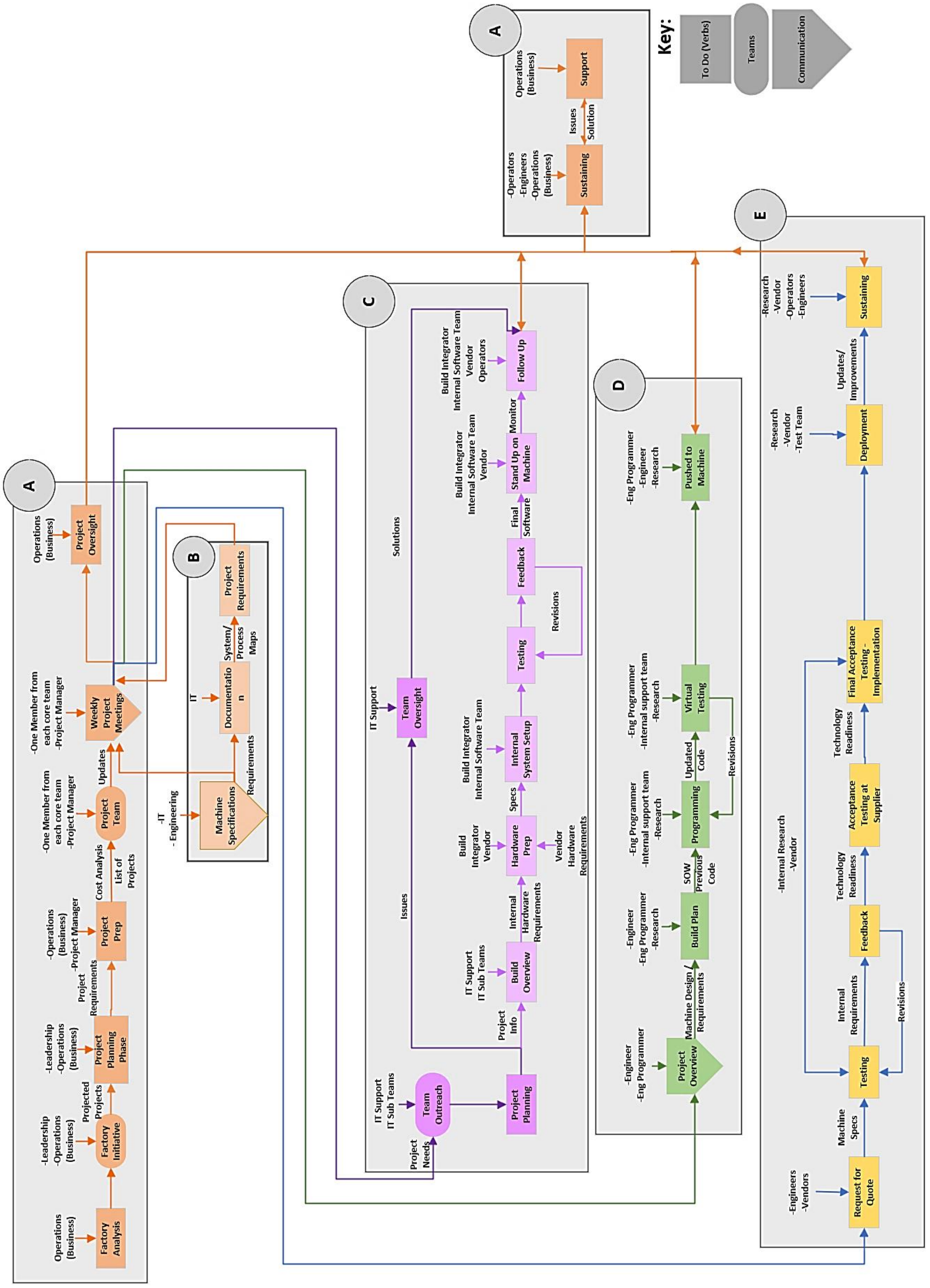


Figure 4.6. Process Model

To better explain the process model, Figure 4.7 shows what the arrow represents. Since this automation implementation was executed by internal teams and a vendor, there are internal and external inputs. This can be information such as requirements, project updates, etc. Above each task, is the assignee or the team that collaborated to complete the task. The arrow on the right is the output, which in-turn becomes the input for the next task.

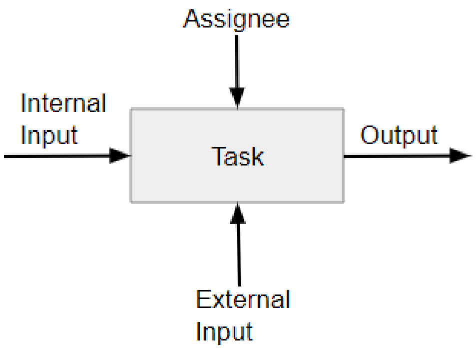


Figure 4.7. Process Model Explanation

4.4.1 Review of Process Model

Reviewing the model, the process started with a regular analysis of production by the business team supporting operations. During this time leadership was looking to promote an initiative for advanced technologies. Each project went through a reviewal process where the objective, plan, resources, and return on investment (ROI) got either approved or rejected by leadership. The approved projects went through a planning phase and then a project team was assigned accordingly. This project team would meet weekly for the course of several years to review requirements, help-needed, and other project needs. It was during this phase of the project where the project team was constantly changing, and different people would be sent to represent their department on an as needed basis. As the project developed and further details of the machine were specified, a person from IT architect familiar with building system models, was brought in to gather and track requirements. On a cross-functional team this helped build a visualization for the defined specifications.

After meeting weekly for the project meetings, the representatives would ideally then go back to their team and provide them with the action items. This is where the model starts dividing into the respective roles and tasks, which can be seen in Figure 4.6, as well as in APPENDIX B: FULL PROCESS MODEL. The business focal supporting operations becomes the oversight of the project and helps to mitigate any roadblocks the teams may encounter. Between the different roles in this phase, there is collaboration with the machine provider (vendor) and the required testing/feedback iterations to ensure the machine is functioning properly. Once the machine has been stood up in the factory, the operators are trained, and the machine is put into production. The sustaining period is the current state where the machine is supported by the operations business support to ensure the resources are available to reduce machine downtime.

This process model was validated as briefly mentioned in Section 4.3.3 Interview Recap. To validate, the individuals went through each step of the process model to verify the accuracy and provide feedback. From the feedback, this was an accurate implementation model, but it illustrated more of the ‘ideal state.’ The suggestions implied that the model needed to identify and highlight these challenges in the process, which is how the resistance model was created. This will be discussed later in CHAPTER 5.

The value in mapping a process like this is it provides a visual for the high-level steps that were required to achieve the implementation from beginning to end. With this being a multi-year project, from an internal perspective, it can be difficult to keep track of the step by step process. In fact, throughout the research, no implementation process or general process had been identified. While the process that was created may be considered rudimentary, it establishes a baseline for what an ideal implementation process should look like. This becomes useful for companies especially if they do not have a general to process to follow.

This case example was good to follow because it was a process change through the implementation of automation. Depending on who would be asked, the response would vary on whether this was a change management process or a design process. Much of the evaluation of upstream and downstream analysis was done in the front end of the project during the ramp up period, but this was a dynamic process as requirements changed throughout the project. When analyzing the process similarity to the McKinsey 7S Model, or even the Kotter's Change Management Theory, the beginning of the project certainly encompassed a change management initiative. A plan was created, a team was developed accordingly, a company initiative was formed, and resources were gathered. All of these seen in the study are examples of a change management process, specifically organizational change. However, once the project started and tasks were distributed amongst the different teams, elements of the engineering design process can also be seen throughout the model. Through generating requirements, prototyping, testing these are all seen throughout the implementation. This points to an interesting relationship between the change management process and the design process. Since both processes have elements that overlap, perhaps the change management is a derivative of the engineering design process. This will be explored further in the coming chapters.

Chapter 4 - Takeaways

- Three functions were identified from semi-structured interviews– Engineering, IT, and Operations
- Data from interviews were used to build a process model
    - Feedback was that this model portrayed the ‘perfect-state’
- Obstacles were identified throughout the change process and needed to be resembled in the process model

CHAPTER 5.

RESISTANCE MODEL

After changes are made often resistance follows shortly after [97]. Therefore, methods to reducing resistance has become of high interest in research. In change literature, resistance is often not defined due to assumptions that resistance is a known and common principle [98]. However, in this research, resistance is defined as obstacles and challenges that prevent the change from being efficient.

Based on the feedback from the validation interviews, the process model needed to resemble the challenges, or resistances, throughout the process. Additionally, as will be discussed later in this chapter, the relationship found between change management and design motivated the application of a resistance model to collaborative design. This chapter will cover previous research on resistances as they apply to design methods, apply the resistance to the case study model, review lessons learned, and highlight improvement areas.

5.1 Review Resistance Research

Previous research has looked to apply a collaborative design taxon to model resistance in a process [65,99]. The collaborative design taxon is divided into six core attributes: team composition, nature of the problem, information, communication, distribution, and design approach [65,99]. These core attributes are then expanded and extended to different levels [65,99], which can be seen in APPENDIX C: COLLABORATIVE DESIGN TAXON [104]. Depending on the resistance scale chosen by the researcher (low, medium, high or 1,3,9, etc), each task in a given design process would be evaluated for each taxon [99].

Taking the sum of values found for each taxon, as shown in Equation 1, provides the total resistance per task [99].

$$R_{\text{task}} = \left[\sum_{i=1}^{N} \frac{1}{R_i}\right]^{-1}$$

Equation 1. Total Resistance per Task [99]

In Equation 1, *N* is the number of applicable taxons evaluated for resistance [99]. Since the design taxon has seventy-seven lowest level elements, N will always be less than seventy-seven [99]. The variable *i* is the particular element in the taxon that is evaluated for resistance [99]. Comparing all of the total resistances calculated will highlight the tasks with highest and lowest predicted resistance [99].

5.2 Limitations to Proposed Resistance

With the proposed resistance being applied to collaborative design, there are limitations applying it directly to the case study example. Based on the process model observations, Figure 5.1 shows the perceived process relationship throughout the implementation.

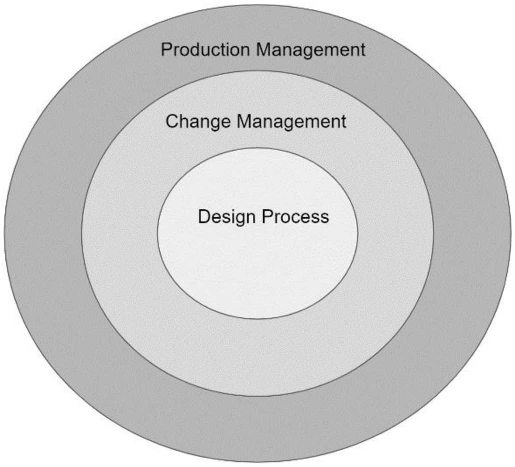


Figure 5.1. Observed Relationship in Process

Since the objective of this automation project was to improve production processes, the motivation is associated with production management [100]. Production management involves altering elements in the manufacturing process to achieve the desired output [100].

Observing trends in production such as throughput and efficiency help to identify these opportunity areas. This initiates the change management process where a strategy is developed, a company initiative is formed, the skills needed are acquired, and a team is created. The front end of the process model follows closely with the change management process. As the project develops, it starts forming into the design process. Requirements are generated, prototypes are created, testing is done, and improvements are made. While these three processes are coupled, they are not the same.

In this case study, there are three processes to account for. However, the proposed resistance model has only been researched for the design process. Therefore, a direct application to this example has its limitations. There were challenges applying resistances from the collaborative design taxonomy to tasks in the change management process. However, for purposes of this research, the taxons were selected based on their applicability for all the tasks in the process model and then the resistances were calculated.

5.3 Application of Resistances

Taking into consideration the limitations with the previous work on resistance, a direct application was not feasible. For this reason, the taxons needed to be filtered for their applicability to this scenario and then a ranking process needed to be outlined. This section will introduce the process used to find the resistance, review a few examples from the model, and discuss some of the taxons not used in the study.

5.3.1 Process Used to Apply Resistance

Some of the limitations to the previous resistance research is that there are no definitions or standard process for determining the resistance values. For this reason, a protocol was created to be able to apply the resistance model. Future research should identify a standard process.

From the taxonomy, three key categories were applied for this case example: Team composition, Information, and Communication. Each of these categories had components that were evaluated through the resistance model: Group size, group culture, problem abstraction, problem complexity, information form (design artifact/background), ownership, information dependability (completeness), and verbal/written communication. Each task identified in the process model was analyzed and using a geometric scale was given a low (1), medium (3), or high resistance (9) for each category.

The protocol for applying resistance values is as follows: Group size was ranked a low resistance for teams smaller than 5 people, medium resistance for teams between 5-10, and high resistance for teams greater than 10 people. Culture was dependent on how many different departments were contributing to a task, as the focus was on shared or unshared culture amongst functional teams. Low resistance was if there was one department per team, medium resistance was if there were 2-3 departments per team, and high resistance was if there were more than 3 departments per team.

Abstraction of the problem was based on how much information or context was available for that task. If this was a routine task it was valued with a low resistance. If there was a set objective, or context to the problem but certain elements were unknown or changing, such as requirements, then it was considered to have a medium resistance. If the task did not have many guidelines or parameters or did not seem to have much context to the project, it was considered to have high resistance.

Complexity was based on its definition, whether the task had many embedded steps or whether it was a more simple process [101]. If there were any challenges identified, this was considered into the complexity scoring. If the task was easy to accomplish and had few steps it was considered low resistance (1). If the task had some challenges and few intertwined steps it was considered medium resistance (3). If the task had many challenges and many connected steps it was considered high resistance (9).

The information form (design artifact or background) was evaluated based on how information or context was available for each task. If the context of the task was well known and the information was readily available, then this was considered low resistance (1). If there was some context, but some information needed further investigation, then this was considered medium resistance (3). If there was little context to the task, a lot of unknowns, and little information available at the start of the task, this was considered high resistance (9).

Ownership was evaluated based how many people were responsible for the tasks. If there was one role responsible for the task, then it was considered to have a low resistance (1). If there were a couple of roles responsible for the task, and there was an obstacle identified regarding who “owned” the task or product, then this was considered medium resistance (3). If there were several teams and the responsibility was unclear, then this was considered high resistance (9).

Completeness evaluates the task based on the amount of changes that will be made to the information after the task is completed. If there were few to no changes to the information in later tasks, then the completeness for the task was rated a low resistance (1). If there were some changes occurring during the task that would change the information during that task, then this was considered medium resistance (3). If there were many changes to the information in proceeding tasks, then this was considered to have a low completeness leading to a high resistance value (9).

Lastly, for communication, the verbal/written mode was evaluated based on the amount of perceived communication. The team familiarity would also be considered during this step, as well as team size, as information sharing often becomes more challenging as team size increases [102]. If there were no challenges identified with communication or collaboration and high team familiarity, then the task was evaluated a low resistance (1). This follows with high team familiarity leading to higher team performance [64]. If there were some challenges identified with communication or collaboration during a task, then a medium resistance (3) was applied. If there was low team familiarity due to turnover or issues communicating due to department specific vocabulary (acronyms, etc.), then this was considered a high resistance (9).

5.3.2 Resistance Ranking

An example for how the tasks were rated for resistance can be found in Table 5.1. The three example scenarios that were selected were pre-change analysis, a planning program, and weekly all-team project meetings. The pre-change analysis is where the current business process is evaluated, which primarily consisted of business support individuals. The planning program is the projection of the future business process, such as calculating return on investment. This usually involved business support and leadership. The weekly all-team project meeting were status updates throughout the life of the project involving a representative from all core teams of the company. This resulted in a large cross-functional rotating team. These examples were chosen because of the distribution between low, medium, and high resistance tasks.

Table 5.1. Examples of Resistance Ranking

			Factory Analysis	Project Planning Phase	Weekly All-Team Project Meeting
Team Composition	Group	Size	Low	Medium	High
		Culture	Low	Low	High
	Abstraction		Low	High	Medium
	Complexity		Low	Medium	High
Information	Form (Design artifact or background)		Low	Low	Medium
	Management	Ownership	Low	Medium	High
	Dependability	Completeness	Medium	High	High
Communication	Mode	Verbal / Written	Low	Medium	High
Total:			Low	Medium	High
R_{task}			0.1200	0.257	0.6923

The resistance values that were applied were based on the authors interpretation of the case study data. However, the values were supported with literature as applicable. Reviewing each of the resistance values that were applied, the pre-change analysis consisted of a small team size (less than 5 individuals), therefore it was labeled with a low resistance. The project planning phase consisted of medium team size (between 5 and 10), so it was given a medium resistance rating. However, the weekly all-team project meetings were given a high resistance rating, because the size of the team was large (greater than 10).

Next was the evaluation of culture, which was viewed as shared or unshared culture between cross-functional teams. While there are many advantages to cross-functional teams, there are some challenges that follow with it. From literature, functional characteristics, such as language (team specific acronyms, etc.) and team responsibilities can create a hurdle for effective collaboration [103]. So, following the composition of the teams, since both the factory analysis and the planning program consisted of mostly members from the same department, they were labeled with a low resistance. While the weekly all-team project meeting consisted of over seven different functional departments, the unshared culture led to a higher resistance.

The next evaluation was for the abstraction of the problem. As previously stated, the pre-change analysis was a routine analysis of the factory process, meaning it was a more concrete process, deeming it a low resistance [104]. The planning program was the development and refinement of the project. Since this was an opened-ended step, a design team could have aided in the abstraction of the task. However, this was a team consisting of individuals from the same department proposing a plan to leadership. This plan consisted of a broad project idea, return on investment, and resources needed, however, this information was high-level and is what led to a high resistance [104]. This defining stage of the planning program could have benefited from a diverse team to help work through some of the ambiguity in this step. With the weekly all-team project meeting while there was a problem statement, there were many elements that needed defining along the way, but there was more context to the task, so the level of abstraction was considered intermediate. Additionally, since there was a cross-functional 'design team', the resistance was lower than the planning program. For this reason it was evaluated as medium resistance [104]. Lastly, complexity was evaluated based on its definition looking at the degree of overlapping components and difficulty to complete the task [105,106]. The factory analysis was reviewing the production data and processes. This was done routinely to ensure timely throughput, so the complexity was low leading to a low resistance. For the project planning phase, there were several components that affected the outcome of this task, but it also could be completed with less difficulty by having the right information. For this reason, the resistance was considered medium. Now due to the many overlapping components in the weekly project meetings and the challenges faced with larger team this led to a high complexity resulting in a high resistance.

The next section to be evaluated was on the information, specifically the design artifact and background [99]. The design artifacts are the information and data that provide context to the project or task [65]. The resistance scoring was based on the presence of design artifacts, the less information the higher the resistance. Since the factory analysis was all based on manufacturing data, this stage curated many artifacts, this resulted in a low resistance. Since the planning program required presenting the design artifacts to leadership for approval, such as defining the context of the project, the return on investment, etc., this resulted in a low resistance. As the project picked up speed, the weekly all-team project meetings generated project updates and defined requirements. However, the resistance here was the lack of thorough tracking of these artifacts, resulting in medium resistance. A high resistance rating would be if there were no design artifacts or context to the given task.

The next evaluation was on the ownership of the information. In this project, it seemed that the more teams that were involved, the more distributed the ownership was on who was able to make changes to the information. This relates closely to change management [65], because if someone made a change and any questions arose, then proper documentation would provide with who made the change so they can be contacted. Additionally, with more individuals capable of making changes to the information there is less sense of ownership which can cause resistance if individuals are not making the proper updates as a result of relying on someone else to make the appropriate changes [65]. For the pre-change analysis, since there was only one team involved, few were able to make official changes to documentation which is why the resistance rating was low. For the planning program, since there were several teams involved this increases the ownership of the information, which is why the resistance is medium. Similarly, since the weekly all-team project meetings involved all the core teams (7+ teams), the ownership of the information was widespread, which led to a high resistance rating.

The last resistance evaluated for information was for the dependability and completeness. Completeness evaluates the task based on the amount of changes that will be made to the information after the task is completed [107]. While the pre-change analysis evaluated the production process, changes were always being made to the process which meant the information was changing, this resulted in a medium resistance. Due to the high level of abstractness in the planning program, particularly when defining the project, there were a lot of variables that needed to be defined later in the project. For this reason, the resistance was considered high. The reason the weekly all-team project meeting was also rated a high resistance was because it was the responsibility for each team to update and add their information to the shared database, however, the information stopped being updated causing incomplete information. Incomplete information causes resistance and can introduce issues later on in the process [65,104].

The next section evaluated was communication throughout each task. The modes of communication identified for this project were both verbal and virtual (written). The resistance rating was evaluated based on the team size, as information sharing becomes more challenging as the team size increases [102]. Applying this, the factory analysis had a lower resistance, the planning program had a medium resistance, and the weekly project meetings had a high resistance. APPENDIX D: RESISTANCE DATA shows all the taxon resistance values for each of the tasks found in the process model. Taking this data, the total resistance for each task could be calculated and was added to the resistance model.

5.4 Lessons Learned from Resistance Model

The constructs of the resistance model are based on the process model tasks and circuit properties. Figure 5.2 shows the proposed resistance model, a larger model can be found in APPENDIX E: RESISTANCE MODEL. The resistors represent that each task exhibit resistance to some capacity. The switches found at the beginning signify critical decisions made throughout the project. For example, there is a switch after the project planning phase because leadership decides whether to invest in the project or not. Depending on the decision, the switch will be open or closed to either pause or continue to the next step, respectively.

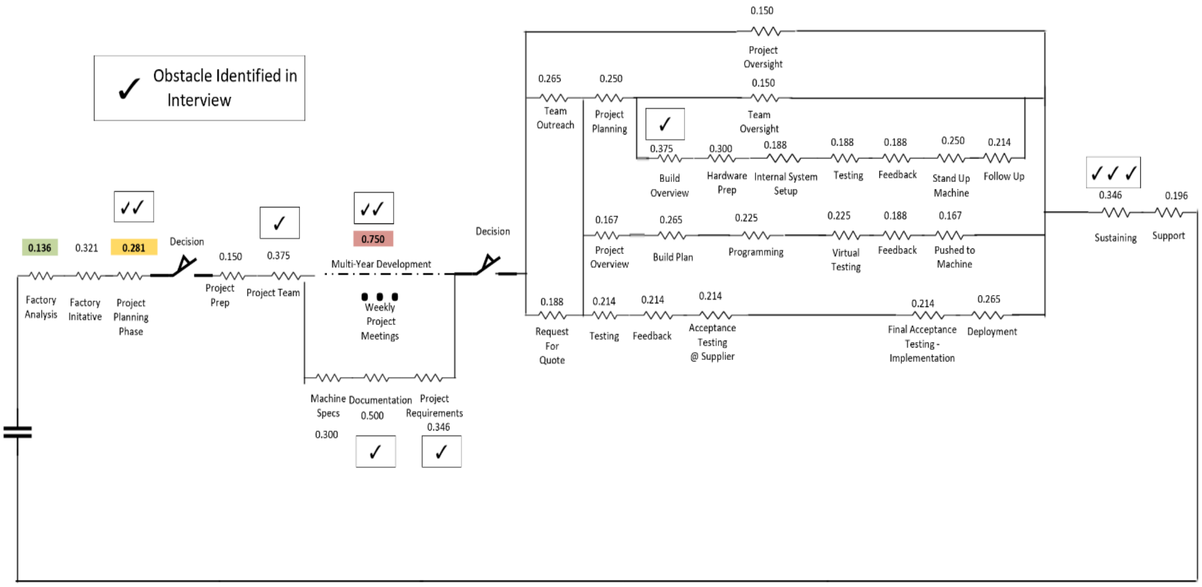
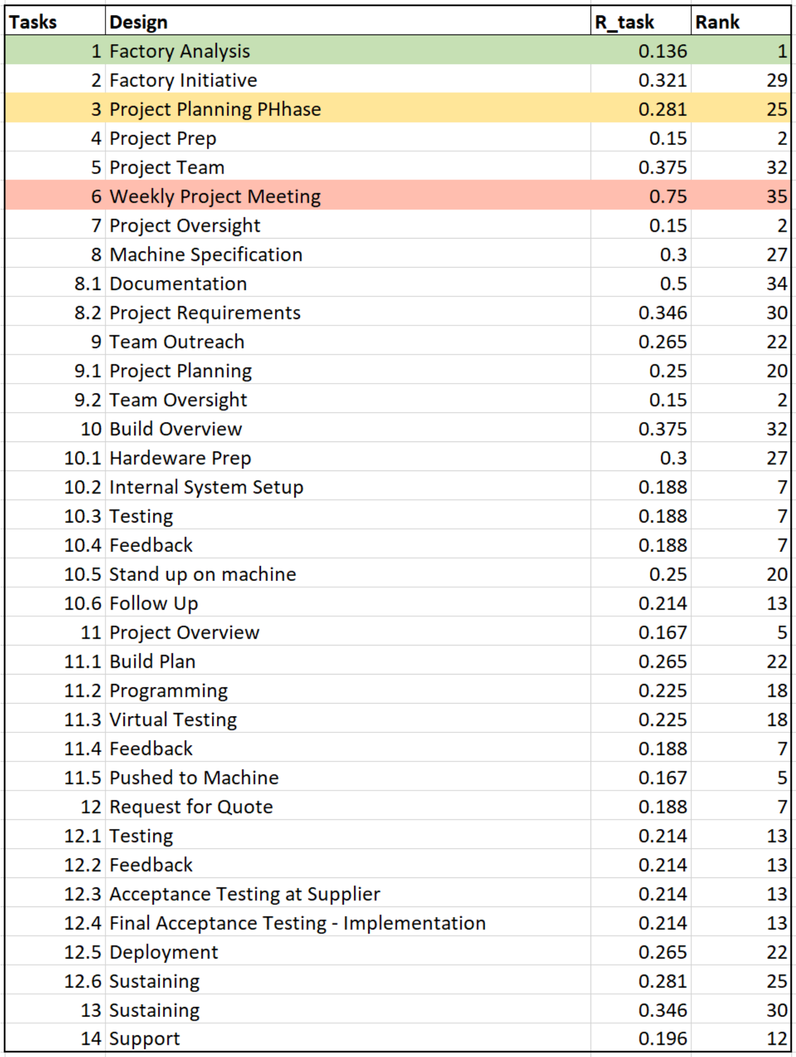


Figure 5.2 Resistance Model

Taking each of the taxon resistance values per task and plugging them into Equation 1 gives the total resistance per task. The aggregated data can be found in Table 5.2. From the table, Task 1 'Factory Analysis' has the lowest resistance Task 6 'Weekly Project Meetings' has the highest resistance. Each of the resistance values per task are also depicted in the resistance model from Figure 5.2.

Table 5.2. Resistance Value per Task



Tasks	Design	R_task	Rank
1	Factory Analysis	0.136	1
2	Factory Initiative	0.321	29
3	Project Planning PHhase	0.281	25
4	Project Prep	0.15	2
5	Project Team	0.375	32
6	Weekly Project Meeting	0.75	35
7	Project Oversight	0.15	2
8	Machine Specification	0.3	27
8.1	Documentation	0.5	34
8.2	Project Requirements	0.346	30
9	Team Outreach	0.265	22
9.1	Project Planning	0.25	20
9.2	Team Oversight	0.15	2
10	Build Overview	0.375	32
10.1	Hardeware Prep	0.3	27
10.2	Internal System Setup	0.188	7
10.3	Testing	0.188	7
10.4	Feedback	0.188	7
10.5	Stand up on machine	0.25	20
10.6	Follow Up	0.214	13
11	Project Overview	0.167	5
11.1	Build Plan	0.265	22
11.2	Programming	0.225	18
11.3	Virtual Testing	0.225	18
11.4	Feedback	0.188	7
11.5	Pushed to Machine	0.167	5
12	Request for Quote	0.188	7
12.1	Testing	0.214	13
12.2	Feedback	0.214	13
12.3	Acceptance Testing at Supplier	0.214	13
12.4	Final Acceptance Testing - Implementation	0.214	13
12.5	Deployment	0.265	22
12.6	Sustaining	0.281	25
13	Sustaining	0.346	30
14	Support	0.196	12

The resistance model also shows the obstacles that were identified in the interviews, represented as check marks. An interesting observation from this is that the most obstacles were found at the beginning and end of the process. This could be a result to the many changes that were occurring during these phases of the project. At the beginning, many requirements were changing as the project developed. Depending on the level of communication or collaboration regarding these requirements can affect the success of proceeding tasks. Additionally, as identified in previous sections, there was high change amongst the representatives in the weekly project meetings. At the end of the project, sustaining the machine created major changes at the operational level. In all, the preparation and planning for these changes seem to have a heavy influence on the resistance or adoption to these changes.

Looking at the high resistance values and the obstacles in the model, the resistance values did identify where the challenges would be in the process. While the interviews were used to apply the resistance values, these highlighted objective characteristics which were used to build the process model, and then resistance model. From the resistance model the top resistances were identified. The interviews also highlighted subjective obstacles from each individual. The top resistances from the model and the subjective obstacles were then compared to determine that the resistance model accurately identified the challenges in the process. Figure 5.3 illustrates this interview data comparison.

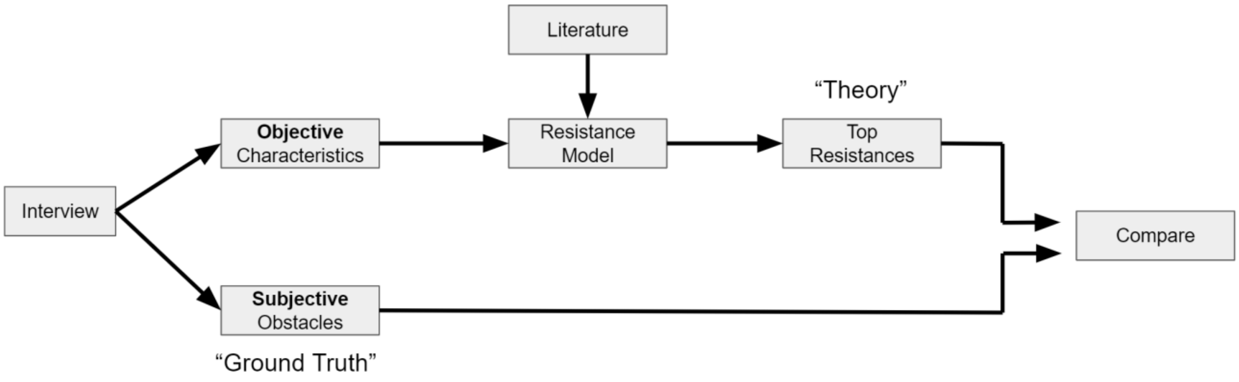


Figure 5.3. Interview Data Comparison

5.5 Resistance Model Improvements

There are many opportunities to improve the resistance model presented here due to the limitations of previous research. The resistance model would certainly benefit from a more well-defined scoring method. This would greatly enhance the objectivity of the resistance scoring when applied to a future process.

In addition to this, the taxon used for the resistance scoring was specifically for collaborative design. To make this more applicable, the resistance model would benefit from a change management taxon. Since the process was divided between change management and design, an additional taxon would help improve the resistance rating for each of the tasks.

To review the resistance data, another opportunity area would be to have several people code the resistances and use statistical methods, like inter-rater reliability to verify the results. This would help ensure that the rating process was clear and consistent amongst the raters, as well as increase the validity of the results.

Chapter 5 - Takeaways

- Limitations to a direct application of the collaborative design resistance model to this change management process
- Design process was found embedded in the change management process
- Resistance model showed the tasks of highest resistance
    - These tasks of highest resistance matched with subjective obstacles

CHAPTER 6.
RESEARCH QUESTIONS ANSWERED

Alongside the change to the manufacturing process, there were many other changes identified within the implementation process through building a process model. From the case study data, the more changes that were encountered in the task led to higher resistances. Mitigating these resistances with a thorough change management process will reduce cost and time [108]. This section will cover the answers to the two proposed research questions addressed in Chapter 2.2.

6.1 Answers to Research Question 1

What is the change management process for large-scale automation implementations processes?

During the case study there was no formal change management process identified. Therefore, to understand the implementation, a change management process was mapped based on the case study data, which was shown in Figure 4.6. Comparing to other change management processes found in literature, this process had a defined goal for what the company wanted to achieve with the implementation. However, throughout the change process there did not appear to be a structured team. There was a heavy rotation in the representatives in the weekly project meetings which led to a high resistance. Despite this, there was a level of awareness to the changes due to the factory initiative. By getting the entire factory involved helped empower the employees to be a part of the change, even if they weren't directly involved in the implementation. Lastly, with this being a multi-year project there was plenty to learn about the process. In the interviews, this implementation was considered to have been better than others. However, there was no clear justification provided to support this. Through a project debrief, the lessons learned and process overview could have identified opportunities for future implementations. Table 6.1 shows the key elements found within the case study process model. Recall in Chapter 2.1.5, this table was used to compare other change management processes from literature to the key elements found for successful change management. The conclusions from the constructed change process show that there was defined goal and an awareness of change. However, due to the rotation in team representatives, there was not a structured team, nor was a project debrief identified.

Table 6.1. Change Process Elements

Change Model	**Defined Goal**	**Structured Team**	**Awareness of Change**	**Project Debrief**
Case Study Process Model	**Yes**	**No**	**Yes**	**No**

Through validation interviews, it was confirmed that the process model represents a ‘perfect state’ implementation, however, it did not identify some of the obstacles that were encountered throughout the process. Therefore, a resistance model was applied to identify the tasks of highest resistance and was verified with the subjective challenges from the interviews. To conclude, the resistance model accurately represented the challenges identified throughout the process.

6.2 Answers to Research Question 2

How does the Change Management Process differ from the Design Process?

Upon constructing the change management process, it appeared that there were many similarities with the design process. After comparing the characteristics of both processes from literature, it became apparent that, in this scenario, the design process was embedded in the change management process. Figure 6.1 shows elements of change management and design processes. The black dotted section of the process coincided with the change process at the frontend of the project, while the solid blue box signified tasks that followed the design process.

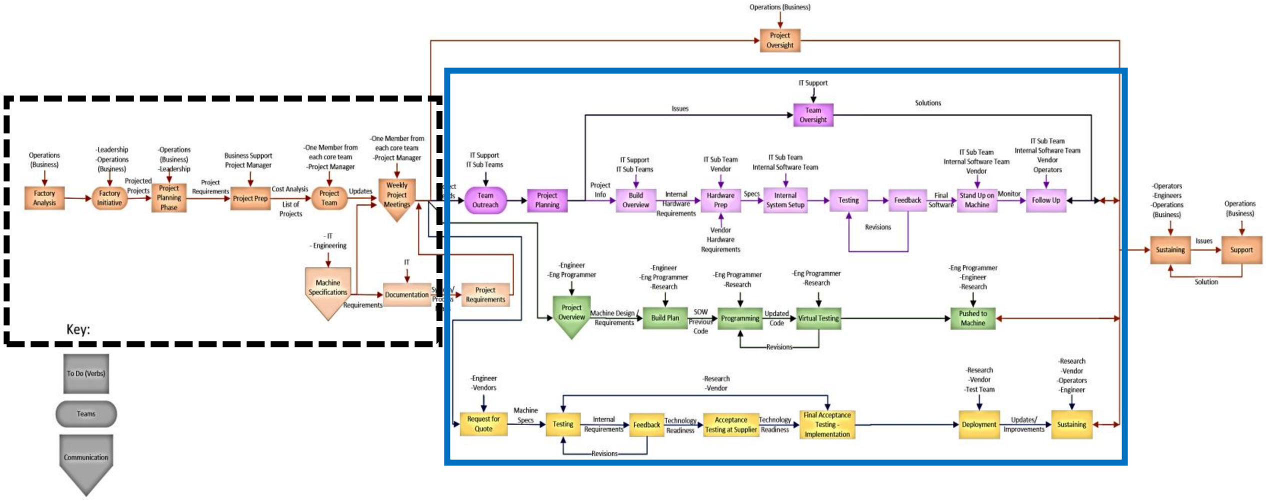


Figure 6.1. Identified Change Management and Design Process

As previously discussed, even though the processes appear to be similar, they are distinct processes. While in this scenario, the design process is embedded in the larger change management process, this does not mean that the design process is a part of the change management process or vice versa.

To distinguish the two, in this case study, the change management process focusses mainly on the human element [66]. While design processes can be people-centric as well, in this example, it was found that the design process was problem and solution focused. For an automation implementation, there are human elements to consider, as well as machinery and tooling to account for. Therefore, it is logical that the process was a combination of change management and design processes. Further research should continue elements of this study to identify whether this holds true for other automation implementations, or whether this combination was case specific.

Chapter 6 - Takeaways

- Change process was constructed based on case study data
- Change management process and design process have many similarities, but are distinct processes
- In this scenario, change management process was people-centric and the design process was problem/solution focused

CHAPTER 7.
OPPORTUNITIES AND RECOMMENDATIONS

From this research, it is apparent that automation implementations are quite complex and there are many intertwined, variable parts. Like any manufacturing process, there are always opportunities for improvement. Based on observations from this study, this section will highlight some recommendations for future implementations. The following list are suggested opportunities for future implementations that resulted from the obstacles addressed in the interviews:

- Thorough documentation and requirements tracking
- Construct a standard process model, ending with a project review
- Strong involvement of IT in the development phase
- Increased communication and collaboration between all teams
- Incorporate the operators at the beginning of the process

In a project, requirements help establish what criteria needs to be achieved. As such, requirements can also help measure the success at the end of the project, based on whether they have been achieved or not. Since requirements are often dynamic and can change throughout the course of the project, proper documentation of this information is critical. For future implementations, thorough documentation and list of requirements creates a foundation for proceeding projects. It is suggested to standardize the requirements process and ensure that all teams are contributing and making updates to the requirements accordingly. While requirements documentation can help align all departments involved, it can also help track useful technological knowledge.

In conjunction with requirement standardizations, there should be an overall standard process to follow for these types of implementations. With so many different components to the project, having a general best practice process will provide guidance to the implementation teams. Additionally, a database of feedback and lessons from each completed project can enhance the efficiency of the process, in turn improving future implementations. These guidelines can accelerate the project schedule and mitigate running into common obstacles. These different lessons learned from each project can provide basic parameters to follow for future implementations.

As was seen in this project, automation implementations require a large set of diverse skills. However, with the increase of digital technologies within these systems, the involvement of IT is required more than ever. Especially as companies begin to setup and standardize their own technological requirements, IT is typically the only department to proficiently set up these processes. From this, it is recommended to increase the collaboration between engineering and IT earlier in the development phase to ensure the physical and hardware requirements align and the standardizations are met prior to the machine entering the facility.

Alongside this, increasing the communication and collaboration cross-functionally will help to decrease the siloed teaming observed throughout the process. Challenges often arise when there is a lack of communication or missing information. To prevent this throughout the process, it is suggested to increase the cross-functional teaming to bring awareness to other departments.

Finally, the operators are such a valuable aspect to the automation implementation process. Through daily interactions with automated systems, operators can provide helpful manufacturing insight to the process. Taking the principles of user-centered design and the overall user-experience, the operator should help develop the requirements and provide input prior to the machine being brought into the factory. For this reason, it may be helpful to include the operators earlier in the design process, while developing these machine requirements.

Chapter 7 – Takeaways

Opportunities identified throughout the process:

- Thorough documentation and requirements tracking
- Construct a standard process model, ending with a project review
- Strong involvement of IT in the development phase
- Increased communication and collaboration between all teams
- Incorporate the operators at the beginning of the process

CHAPTER 8.

CONCLUSIONS AND FUTURE WORK

This section will cover the conclusions, providing an overview of the study, the results and answers to the research questions. Additionally, future work topics will be proposed for advancing this research.

8.1 Conclusions

Smart manufacturing and Industry 4.0 literature introduces a broad range of topics on the advancement of technology, such as automation and IoT, in manufacturing. However, this literature does not discuss the implementation, or the change management processes for these topics. With continual changes in production environments, understanding the processes can help identify opportunities to increase the efficiency and reduce resistance to the changes.

To further study this, a case study method was used. This use of empirical research provided insight to how one automation implementation was conducted. While the findings don't guarantee repeatability, it creates a foundation for future work. The focus of this research was to answer the following two research questions:

Research Question 1: What is the change management process for automation implementations?

In this case study, since no formal change management process was identified, a process model was constructed based on the interview data gathered. This helped layout the core tasks in the implementation process, as well as visualize the collaboration amongst the different teams. The process model was a representation of the ideal state implementation. However, it did not identify some of the obstacles that occurred throughout the process. For this reason, a collaborative resistance model was applied to see where in the process was the highest resistance. The resistances indicate areas that are prone to cause delays or bottlenecks in the process. Identifying these areas in advance can lead to increased efficiency. The results from the process model led to the second research question.

Research Question 2: How does the change management process differ from the design process?

Throughout the analysis of the process model, several tasks resembled elements of design. Further analysis was conducted to see what distinguishes change management and design. The distinction identified is that change management is a people-centric process, while the design process is problem and process-centric. In the process model (Figure 4.6 and in APPENDIX B: FULL PROCESS MODEL), the front-end of the process was focused on preparing for the change by collecting data, forming the right teams, and creating awareness to the changes. As the project shifted towards integration and development of the automated system, there was an apparent shift to the design process. In this phase, many of the requirements were gathered and iterations of testing/modifications were done.

With automation implementations needing to account for human and machine elements, it is not surprising that the process accommodates for both elements. However, the combination of both processes (change management and design process) suggests the need for future work to attempt to distinguish and develop them further.

8.2 Future Work

The results of this study introduce new concepts that should be studied further. Since this process model was constructed based on the case example, future research would benefit from investigating how similar or dissimilar this process is to others found in industry. The following research questions are proposed for future work:

Question 1: How would small to medium enterprises affect the change management process?

With the amount of resources varying based on the size of the enterprise, the objective would be to see how the size of the company influences the change management process. Would less resources make an impact on the process or not?

Question 2: How would product changes (such as higher volume and lower complexity) affect the change management process?

The objective with this research question would be to determine whether product complexity influences the rigor of the change management process. Do less complex products have a more simple change management process or do they follow closely with the change management process found in this research?

Question 3: How would the change management process differ if followed from the beginning of an implementation?

In this research, we observed the process after the implementation was already completed. The objective of this question would be to see whether observing the implementation from the beginning would identify new elements or change the process found in this work.

Additionally, the resistance model was beneficial in identifying the areas of highest resistance in the process model. However, for future applications the following question and research objective is proposed:

Question 4: How would evaluating resistance prior to the implementation affect the obstacles within the change process?

This question looks to apply the resistance model prior to a change to see whether the challenges or obstacles can be mitigated, leading to a reduction in resistance.

Objective 1: Using artificial intelligence (AI) to predict the resistances based on the process model data.

As data is collected when changes are made, the objective would be to see whether artificial intelligence can predict the areas of resistance so that they can be mitigated prior to the implementation of a change.

Throughout the research, there were some limitations identified towards applying a collaborative design scenario to the change management process identified. For this reason, it is suggested that the resistance model would benefit from another taxon, but for collaborative change management. Additionally, the resistance model can be used to track information flow throughout the process through quantifying active knowledge (current) and passive knowledge (voltage). Measuring the current and voltage throughout the resistance model can provide a different perspective on the resistance from what was looked at in this research.

In the future, manufacturing will continue to adopt new technologies and will transform as industry shifts towards the fourth industrial revolution. In preparation, future work should look at the needs of the operators.

Question 5: What are effective methods of training these advanced technologies for future operators?

As more automation and advanced technologies are implemented, the needs of operators will change requiring a unique set of training. Thus, this question looks to investigate what methods will most effectively train and prepare operators.

Question 6: How can it be ensured that operators have been properly trained?

Alongside the previous question on training methods, this question seeks to know how much training is required. Since many of these advanced technologies do not involve trivial processes, it's important for operators to be fully trained prior to being put in production, but this measure needs to be developed.

Lastly, since this research constructed and validated the process model, it would be beneficial in future work to use another research method to gather the process model data. This could be done by having the participants build the process models themselves. This leads to the following research objective:

Objective 2: Conduct a workshop in which participants engage in mapping out the change management process.

By having the participants build their own model provides a different perspective. Such as real-time data on their thought process, feedback on the challenges identified during the change, and elements of collaboration throughout the activity. It would be of interest to see how similar or dissimilar this is to the process identified in this research.

Chapter 8 - Takeaways

- A Change management *process* was constructed from this case study
- Resistance model accurately predicted the challenges addressed in the interviews
- In this example, the design process was embedded in the change management process

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CHAPTER 10. APPENDICES

APPENDIX A: DYNAMO++ LOA EXAMPLES [6]

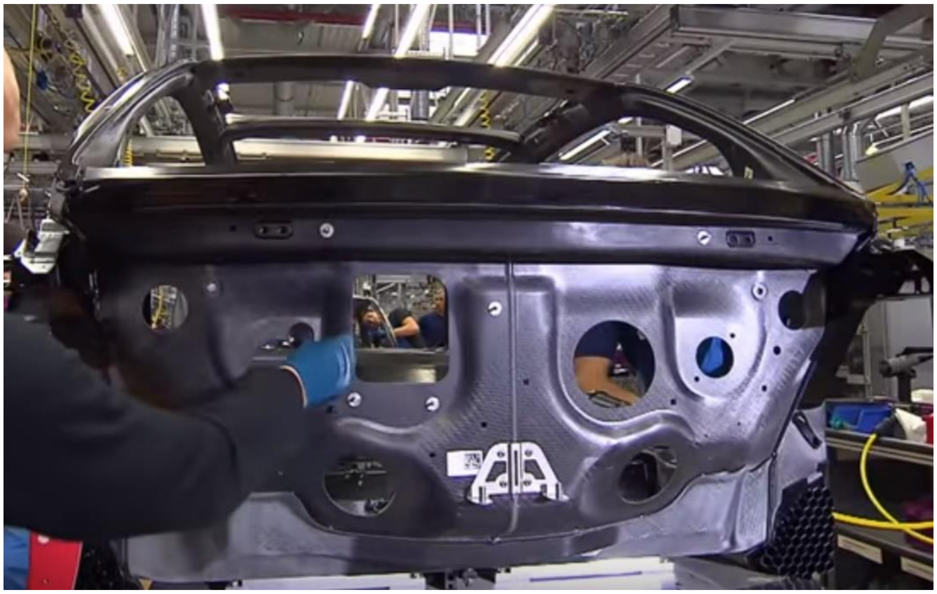


Figure 1: Operator places sticker component on vehicle (Physical: 1, Cognitive: 3)

Figure 2: Operator moves drill so machine can install screws (Physical: 5, Cognitive: 3)

Figure 3: AGV moves chassis throughout factory (Physical: 6, Cognitive: 7)

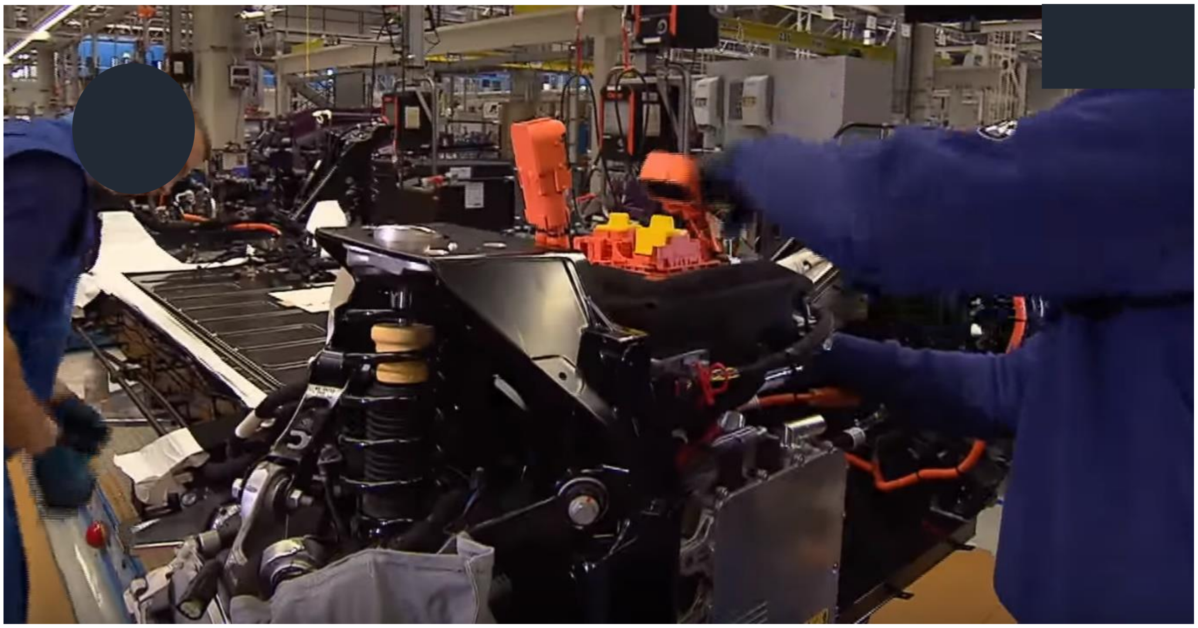


Figure 4: Operators connecting cables (Physical: 1, Cognitive: 1)

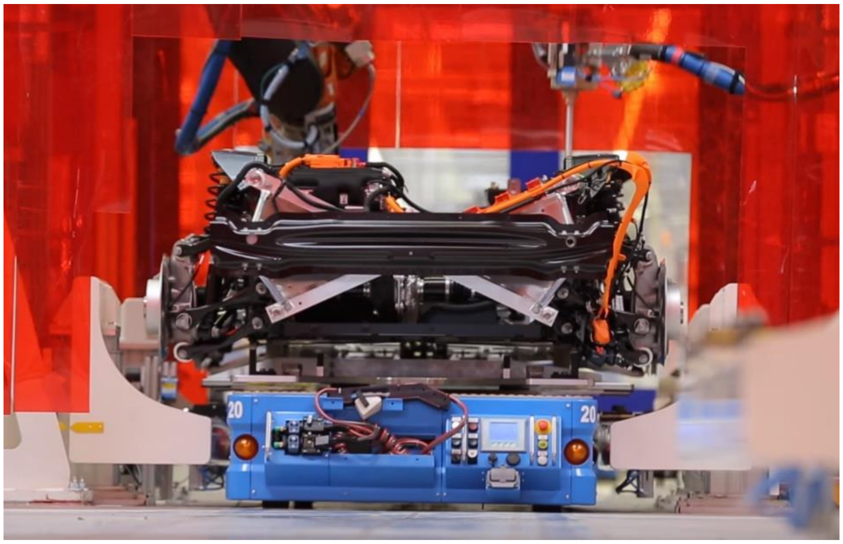


Figure 5: AGV brings chassis to machine for inspection (Physical: 7, Cognitive: 7)

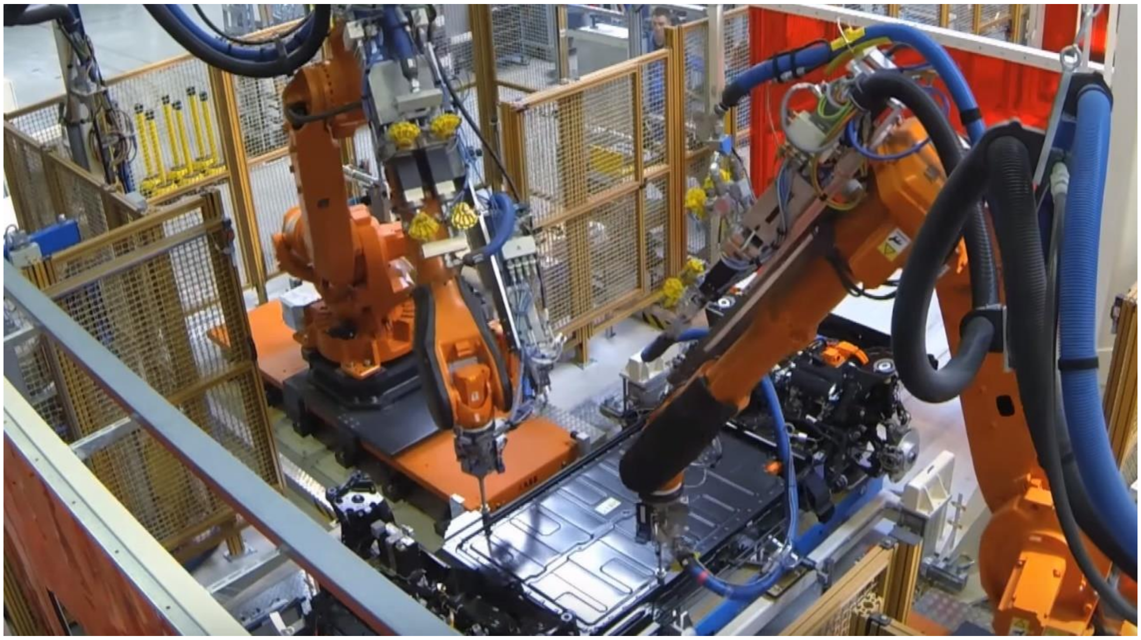
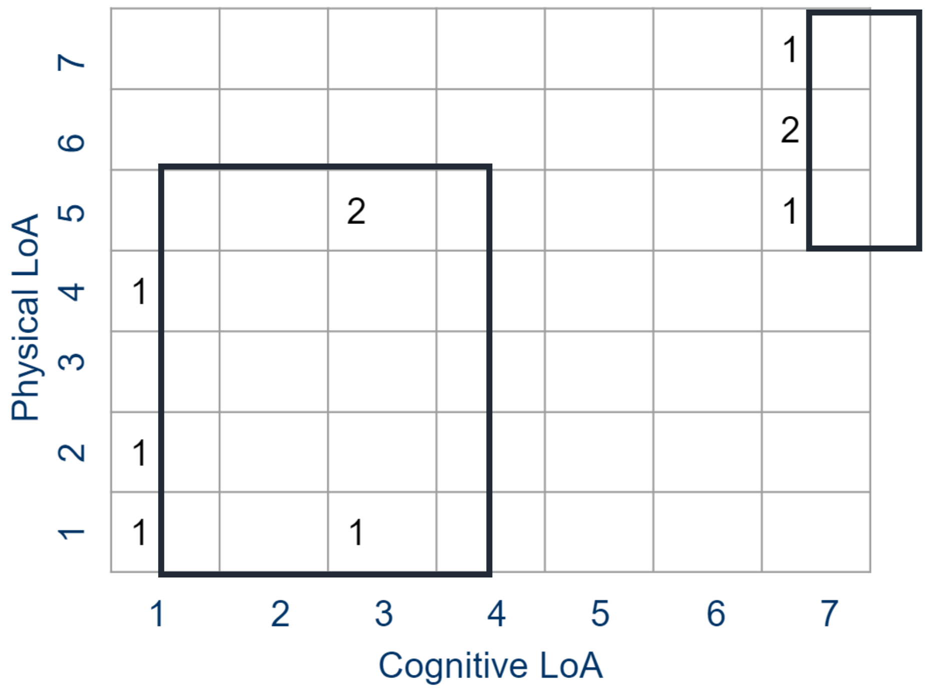


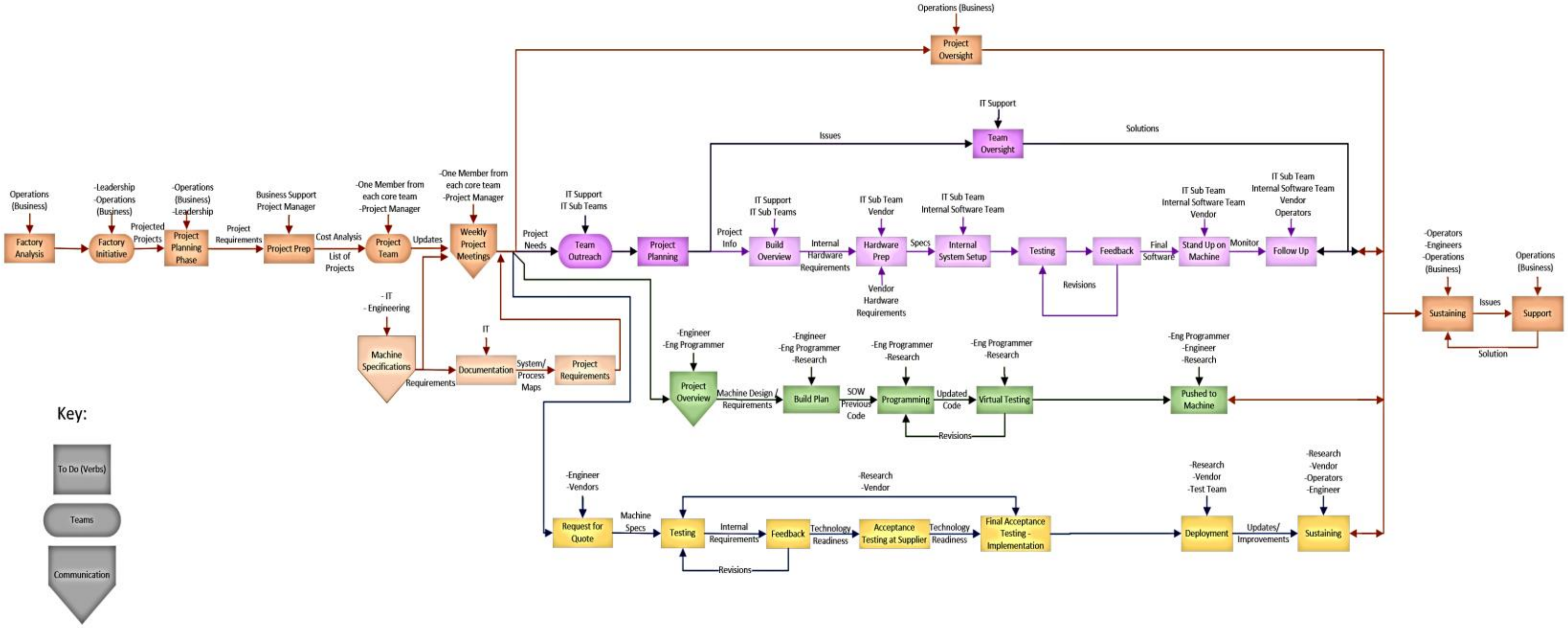
Figure 6: Machine tightens bolt in zoned off area (Physical: 5, Cognitive: 7)

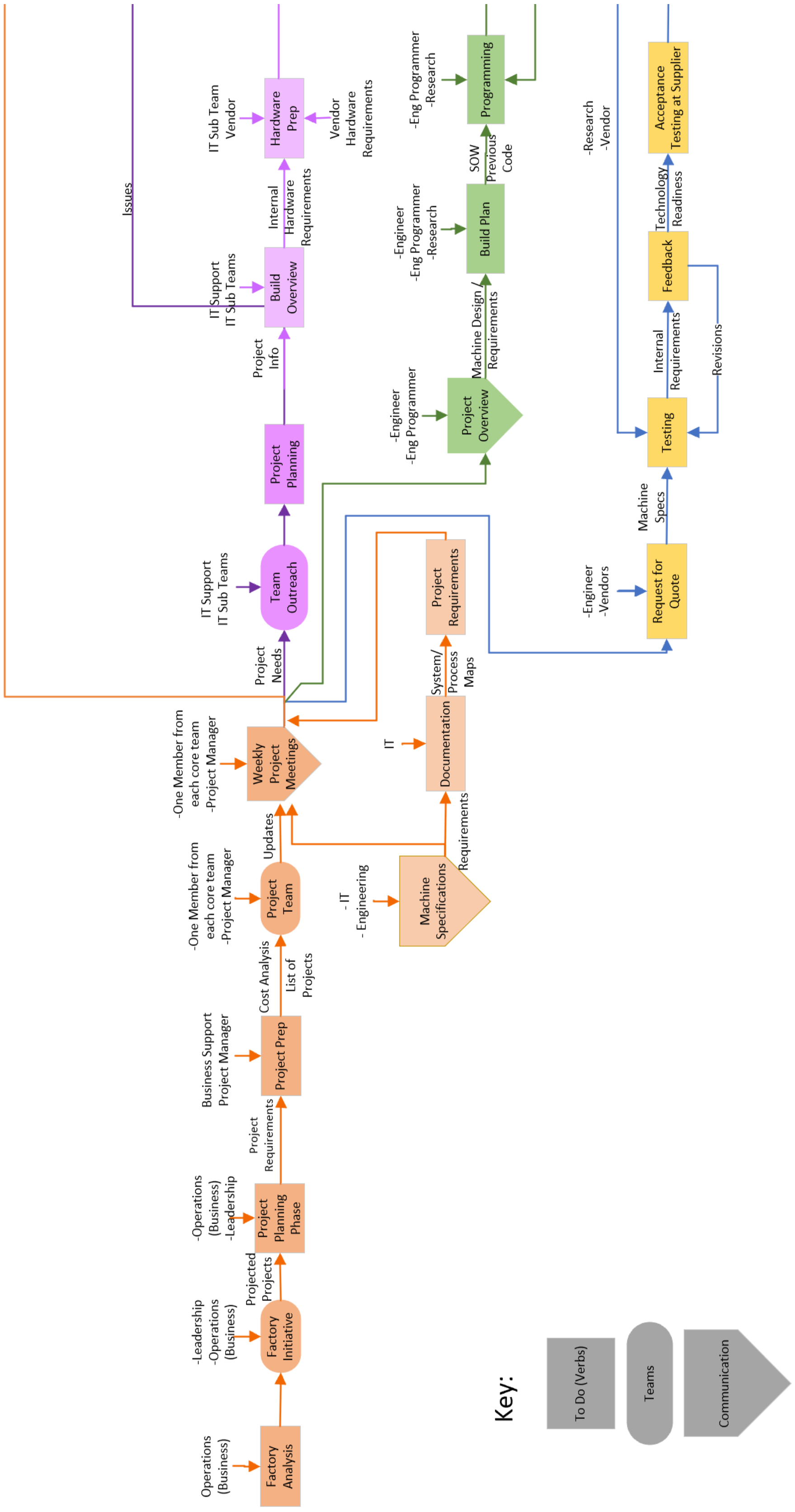
Table 1: Total Physical and Cognitive LoA for each task identifying improvement areas

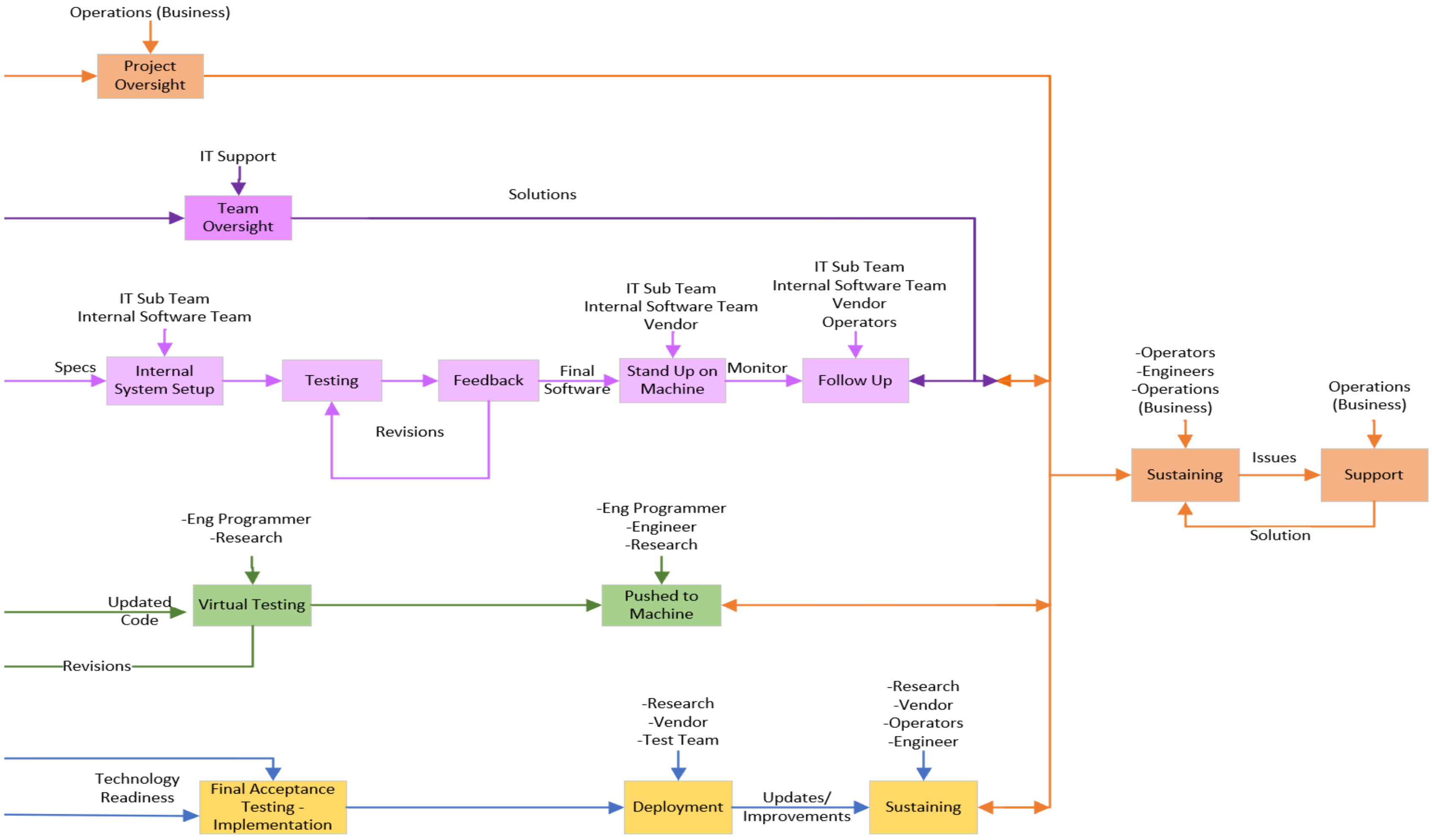


Physical LoA \ Cognitive LoA	1	2	3	4	5	6	7
7							1
6							2
5			2				1
4	1						
3							
2	1						
1	1		1				

APPENDIX B: FULL PROCESS MODEL




Factory Analysis
Operations (Business)
Factory Initiative
-Leadership
-Operations (Business)
Projected Projects
Project Planning Phase
-Operations (Business)
-Leadership
Project Requirements
Project Prep
Business Support
Project Manager
Cost Analysis
List of Projects
Project Team
-One Member from each core team
-Project Manager
Updates
Machine Specifications
- IT
- Engineering
Requirements
Weekly Project Meetings
-One Member from each core team
-Project Manager
Documentation
IT
System/ Process Maps
Project Requirements
Project Needs
Team Outreach
IT Support
IT Sub Teams
Project Planning
Project Info
Build Overview
IT Support
IT Sub Teams
Issues
Internal Hardware Requirements
Hardware Prep
IT Sub Team
Vendor
Vendor Hardware Requirements
Project Overview
-Engineer
-Eng Programmer
Machine Design / Requirements
Build Plan
-Engineer
-Eng Programmer
-Research
SOW
Previous Code
Programming
-Eng Programmer
-Research
Request for Quote
-Engineer
-Vendors
Machine Specs
Testing
-Research
-Vendor
Internal Requirements
Feedback
Revisions
Technology Readiness
Acceptance Testing at Supplier
Key:
To Do (Verbs)
Teams
Communication

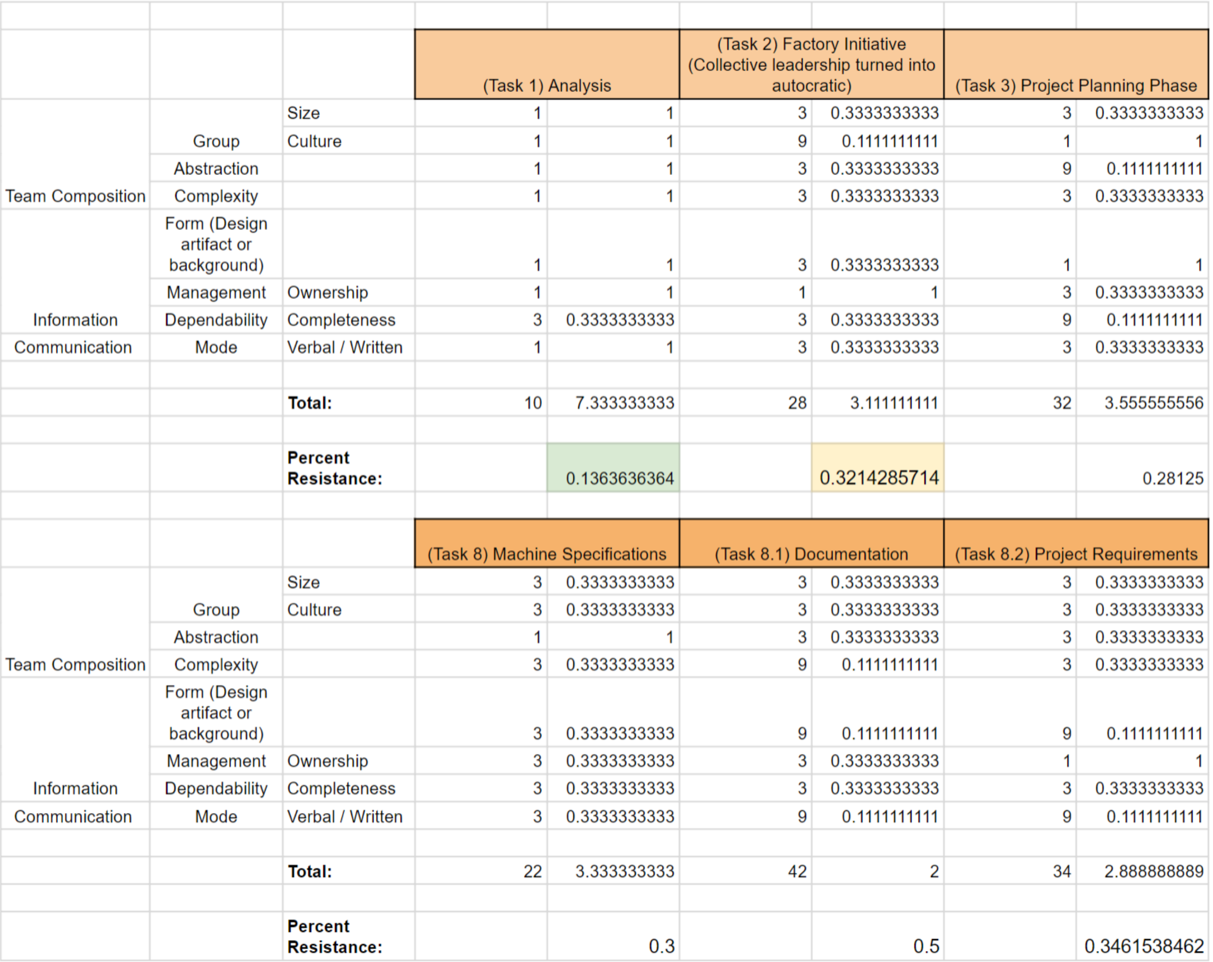

Operations (Business)
Project Oversight
IT Support
Team Oversight
Solutions
IT Sub Team
Internal Software Team
Specs
Internal System Setup
Testing
Feedback
Revisions
Final Software
IT Sub Team
Internal Software Team
Vendor
Stand Up on Machine
Monitor
IT Sub Team
Internal Software Team
Vendor
Operators
Follow Up
-Operators
-Engineers
-Operations (Business)
Sustaining
Issues
Operations (Business)
Support
Solution
-Eng Programmer
-Research
Updated Code
Virtual Testing
Revisions
-Eng Programmer
-Engineer
-Research
Pushed to Machine
Technology Readiness
Final Acceptance Testing - Implementation
-Research
-Vendor
-Test Team
Deployment
Updates/ Improvements
-Research
-Vendor
-Operators
-Engineer
Sustaining

APPENDIX C: COLLABORATIVE DESIGN TAXON [104]

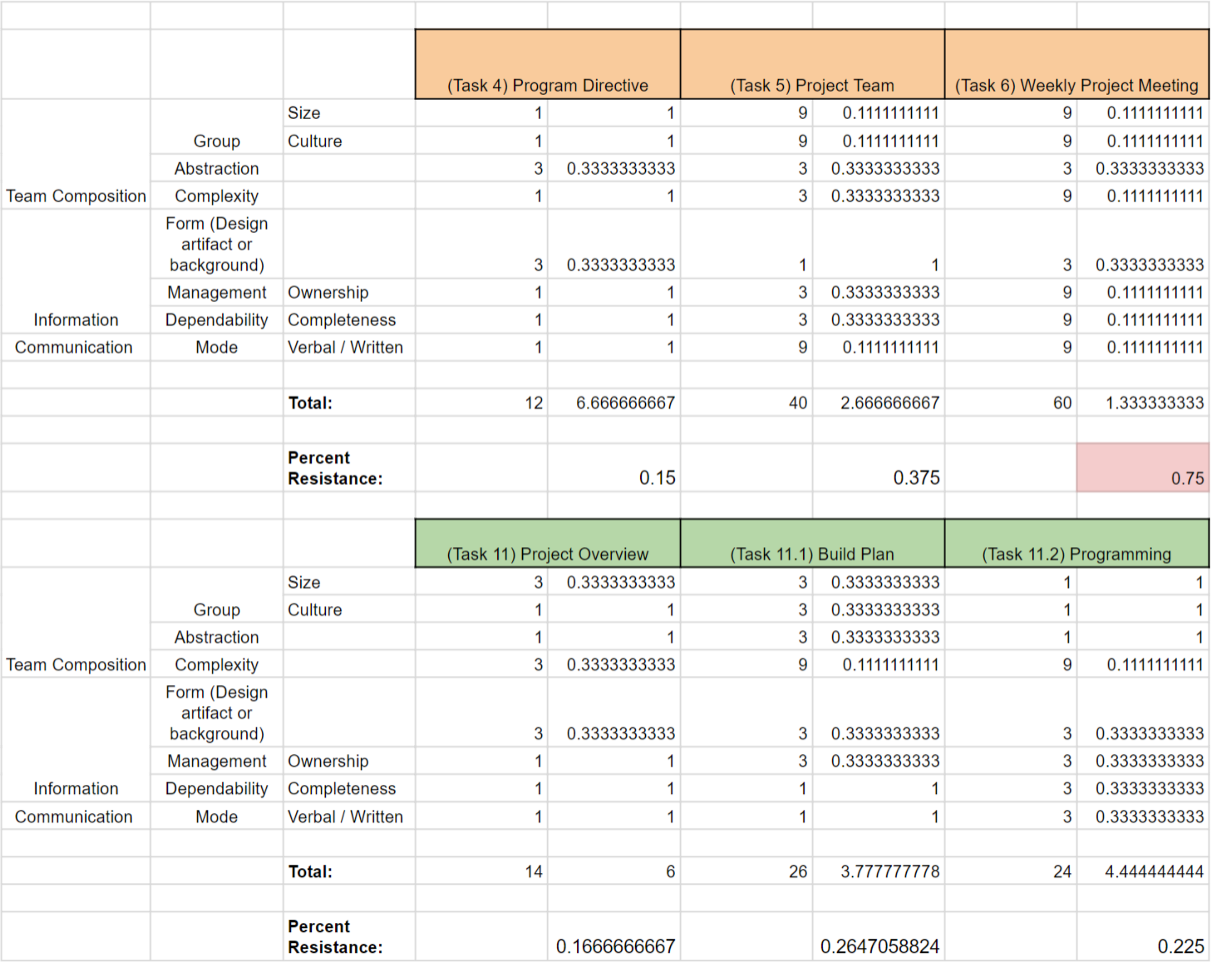
Team Composition	Group	Size
		Culture
	Individual	Personality
		Expertise
	Team Member Relations	
	Leadership Styles	
Nature of Problem	Type	
	Concurrency	
	Coupling	
	Abstraction	
	Scope	
	Complexity	
Information	Form	
	Management	Ownership
		Permission to Change
		Security
		Change Propagation
	Perceived level of criticality	
	Dependability	Reliability
		Completeness
Communication	Mode	Verbal
		Written
		Graphic

		Gestures
	Quantity	Frequency
		Duration
	Syntax	Language
		Translators
	Proficiency of Team	Techniques
		Technology
	Dependability of Resources	Reliability
		Availability
	Intent	
Distribution	People	Geographically
		Organizationally
		Temporally
	Information	Geographically
		Organizationally
		Temporally
Design Approach	Design Tools	
	Evaluation of Progress	
	Degree of structure	
	Process Approach	
	Stage	

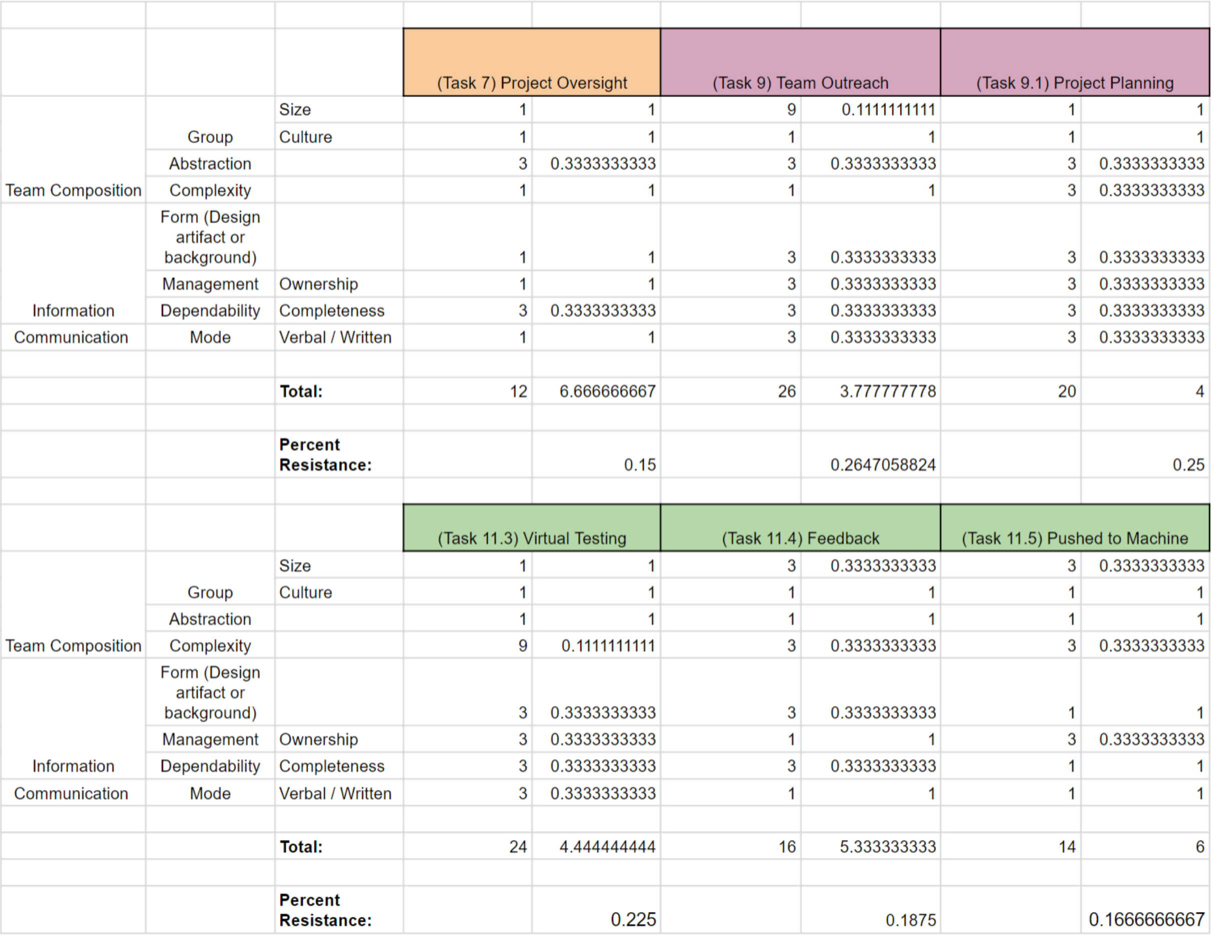
APPENDIX D: RESISTANCE DATA



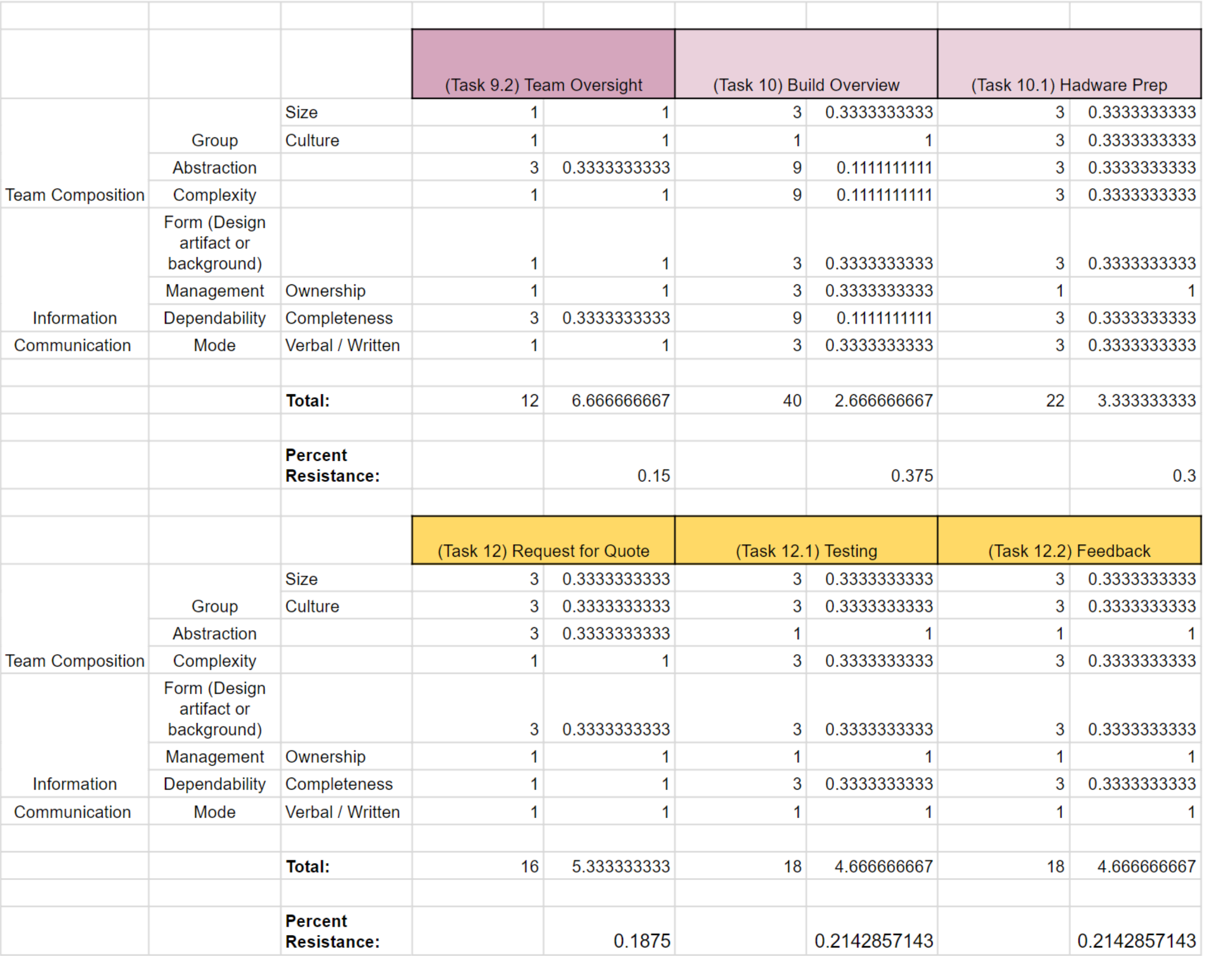
			(Task 1) Analysis		(Task 2) Factory Initiative (Collective leadership turned into autocratic)		(Task 3) Project Planning Phase	
		Size	1	1	3	0.3333333333	3	0.3333333333
	Group	Culture	1	1	9	0.1111111111	1	1
	Abstraction		1	1	3	0.3333333333	9	0.1111111111
Team Composition	Complexity		1	1	3	0.3333333333	3	0.3333333333
	Form (Design artifact or background)		1	1	3	0.3333333333	1	1
	Management	Ownership	1	1	1	1	3	0.3333333333
Information	Dependability	Completeness	3	0.3333333333	3	0.3333333333	9	0.1111111111
Communication	Mode	Verbal / Written	1	1	3	0.3333333333	3	0.3333333333
		Total:	10	7.333333333	28	3.111111111	32	3.555555556
		Percent Resistance:		0.1363636364		0.3214285714		0.28125
			(Task 8) Machine Specifications		(Task 8.1) Documentation		(Task 8.2) Project Requirements	
		Size	3	0.3333333333	3	0.3333333333	3	0.3333333333
	Group	Culture	3	0.3333333333	3	0.3333333333	3	0.3333333333
	Abstraction		1	1	3	0.3333333333	3	0.3333333333
Team Composition	Complexity		3	0.3333333333	9	0.1111111111	3	0.3333333333
	Form (Design artifact or background)		3	0.3333333333	9	0.1111111111	9	0.1111111111
	Management	Ownership	3	0.3333333333	3	0.3333333333	1	1
Information	Dependability	Completeness	3	0.3333333333	3	0.3333333333	3	0.3333333333
Communication	Mode	Verbal / Written	3	0.3333333333	9	0.1111111111	9	0.1111111111
		Total:	22	3.333333333	42	2	34	2.888888889
		Percent Resistance:		0.3		0.5		0.3461538462



			(Task 4) Program Directive		(Task 5) Project Team		(Task 6) Weekly Project Meeting	
		Size	1	1	9	0.1111111111	9	0.1111111111
	Group	Culture	1	1	9	0.1111111111	9	0.1111111111
	Abstraction		3	0.3333333333	3	0.3333333333	3	0.3333333333
Team Composition	Complexity		1	1	3	0.3333333333	9	0.1111111111
	Form (Design artifact or background)		3	0.3333333333	1	1	3	0.3333333333
	Management	Ownership	1	1	3	0.3333333333	9	0.1111111111
Information	Dependability	Completeness	1	1	3	0.3333333333	9	0.1111111111
Communication	Mode	Verbal / Written	1	1	9	0.1111111111	9	0.1111111111
		Total:	12	6.666666667	40	2.666666667	60	1.333333333
		Percent Resistance:		0.15		0.375		0.75
			(Task 11) Project Overview		(Task 11.1) Build Plan		(Task 11.2) Programming	
		Size	3	0.3333333333	3	0.3333333333	1	1
	Group	Culture	1	1	3	0.3333333333	1	1
	Abstraction		1	1	3	0.3333333333	1	1
Team Composition	Complexity		3	0.3333333333	9	0.1111111111	9	0.1111111111
	Form (Design artifact or background)		3	0.3333333333	3	0.3333333333	3	0.3333333333
	Management	Ownership	1	1	3	0.3333333333	3	0.3333333333
Information	Dependability	Completeness	1	1	1	1	3	0.3333333333
Communication	Mode	Verbal / Written	1	1	1	1	3	0.3333333333
		Total:	14	6	26	3.777777778	24	4.444444444
		Percent Resistance:		0.1666666667		0.2647058824		0.225

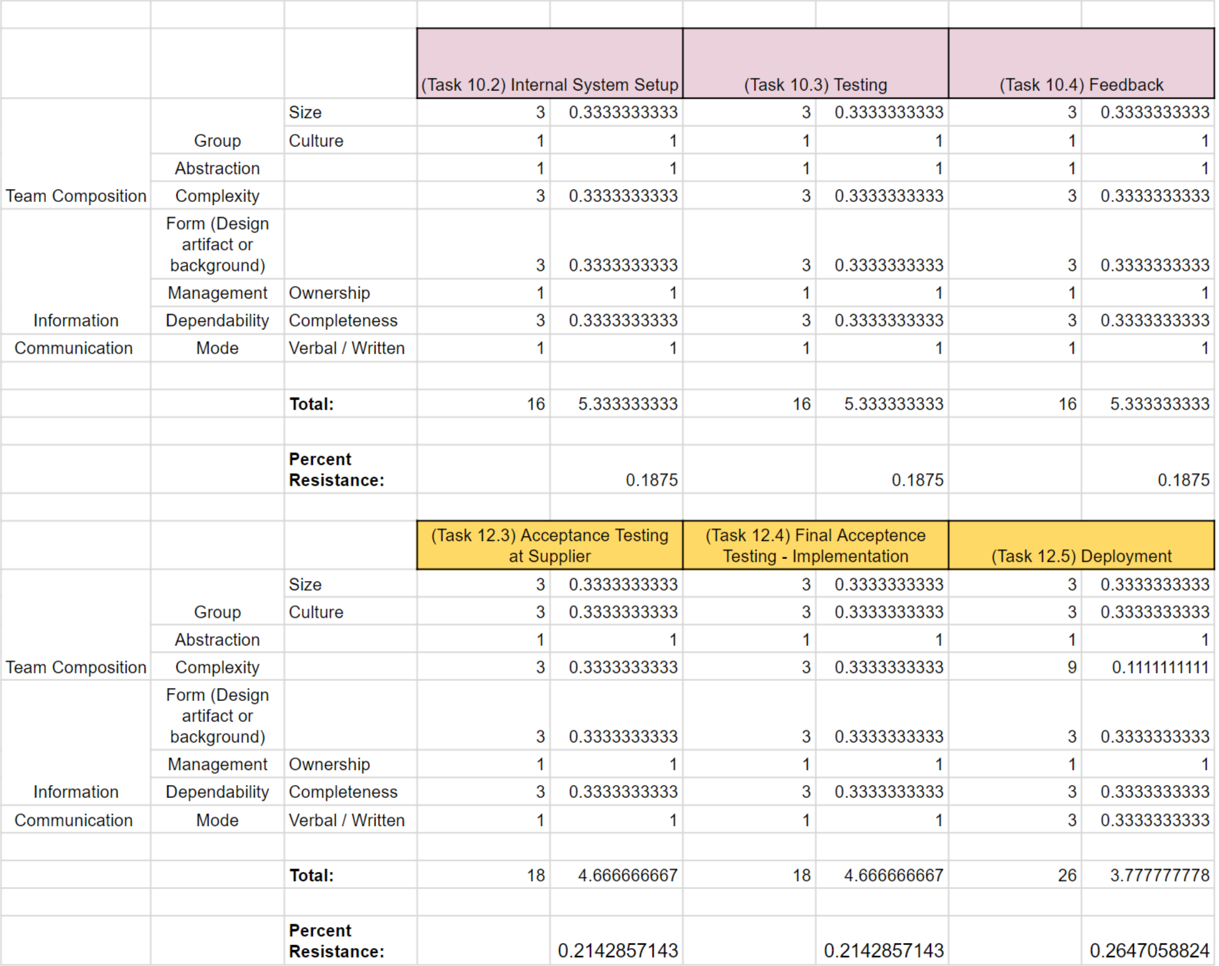


			(Task 7) Project Oversight		(Task 9) Team Outreach		(Task 9.1) Project Planning	
		Size	1	1	9	0.1111111111	1	1
	Group	Culture	1	1	1	1	1	1
	Abstraction		3	0.3333333333	3	0.3333333333	3	0.3333333333
Team Composition	Complexity		1	1	1	1	3	0.3333333333
	Form (Design artifact or background)		1	1	3	0.3333333333	3	0.3333333333
	Management	Ownership	1	1	3	0.3333333333	3	0.3333333333
Information	Dependability	Completeness	3	0.3333333333	3	0.3333333333	3	0.3333333333
Communication	Mode	Verbal / Written	1	1	3	0.3333333333	3	0.3333333333
		Total:	12	6.666666667	26	3.777777778	20	4
		Percent Resistance:		0.15		0.2647058824		0.25
			(Task 11.3) Virtual Testing		(Task 11.4) Feedback		(Task 11.5) Pushed to Machine	
		Size	1	1	3	0.3333333333	3	0.3333333333
	Group	Culture	1	1	1	1	1	1
	Abstraction		1	1	1	1	1	1
Team Composition	Complexity		9	0.1111111111	3	0.3333333333	3	0.3333333333
	Form (Design artifact or background)		3	0.3333333333	3	0.3333333333	1	1
	Management	Ownership	3	0.3333333333	1	1	3	0.3333333333
Information	Dependability	Completeness	3	0.3333333333	3	0.3333333333	1	1
Communication	Mode	Verbal / Written	3	0.3333333333	1	1	1	1
		Total:	24	4.444444444	16	5.333333333	14	6
		Percent Resistance:		0.225		0.1875		0.1666666667

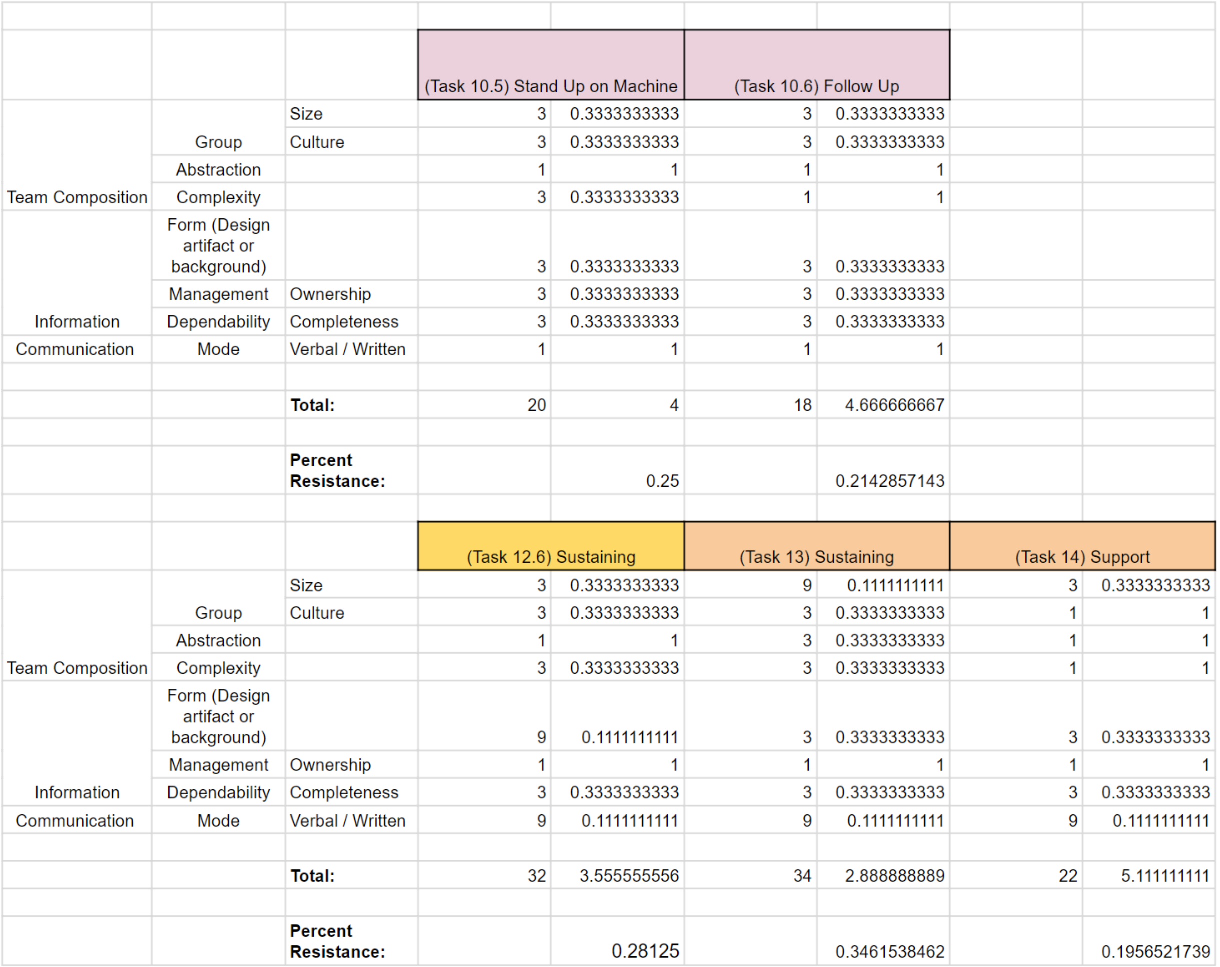


			(Task 9.2) Team Oversight		(Task 10) Build Overview		(Task 10.1) Hadware Prep	
Team Composition	Group	Size	1	1	3	0.3333333333	3	0.3333333333
		Culture	1	1	1	1	3	0.3333333333
	Abstraction		3	0.3333333333	9	0.1111111111	3	0.3333333333
	Complexity		1	1	9	0.1111111111	3	0.3333333333
	Form (Design artifact or background)		1	1	3	0.3333333333	3	0.3333333333
Information Communication	Management	Ownership	1	1	3	0.3333333333	1	1
	Dependability	Completeness	3	0.3333333333	9	0.1111111111	3	0.3333333333
	Mode	Verbal / Written	1	1	3	0.3333333333	3	0.3333333333
		Total:	12	6.666666667	40	2.666666667	22	3.333333333
		Percent Resistance:		0.15		0.375		0.3

			(Task 12) Request for Quote		(Task 12.1) Testing		(Task 12.2) Feedback	
Team Composition	Group	Size	3	0.3333333333	3	0.3333333333	3	0.3333333333
		Culture	3	0.3333333333	3	0.3333333333	3	0.3333333333
	Abstraction		3	0.3333333333	1	1	1	1
	Complexity		1	1	3	0.3333333333	3	0.3333333333
	Form (Design artifact or background)		3	0.3333333333	3	0.3333333333	3	0.3333333333
Information Communication	Management	Ownership	1	1	1	1	1	1
	Dependability	Completeness	1	1	3	0.3333333333	3	0.3333333333
	Mode	Verbal / Written	1	1	1	1	1	1
		Total:	16	5.333333333	18	4.666666667	18	4.666666667
		Percent Resistance:		0.1875		0.2142857143		0.2142857143



			(Task 10.2) Internal System Setup		(Task 10.3) Testing		(Task 10.4) Feedback	
Team Composition	Group	Size	3	0.3333333333	3	0.3333333333	3	0.3333333333
		Culture	1	1	1	1	1	1
	Abstraction		1	1	1	1	1	1
	Complexity		3	0.3333333333	3	0.3333333333	3	0.3333333333
Information	Form (Design artifact or background)		3	0.3333333333	3	0.3333333333	3	0.3333333333
	Management	Ownership	1	1	1	1	1	1
	Dependability	Completeness	3	0.3333333333	3	0.3333333333	3	0.3333333333
Communication	Mode	Verbal / Written	1	1	1	1	1	1
		Total:	16	5.333333333	16	5.333333333	16	5.333333333
		Percent Resistance:		0.1875		0.1875		0.1875
			(Task 12.3) Acceptance Testing at Supplier		(Task 12.4) Final Acceptence Testing - Implementation		(Task 12.5) Deployment	
Team Composition	Group	Size	3	0.3333333333	3	0.3333333333	3	0.3333333333
		Culture	3	0.3333333333	3	0.3333333333	3	0.3333333333
	Abstraction		1	1	1	1	1	1
	Complexity		3	0.3333333333	3	0.3333333333	9	0.1111111111
Information	Form (Design artifact or background)		3	0.3333333333	3	0.3333333333	3	0.3333333333
	Management	Ownership	1	1	1	1	1	1
	Dependability	Completeness	3	0.3333333333	3	0.3333333333	3	0.3333333333
Communication	Mode	Verbal / Written	1	1	1	1	3	0.3333333333
		Total:	18	4.666666667	18	4.666666667	26	3.777777778
		Percent Resistance:		0.2142857143		0.2142857143		0.2647058824



			(Task 10.5) Stand Up on Machine		(Task 10.6) Follow Up			
		Size	3	0.3333333333	3	0.3333333333		
	Group	Culture	3	0.3333333333	3	0.3333333333		
	Abstraction		1	1	1	1		
Team Composition	Complexity		3	0.3333333333	1	1		
	Form (Design artifact or background)		3	0.3333333333	3	0.3333333333		
	Management	Ownership	3	0.3333333333	3	0.3333333333		
Information	Dependability	Completeness	3	0.3333333333	3	0.3333333333		
Communication	Mode	Verbal / Written	1	1	1	1		
		Total:	20	4	18	4.666666667		
		Percent Resistance:		0.25		0.2142857143		

			(Task 12.6) Sustaining		(Task 13) Sustaining		(Task 14) Support	
		Size	3	0.3333333333	9	0.1111111111	3	0.3333333333
	Group	Culture	3	0.3333333333	3	0.3333333333	1	1
	Abstraction		1	1	3	0.3333333333	1	1
Team Composition	Complexity		3	0.3333333333	3	0.3333333333	1	1
	Form (Design artifact or background)		9	0.1111111111	3	0.3333333333	3	0.3333333333
	Management	Ownership	1	1	1	1	1	1
Information	Dependability	Completeness	3	0.3333333333	3	0.3333333333	3	0.3333333333
Communication	Mode	Verbal / Written	9	0.1111111111	9	0.1111111111	9	0.1111111111
		Total:	32	3.555555556	34	2.888888889	22	5.111111111
		Percent Resistance:		0.28125		0.3461538462		0.1956521739

APPENDIX E: RESISTANCE MODEL