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UNDERSTANDING WORK: A CRITICAL EXPLORATION OF INDUSTRY 4.0 TECHNOLOGIES IN ADVANCED MANUFACTURING

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ABSTRACT

With the emergence of the fourth industrial revolution, or Industry 4.0, manufacturing companies in Canada, and elsewhere, have begun investing in a variety of advanced technologies to improve various organizational outcomes, such as improved efficiency, reduced costs, the maximization of output, and to facilitate flexibility in their operations. These technologies, which include the Internet of Things (IoT), cyber-physical systems, data analytics and augmented reality, among others, have a discernable impact on employees.

There is limited research on, and a limited focus on, the extent to which these advanced technologies benefit employees. Proponents of Industry 4.0 make several claims to that effect, which are tested. This dissertation uses a mixed-method, multiple case study approach to explore five different claims regarding Industry 4.0 technologies in a manufacturing context: (1) they enhance employee autonomy; (2) they improve training; (3) they improve productivity; (4) they enhance job control; and (5) they improve safety. The role that a formal lean manufacturing program plays regarding the claims is also explored. The study relies on an employee survey to generate quantitative data, and semi-structured employee interviews to generate qualitative data.

A critical realist perspective is adopted. Situating the study within a critical realist framework facilitated an analysis of structures, agents, events, actions, and context to identify and explicate the causal mechanisms that inform empirical outcomes and identify emergent themes.

The study finds that, through the exploration of three cases, the adoption of Industry 4.0 technologies contributes to increased Employee Autonomy (EA), Employee Productivity (EP), Job Control (JC) and Safety Awareness (SA). The study does not support the claim that the adoption of Industry 4.0 technologies contributes to increased Training Effectiveness (TE). An examination of semi-structured interviews revealed several common themes. The study finds that employees generally benefit from newly adopted technologies and enjoy a commensurate benefit with respect to an increased level of satisfaction with their work. Employees in organizations that have a formal lean manufacturing program tend to experience higher levels of satisfaction, due to its moderating role. Overall, the subjective experiences of employees support four of five of the positivist claims made in manufacturing.

Keywords: critical realism, lean manufacturing, Industry 4.0, technology, subjective experience, critical analysis

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Introduction

a. Statement of the Problem

Following a review of the literature on the topics of Industry 4.0, lean manufacturing, and the subjective experience of work, it is evident that there has been little critical research conducted that explores the relationship between the implementation of technology and the experience of work within an Industry 4.0 context. The implementation of technologies such as the Internet of Things (IoT), cyber-physical systems, big data analytics, digital twins, and augmented reality (AR)—among others—are altering the ways in which work and organizations are structured, how individuals engage in the process of work, how they interact with one another, and how they engage with contemporary technology within an organizational context.

Broadly, the implementation of new technologies in organizations is regarded as beneficial in that it supports the managerial imperatives of increased productivity, decreased costs, and enhanced competitive advantage. Several studies demonstrate that Industry 4.0 technologies significantly improve industrial performance: notably, flexibility, productivity, delivery time, cost, and quality (Moeuf et al., 2020). Importantly, organizations seek the implementation of these technologies to achieve customized production at the cost of mass production (Wang et al. 2016), and to enable modular and changeable production (Kolberg et al. 2015). These outcomes tend to be framed as beneficial from an organizational perspective, but not necessarily from the perspective of individuals within those same organizations. The scant discussion of employee experience suggests that the subjective interpretations and lived realities of working in such environments is secondary to the potential benefits for organizational efficiency and profitability. This positivist rationale is limited, and a critical exploration of this issue will provide a more comprehensive and complete understanding of the role of Industry 4.0 technology within organizations.

A critical perspective questions the development and implementation of these new technological systems, questions the positivist rationale for the implementation, and allow for the exploration of individual and social consequences. The objective of the study is to understand whether the subjective experience of work by employees within organizations that are utilizing advanced Industry 4.0 technologies supports or disputes the stated claims about the benefits of those technologies.

Seeking to better understand the impact of technological implementation in organizations addresses an important workplace issue—the concern with how technology is transforming the way people work and interact. The application of research in this area has the potential to promote thoughtful, rational, and effective action related to improving conditions of work and addresses issues related to human welfare and organizational effectiveness.

Researching both organizations that already have embraced lean manufacturing methodology and those that have not (the presence of an existing lean program is conceptualized as a moderating variable in the study) provide a comparative means of exploring the implication of the methodology and tools used to design their work processes. The research offers a novel means of exploring how new technologies—specifically, the autonomous and highly interconnected technologies associated with Industry 4.0—affect the subjective experience of work within different types of organizations. 'Lean' organizations differ from those that are not in two ways: (1) lean organizations fully understand their processes and value chains, and the decision to integrate new technologies is not made on a whim, but for a specific purpose with a specific outcome in mind; and (2) organizations that have successfully implemented lean methodology tend to be mature, stable organizations that have the resources and capital to implement Industry 4.0 in a meaningful way. Whether lean is a significant factor in the successful implementation of Industry 4.0 technologies is explored in the research.

Exploring the subjective experiences of work within organizations that have implemented Industry 4.0 technologies provides meaningful insight into how lean methodology and technology interact, and how that interaction informs the experience of work. Importantly, exploring the lived experiences of employees within these environments helps assess whether the beneficial claims of technological implementation translate into beneficial working conditions and experiences for employees, and whether the impact of Industry 4.0 technology is negligible, or detrimental.

A critical examination of the effects of technological implementation presents an opportunity to better understand whether employees reap the benefits of newly adopted and integrated technologies and enjoy a commensurate benefit with respect to an increased level of satisfaction with their work within lean workplaces, or not.

Framing the exploration of the role of technology in organizations from a critical realist perspective allows for an exploration of structures, events, actions, and context to identify and explicate causal mechanisms within those organizations that generate employee outcomes. It also provides a framework within which to contextualize the use of Industry 4.0 technologies and assess how they affect the experience of work in relation to how they are claimed to work, and what their stated benefits are.

b. Purpose of the Study

As the purpose of this study is to understand whether the subjective experience of work supports or disputes the stated claims about the benefits of Industry 4.0 technologies in organizations, it offers new insights into the evolving role of technology in lean workplaces, and how it shapes employees' experience of work in that context. Practically, a critical analysis informs a more comprehensive understanding of the impact that advanced technological solutions have on employees. It also informs an assessment framework for considering technologies within a manufacturing context.

Subjective experience involves individual accounts of the workplace environment, rated by level of engagement, happiness, and satisfaction. According to Clancy et al. (2019) the subjective experience of work, ontologically, emerges from the "interplay of individual sense-making and social/organizational contexts" (p. 521). The introduction of new forms of Industry 4.0 technologies can alter, sometimes radically, how tasks are completed, how organizational hierarchies are structured, and how workplace relationships are formed and maintained over time. The changing nature of work informs a changing construction of knowledge, communication, and shared meaning. Through a critical lens, further exploration of the relationship between Industry 4.0 technologies and work will help determine whether the subjective experience of work reflects the positivist claims made by proponents of advanced technological solutions.

c. Research Question and Objective of the Study

The following question is the focus of the dissertation research:

Q: How do employees in organizations with a formal lean manufacturing program experience work in relation to the stated claims about the implementation of Industry 4.0 technologies for organizations?

In order to answer the research question, the stated claims are explored in six hypotheses:

H1: Employee Autonomy (EA) is a significant component of a composite index, Overall Employee Satisfaction (OES).

H2: Training Effectiveness (TE) is a significant component of a composite index, Overall Employee Satisfaction (OES).

H3: Employee Productivity (EP) is a significant component of a composite index, Overall Employee Satisfaction (OES).

H4: Job Control (JC) is a significant component of a composite index, Overall Employee Satisfaction (OES).

H5: Safety Awareness (SA) is a significant component of a composite index, Overall Employee Satisfaction (OES).

H6: The presence of a formal lean program will have a positive moderating effect on the relationship between the five dimensions and Overall Employee Satisfaction (OES).

The questionnaire builds the factors that will test H1-H6.

Each of the hypotheses tests a dimension of subjective experience of Industry 4.0 implementation. The dimensions combine to construct a composite measure of satisfaction, Overall Employee Satisfaction (OES).

A composite index represents complex information from multiple indicators (dimensions) as a single metric that measures progress toward a goal and facilitates decisions. A higher OES score reflects a higher degree of subjective satisfaction in relation to the stated claims about the implementation of Industry 4.0 technologies.

Whether organizations have an existing lean manufacturing system in place will serve as a moderating variable (MV) in the OES score. As opposed to a mediating variable which explains the process through which two variables are related, a moderating variable affects the strength and direction of the relationship. Analysis of the data provides a determination on whether the presence of an established lean program plays a significant role in how employees subjectively experience Industry 4.0 implementation, as measured by OES.

d. Significance of the Study

The study is significant in several ways. The study addresses the issue of the changing nature of work, which is both a timely and important topic given the pace of change in work, precipitated by recent social trends and technological advancements. As technological intervention becomes more widespread in organizations—whether they are involved in manufacturing or the provision of services—they are becoming increasingly defined by the ubiquitous nature of that technology. As organizations redefine the ways in which they design, deliver, and monetize products and services, they are increasingly focusing on developing customized experiences, coordinating, and collaborating with a wide range of value-chain participants, and many are utilizing the methodology of lean manufacturing to improve competitiveness in the marketplace. The evolution of advanced manufacturing systems and the application to a wide variety of industries and organizations means that increasing numbers of workers will find themselves working with Industry 4.0 technologies and living with the resulting changes in their daily tasks. As tasks and, ultimately, jobs are fundamentally changed by new technologies, the ways in which employees interact with the experience of work will change, including the ways individuals interact with one another, interact within organizational hierarchies, construct meaning, and understand power dynamics. The digitalization of work processes means that individuals must acquire new skills and expertise to successfully navigate a new type of work. By exploring the subjective experience of work in relation to the stated claims about the implementation of technology, this research contributes to understanding the relationship between how change is envisioned at the organizational level, and how it is experienced at the level of the individual. Whether the desired changes are achieved at the operator and task level has implications for organizational effectiveness, the sustainability of technology programs, and for long-term competitiveness in the market. Understanding how individuals perceive and experience new forms of work has implications for employees in terms of designing training programs, communicating desired outcomes, setting goals and targets, and aligning motivation with desired outcomes. Recruitment and retention initiatives designed for employees will also benefit from this research, as it provides a glimpse into the subjective experience of work in technologically advanced lean organizations.

While the dissertation work furthers scholarship in several different areas of academic inquiry including lean manufacturing, Industry 4.0, critical realism and organizational behavior, business practitioners will benefit from the research. Notably, it will help organizations understand how Industry 4.0 adoption will affect employees in organizations, and how organizational initiatives can best be executed to ensure that employees' experiences are both positive and aligned with desired organizational outcomes.

Chapter 2: Literature Review

a. Introduction

This literature review examines the subjective experience of work, the study of technology in the workplace, the adoption of technology, Industry 4.0, and lean manufacturing. The review seeks both a broad understanding of the relevant literature, and an understanding of the stated claims of practitioners and theorists regarding the promise of Industry 4.0 implementation. An exploration of the current literature has helped expose gaps in scholarship and identify opportunities for further academic inquiry.

The literature has indicated that the fields of lean manufacturing and Industry 4.0 are approached from a predominantly positivist perspective, and there has been little desire for a critique of the fields. The potential dysfunctions of this modernity and the pathologies created and exasperated by the proliferation of technology within workplaces need to be examined and understood, particularly in relation to the stated claims about the benefits of this proliferation. Scant research exists regarding the role of technology in contemporary organizations, and how its implementation influences individuals and their experience of work. Further exploration of organizational conditions, structures, and practices in such a dynamic and ever-changing environment will represent an important theoretical and practical contribution to the scholarship of lean manufacturing, Industry 4.0, the role of technology in work, and the subjective experience of work.

b. Approach

A review of the literature informing this study was conducted, exploring the current literature on lean manufacturing, Industry 4.0, the relationship between technology and work, and on the study of the subjective experience of work.

Scholarly articles from a variety of academic databases, including CiteSeerX, AISeL, ACM, EBSCOhost, Emerald Insight, Taylor Francis, Science Direct, accessed through the Athabasca University library, as well as Google Scholar, were accessed and reviewed.

c. Current Literature

i. Lean Manufacturing

I) Origins of Lean

The evolution of lean production systems is typically linked to the successful narrative of the Toyota Motor Company's *Toyota Production System* (TPS). According to Teich et al. (2013) TPS was characterized by five principles:

1. Identification of customer value.
2. Management of "value stream."
3. Developing capabilities of flow production.
4. Use of "pull" mechanisms to support flow of materials at constrained operations.
5. Pursuit of perfection through reducing to zero all forms of "waste."

Essentially, TPS was an approach that sought to enhance customer value by adding product or service features while eliminating wasteful activities. The term *lean* was coined in 1990 following the adaptation of the TPS concept by a number of non-Japanese enterprises which identified similar challenges and problems in a variety of applications, from manufacturing to healthcare. The concept of lean is not new, however. Early industrial theorists including Adam Smith and Frederick Taylor refined variants of lean production with respect to early manufacturing, identifying a requisite for efficiency. The appeal of lean exceeds the mere cost-reduction philosophy of industrial mass production, as it advocates "teamwork, multi-skilling, job rotation, task enlargement, and worker participation in continuous improvement activities" (Johansson et al. 2013, p. 449).

Lean is a multi-faceted concept that requires organizations to invest considerable resources simultaneously in order to implement the major strategic components of lean, implement practices to support operations, and to validate the effectiveness and sustainability of the initiatives over the long term. Full lean implementation is an ambitious and highly involved undertaking, requiring long-term commitment from leaders and workers alike as it is a transformative process, informed by a methodology devised to change individual and group behaviours and entire organizational cultures. The successful entrenchment of lean within Japanese organizations was successful, in part, because "the main three characteristics of Japanese management thinking are harmony and group loyalty, consensus in decision-making, and lifetime employment, all encompassed in the concept of 'respect for people'" (Teich et al. 2013, p. 3).

Lean methodology has been successfully implemented and operationalized in a number of different organizations and industries since its inception in North America in the early 1990's. According to Cross (2013) lean facilitates improvement in organizational efficiency by freeing up resources—people, time, space, and capital—to focus on and drive innovative projects; eliminates wasteful processes and products that do not add customer value; and creates a sense of scarcity within organizations which fosters creative problem solving.

Sim (2013) advocates that the future of organizations in advanced industrial countries depends on the ability to achieve dramatic improvements in productivity—output per employee—while continuously improving quality: it is regarded "as one of the most important strategies for business to achieve world class performance by doing more with less" (p. 98). While lean manufacturing is widely accepted as a proven method to achieve improvements in productivity while realizing customer value, it should not be viewed as a panacea for every business situation, nor should it be employed by every organization. According to Deflorin et al. (2012) to become lean, an organization or company "must account for each of the four dimensions of the *4P model*: philosophy, process, people and partners, and problem-solving"

(p. 3958). Ultimately, successful lean implementation is suited for organizations with a long-term philosophy with the goal of being a value-added contributor to a specific industry, which necessitates a workforce characterized by long-term thinking—achieved through the implementation of a “learning organization” philosophy (Cullinane et al., 2012). Lean has typically been most successful in industries and organizations which rely on mass production and standardization of products and services—organizations which rely on craft production or mass customization must be cautious when adopting lean methodology, or aspects of it, as it necessitates a number of dramatic cultural changes, including the standardization of work processes, cross-training, and the de-skilling of a tasks to promote interchangeability of labour (Deflorin et al., 2012). Organizations may benefit from the implementation of alternative methodologies, such as Quick Response Manufacturing (QRM), Agile Manufacturing, Total Quality Management (TQM), or even ‘Traditional Manufacturing,’ in which production is driven by sales forecasts (a *push* system versus Lean’s *pull* system), change is driven from the top, and the status quo is deemed acceptable.

II) Organizational Implications

Research on lean implementation suggests that organizations must change at a behavioural and cultural level to facilitate long-term entrenchment, and that this should be translated directly into an endless process for continuous improvement (Teich et al, 2013). Despite being framed within the realm of tangible strategic business direction, “cultural change” and “continuous improvement” are abstract concepts, which imply that there is no horizon for successful completion as the process is infinite. The abstract natures of these concepts, coupled with the nebulous cultural characteristics supportive of lean implementation often prove too intricate, too daunting, or too formidable for many companies to sustain over the long-term. According to Bhasin et al. (2006), although lean has been widely recognized for its effectiveness in continuously improving productivity, product quality, and on-time delivery to customers, a mere 10 percent of companies which implement lean are able to sustain the practices and cultural reformation for more than five years. However, it has been suggested that only some 10 percent or less of companies succeed at implementing lean practices and philosophy entirely: many companies and organizations implement initiatives almost as a fad, and submit that "the number of tools, techniques and technologies available to improve operational performance is growing rapidly, on the other hand, despite dramatic successes in a few companies, most efforts to use them fail to produce significant results" (Repenning et al., 2001, p. 1).

Academic research on lean manufacturing has typically focused on four broad categories: just in time (JIT) methodology, total productive maintenance (TPM), total quality management (TQM), and human resource management (HRM). Lean Manufacturing research has been largely concentrated in studies of large organizations, and increasingly, the application of the methodology to logistics and supply chain management. Most of the literature has focused on the positivist tradition, namely the implementation of lean tools and technique/practices in the manufacturing sector, rather than exploring leadership practices, cultural issues, employee issues, or organizational culture. The first three categories have received the greatest attention and exploration. The following is an exploration of the literature on the last category, HRM.

According to Bhamu et al. (2014) the success of lean manufacturing implementation depends largely on work organization practices, including standardization, discipline and control, continuous training and learning, team-based organization, participation and empowerment, multi-skilling and adaptability, common values and communication. Lean implementation is affected by different cultural customs, labor densities, degrees of development, industrialization, and a host of other factors that influence organizational practices. Yet, little research has been conducted in these areas. As such, there exist potential opportunities to explore lean manufacturing from the perspective of cultural influence, power, and knowledge creation.

III) Lean and the Experience of Work

Early research examining lean methodology had argued that it leads to work intensification (Delbridge et al., 1992), as it was perceived to rely upon management by stress. Other research, however, has suggested that if implemented effectively, employees would work "smarter, not harder" (Womack et al., 1994), and experience a decrease in work-related stress. However, as Cullinane et al. (2012) point out, studies which have "empirically assessed the implications of lean manufacturing for employees have yielded contradictory findings which either demonstrate solely negative outcomes or contingent outcomes where improved well-being is dependent on specific management practices" (p. 2). Although there is a body of literature that examines the benefits of lean production methods for employees (Delbridge et al., 2000), very little research, empirical or theoretical, has been focused on how lean *actually* affects employees' experiences of work, or how it contributes to employees' perceptions of self. Rather, much of the research has focused on measures of organizational improvement—largely from an organization perspective—including employee productivity, quality improvement, and reduction in cost. Far less research and scholarly study has been undertaken with respect to the 'softer' human issues associated with lean implementations (Losonci et al., 2011), and of the research completed, much remain theoretical or anecdotal rather than empirical (Farris et al. 2009). An understanding of the "relationships between [Lean Production] implementation activities and employee outcomes are not fully understood, and additional research is needed to determine the manner in which lean system design produces the most positive outcomes" (Taylor et al., 2013, p. 6607).

Adler et al. (1993) conducted a comparative assessment of the relatively new lean manufacturing methodology with a "human-centered" model championed by Volvo Motor Company. The pair researched automotive manufacturing plants with respect to which model best stimulated continuous improvement while maintaining worker morale. They concluded that lean production followed a "democratic Taylorism model" (p. 89) where workers participated in designing their own job tasks, which helped democratize the workplace, and bolster employee engagement. However, Adler et al. (1993) found that lean production does not provide nearly as many opportunities as Volvo's Uddevalla model for the development of workers' human potential. Adler et al.'s (1993) comparative study examined the social factors and popular misapprehensions about the sources of employee motivation and of organizational learning. However, the study only assessed lean production systems from a limited perspective, and the authors concluded that while the propensity toward job enlargement in a lean system aided in stimulating employee engagement and bolstering morale, the authors did not assess how knowledge is created or shared, how lean methodology affects perceptions of truth, or how power relationships between employees, or between employees and managers, are created or sustained.

The relentless pursuits of efficiency and the reduction of waste characteristic of lean methodology through process simplification, short cycle times and machine-paced workflow integration, coupled with the standardization of tasks and intense performance monitoring (Carter et al., 2013) have contributed to a re-examination of work. According to Alves et al. (2012) lean manufacturing offers a model of work where individual employees assume roles as thinkers, and their involvement promotes continuous improvement and gives companies the agility they need to face the market demands and environmental changes. Work is, by this definition, both instrumental and formative—it has a significant influence on how individuals construct identity and self-perception—and is ultimately situated in a social context. Meaningful work, that which is considered gratifying, dignifying and autonomous, is created through social experience. Valuable social experience is characterized by emotional support, affirmation of the self, appraisal of the situation, instrumental support, and a free exchange of information.

Although many lean practitioners advocate job rotation, multi-skilling, and empowering teams, scholars such as Lewchuk et al. (1997) have revealed contradictions in practice, including tighter supervision and management control, narrow tasking, reduced involvement in decision making, and greater job strain. In addition to reports of increased risk of injuries, physical, psychological, or psychosocial (Delbridge, 2000), lean often precludes socialization as workers become increasingly alienated from their work (Carter et al., 2013). Socialization at work is a normative process that allows workers to explore meaning and value of their labour whilst simultaneously helping shape workplace culture. Through interaction and the process of socialization, workers participate in addressing workplace issues and inequities, and allow for participative discourse on addressing those problems or limitations. The socialization process in organizations has been regarded as a function of participation, as individuals not only acquire and assimilate knowledge, but participate in its creation and dissemination, shaping the experience of work.

Just as Adler et al. (1993) studied employee morale, Wickramasinghe et al. (2011) explored how a lean production environment influences employee satisfaction and turnover in a manufacturing plant. Their findings indicated that job involvement through participation "gives higher ownership of the process to employees" (p. 825), and employees will effectively increase their level of job involvement if they "perceive that the organization cares about its employees and values their contribution" (p. 827). The authors also identified an inverse relationship between the level of job involvement and employee turnover, however, the influence of job involvement on employee turnover has yielded conflicting findings in other studies. Brown et al. (1991) concluded that the work characteristics of lean implementation could have detrimental effects on employees that would influence employee turnover, while Schouteten et al. (2004) reported that employees in a lean production environment had a low intention to resign. Ultimately, the disparate findings by scholars may indicate that employee morale, job satisfaction, and engagement may be influenced by factors other than the implementation of lean methodology—how lean informs power, organizational culture, or the shared experience of work.

The impact of lean production principles on the experience of work in a production or manufacturing environment frequently is an issue that polarizes scholars. Advocates of lean suggest that team-based work organization at a primary level represents a reversal of Tayorist principles and results in a "significant upskilling of production employees" (Womack et al., 1994). This assertion is based on the assumptions that, under lean teams, employees are: (1) multifunctional (thereby increasing task variety); (2) vested with greater responsibility for many tasks that were previously the prerogative of specialist groups; and (3) able to contribute to task and organizational improvement via group problem-solving activities. Such bottom-up methods, according to Delbridge et al. (2000), make for “higher levels of responsibility and involvement as operators are ‘empowered’” (p. 1461). Furthermore, scholars have suggested that if lean systems are properly implemented and sufficiently supported, workers will be motivated to “contribute their discretionary effort to problem-solving if they believe their individual interests are aligned with those of the company, and that the company will make a reciprocal investment in their well-being (MacDuffie, 1995, p. 201). In contrast, detractors of lean argue that many workers prefer traditional arrangements, and express little desire for tasks which are more empowering (Vidal, 2007, p. 260). Moreover, it has been suggested that lean production may in fact restrict individual autonomy as “collective autonomy” (Keyes, 2013) is idealized. Team-based work organization and participative decision-making may increase job satisfaction only in certain circumstances, for certain organizations or industries, and only for certain individuals. There is no consensus regarding the experience of lean, and no unified, shared empowerment or sense of increased morale (Delbridge, 2000).

Overall, the review of research on lean manufacturing as it relates to employee empowerment, job satisfaction, morale, and development has yielded scant and often contradictory findings. The existing literature on lean ultimately suggests that there is no consensus regarding the extent to which, and the manner in which, the adoption of lean methodology influences employee outcomes (Camuffo et al., 2017). Current research indicates that managerial decision making needs to consider the people management configuration that places the highest values on the HR practices oriented towards enforcing commitment, motivation, and involvement. Research has demonstrated that characteristics such as the completeness of a task, the difficulty and monotony of the work, the level of workplace autonomy, the interaction potential in the work, and information provision—timeliness, completeness and reliability—are important determinants of the experience of working in a lean environment. Research on employee experiences of lean manufacturing has not addressed intersectionality, knowledge creation, or the conceptualization of social identity structures, however. Camuffo et al. (2017) suggest that in order to improve the human side of organizations, companies “could focus in opening up channels to encourage a dialog with employees and to provide them with opportunities to grow and to be exposed to a variety of experiences” (p. 257), a notion that is consistent with lean manufacturing’s principles.

IV) Lean in a Contemporary Context

Understanding lean in a contemporary context involves assessing its role in two growing areas of management research: (1) employee satisfaction and health; and (2) technological innovation.

The increasing awareness of the importance of employees in a lean production environment has been identified by numerous researchers, and the focus on understanding and improving employee health and well-being in lean organizations has become increasingly important (Taylor et al., 2013). The human dimension of motivation, empowerment and respect for people as being critical to the sustainability of lean systems over the long term are being recognized, and as such, understanding how employees interact with, and are affected by, lean systems are becoming increasingly important, both for theorists and practitioners.

The ambivalence of lean manufacturing’s influence on employee outcomes is identified by Bouville et al. (2014) who, by exploring two work organization practices related to lean production—quality management and delegation of responsibilities—suggest that delegation, standardization, job rotation, and quality management lead to the worsening of employees’ attitudes and health at work. However, the pair did find that other work organization practices associated with lean production have a beneficial influence. Broadly, Bouville et al. (2014) suggest that the broadening of responsibilities that comes with the implementation of lean must be accompanied by a reinforcement of skills, and certain aspects of lean, such as the elimination of buffers and machine-paced production, coupled with strong management commitment to providing training and job rotation, almost always end up leading to positive outcomes. Cullinane et al. (2014) came to a similar conclusion, suggesting that although lean-specific demands, in isolation, deplete the energy of employees, they act as motivational challenges which predict work engagement when combined with certain resources. Hence, lean demands should be minimized, while resources maximized for better employee outcomes. Like Hasle (2012), Cullinane et al. (2014) found that lean manufacturing creates a situation in which positive and negative effects thrive side by side and point out that lean resources (i.e., the provision of training, boundary control, and employee feedback) are crucial for promoting engagement, and reducing exhaustion.

Koukoulaki (2014) explored the effects of lean practices on musculo-skeletal disorders, stress and associated risk factors of lean manufacturing through an extensive literature review. Importantly, the exploration of psychosocial risks of work, including job demands, time pressure, low job control, social relations with superiors and colleagues, and job insecurity, helped to further the understanding of these factors on employee outcomes. Koukoulaki (2014) found that there are significant relationships between job stressors and gastrointestinal problems and sleep disturbances, and although the elimination of work-flow buffers (a characteristic of lean manufacturing systems) is thought to play a role in increased stress, the author suggests that the stress could be alleviated with high levels of autonomy and control afforded to employees. This is mirrored by other researchers, such as Klein (1991) and Murakami (1994) who also suggest that worker autonomy and empowerment play a significant role in producing positive health and wellness outcomes for employees.

Little research has been conducted with respect to the extent to which lean manufacturing contributes to the subjective experience of work. It is noteworthy that lean manufacturing is a socio-technical approach that considerers human beings as a fundamental factor to sustain continuous improvement in organizations, influencing both individuals and the quality of the work performed (Pagliosa et al., 2021). Cullinane et al. (2014) concluded that "studies examining the relationship between lean manufacturing and employee well-being to date have yielded contradictory findings, whereby positive, negative and contingent effects have all been demonstrated" (p. 2996). Reviews of existing studies have reported negative effects on both working conditions and employee health, however, the effects are primarily evident for manual types of work with low levels of engagement and complexity (Hasle et al., 2012). Others have suggested that employees working in lean environments in jobs with higher complexity experienced job improvements and participation in decision-making (Parker, 2003). Hasle et al. (2012) advocated for a more open and flexible model of examining lean manufacturing within organizations which accounts for both positive and negative effects. One of the contributors to the inconsistent findings in the study of lean on employees is the lack of an applicable model of job design which captures the complex socio-technical nature of lean manufacturing environments, particularly in contemporary organizations that are coupling the methodology with technological innovation. Prior attempts at understanding employee satisfaction, empowerment, commitment, and perception have thus been limited in scope and focus. No empirical studies have yet addressed the interactive effects of distinctly lean characteristics on employee psycho-social outcomes, such as an increased reliance on group problem-solving or accountability (Cullianne et al, 2014). Given the rapid pace of lean implementation in various industries—nearly 40 percent of all US manufacturing companies describe lean manufacturing as their primary business strategy (Keyes, 2013), and 60 percent adopted 'continuous flow production' practices—a greater understanding of how lean influences individuals (and vice versa) will be required. Moreover, a more comprehensive understanding of the specific organizational conditions that support sustained, positive employee outcomes in contemporary, technological organizations will be important for ensuring positive employee outcomes. Understanding how organizations can optimally apply lean resources (i.e., the provision of training, boundary control, and feedback) to enhance engagement, while understanding how the specific demands of a lean system (i.e., increased work pace, and responsibility and dependency on others) and the use of technology affect employees will be important for both theorists and practitioners.

A growing trend in the research of lean manufacturing and employee outcomes is the study of job design. The job characteristics associated with lean, including greater autonomy, team working, and skill use (Cullinane et al., 2017) require a different approach to the design and execution of jobs and tasks. Recent literature has suggested that the influence on employee well-being is not uniform, and "depends upon management decisions regarding the application of such job design features" (Cullinane et al., 2017, p. 541). While some research by

Hasle et al. (2012) and Cullinane et al. (2017) have focused on the implications of top-down job redesign by management, no empirical research has yet considered how employees working in lean manufacturing environments can actively shape their jobs to enhance their own engagement, particularly in rapidly changing organizations, where employees are interacting more with high levels of technological innovation and automation.

The ambiguity of existing research results suggests that the impact of lean manufacturing can be negative, positive, or both. The subjective experience of working in a lean organization is highly dependent on a number of different variables which vary depending on organization and industry. A critical exploration of the conditions, structures, and practices in a dynamic and ever-changing lean manufacturing environment will represent an important contribution not only to the theory and practice of lean manufacturing, but to critical management studies and organizational theory.

ii. Industry 4.0

I) Origins of Industry 4.0

Industry 4.0 defines a methodology to generate “a transformation from machine dominant manufacturing to digital manufacturing” (Oztemel et al., 2020, p. 128). It is a collective term that encompasses many modern automation systems, production technologies, and data exchanges. It is a collection of values of objects, internet services, and cyber-physical systems that play a role in transforming traditional organizations, notably manufacturing organizations, to smart organizations. This transformation results in more efficient business models as it allows for the immense amounts of data to be collected and analyzed in a well-organized manner, informing faster and more effective decision making.

The evolution of Industry 4.0 mirrors the societal and organizational meta-trends such as the adoption of digitization, cloud computing, artificial intelligence, and Internet of Things (Marr, 2018). As individuals and organizations become more connected due to more readily available, and more affordable technologies, methods of organizing and approaches to work are following suit. Industry 4.0, sometimes regarded as a buzzword in the business world, does not refer to digitization per se, but more precisely “a new approach for controlling production processes by providing real time synchronisation of flows and by enabling the unitary and customized fabrication of products” (Kohler et al., 2019, p. 215). It is a concept with mainstream social appeal and legitimacy, backed by global technology companies, governments, politicians, and business leaders since its inception in Germany in 2011 (Madsen, 2019). It began as a joint initiative supported by the German federal government to enhance German manufacturing competitiveness and technological innovation. The popularization of the concept has been facilitated by similar organizational aspirations around the world (Fox, 2018) including the widespread adoption of the methodology of lean manufacturing and legitimized with government support. Many nations such as Germany, China, Sweden, Belgium, Austria and Japan have formal Industry 4.0 strategies, and provide funding for associated research and development (Schroeder, 2016).

Innovative organizations continue to seek out technological solutions to improve their operations capabilities, in order to secure long-term profitability and viability. Organizations involved in manufacturing, distribution, and the provision of services are looking to automate operations and to leverage embedded intelligence. According to the report by Industryweek “IDS FutureScape: Worldwide Manufacturing Predications 2018,” companies are integrating a number of advanced systems, such as the Internet of Things (IoT) for critical data input, cognitive programs to enhance the analytics, and blockchain technology to maintain the integrity of the data and decision making. This rapid technological innovation and adoption has important implications for lean manufacturing. Notably, since lean methodology is increasingly being used to inform technological approaches to improving organizational performance (Sartal et al., 2017) it suggests that lean manufacturing principles can be “effectively transformed into performance improvement in current technology-intensive environments” (p. 269). Lean methodology establishes the efficient conditions for developing technology in an Industry 4.0 context and guides its use. Utilizing technological solutions to address increasing and changing customer demands, to improve response rates, and reduce environmental impact is a growing trend (Martinez-Pelaez et al., 2023) but is one that has not been studied extensively.

II) Organizational Implications

There is little academic literature that has explored how employee experiences and outcomes are influenced by the use of new technologies within lean manufacturing environments, despite claims that Industry 4.0 is a promising technology that will bring about positive technological, economic and social effects (Hirsch-Kreinsen et al., 2016). This mirrors the absence of critical scholarship within information technology (IT) and information systems (IS), where a positivist, managerial perspective dominates the research agenda. The role of artificial intelligence systems, automation, and the use of IoT have not been studied as they relate to lean organizations, nor has the literature explored the impacts they may have for employee well-being. While Cullinane (2014) demonstrated the crucial role of lean resources (i.e., the provision of training, workplace boundaries, and employee feedback) for promoting engagement and reducing the risks associated with exhaustion, the changing demands of a technologically driven lean environment will differently impact the psycho-social outcomes for employees in these organizations. Moreover, the pervasive nature of technology will likely impact the structures of power within organizations, methods of decision making, feedback, and communication channels. The discursive processes through which influence is created and reproduced will likely be altered. Currently, little is known about how employees are able cope with increasing lean demands in such high-tech environments, where cycle times are becoming ever shorter, feedback is becoming instantaneous, and customer demands are increasing (Cullinane, 2014).

According to Buer et al. (2018) Industry 4.0 is best regarded as a means of supporting lean manufacturing by providing powerful tools and applications to workplaces that have already embraced lean methodology. Conversely, Wang et al. (2016) suggests that lean manufacturing can be used as a foundation upon which to build an Industry 4.0 implementation. Surprisingly, there exists very few academic articles—21, according to Buer et al. (2018)—that explore this relationship between the two, considering the extent to which lean is entrenched in organizations. This observation is further articulated by Wagner et al. (2017) who concludes that "a framework which combines the principles, methods and tools of lean production and the upcoming IT-technology driven Industry 4.0 is missing" (p. 128). The degree to which Industry 4.0 will impact lean manufacturing, and vice versa, is not well understood either from a positivist perspective, or a critical perspective. While there have been positive assessments about the ability of technological application to stabilize and support lean principles (Wagner et al., 2017) there has not been widespread study of integrated applications. Furthermore, Buer et al. (2018) point out that there have been few studies of the shop floor impact of integrated initiatives with respect to "continuous improvement efforts, teamwork, workforce involvement and autonomy, and 5S" (p. 2934). The adoption of Industry 4.0 tools and methods will shape the methodology of lean itself, and vice versa. This interplay between methodology and methods will shape the nature of work, and the experience of work for individuals and groups.

III) Industry 4.0 and the Experience of Work

The integration of lean manufacturing and Industry 4.0 is an important field of research because of the proliferation of the lean methodology and the persistent global demand for increased productivity and efficiency. As more lean organizations adopt these technologies in a quest for competitive advantage, ever-greater numbers of individuals will find themselves working within these new organizational structures, ones which will undoubtedly embody a causal efficacy for organizational members. Since the characterization of Industry 4.0 as the fourth industrial revolution implies an upheaval or a displacement of existing norms, values, and organizational structures, individuals and groups will be consequently affected, and likely not always positively. With respect to the integration of Industry 4.0 technologies into existing lean organizations, Buer et al. (2018) propose a conceptual framework for organizing existing literature into four research streams: (1) Industry 4.0 supports lean manufacturing; (2) lean manufacturing supports Industry 4.0; (3) performance implications of an integration between the two; and (4) the effect of environmental factors on an integration between the two. There is no critical research evaluating the implications of the integration, nor is there any critique of the implications for individuals and groups within these organizations. Most of the studies investigating the performance implications of this integration and new form of working "claim that increased flexibility will be the main benefit, similar to what the proponents of Industry 4.0 claim it will entail" (Buer et al., 2018, p. 2936). The studies frame the benefits from a perspective of instrumental rationality, where the benefit of increased flexibility is for the organization, to the benefit of the organization. While there is a call for additional empirical research regarding the extent to which organizations will experience actual performance benefits (Madsen, 2019), there has been little interest in a critique of the integration and the associated performance benefits.

The positive benefits purportedly associated with the implementation of Industry 4.0 need to be contextualized within the methodology of lean manufacturing in order to understand the experiences of individuals within lean organizations. According to Pereira et al. (2019) lean capabilities can be enhanced through the integration of cyber-physical systems; the Internet of Things (IoT); data analytics; cloud manufacturing; virtual and augmented reality; autonomous and collaborative robotics; and related technologies, which include the use of 3D printing, simulation technologies and optimization algorithms. Moreover, Tortorella et al. (2021) suggest that Industry 4.0 must be embedded within an existing concept for technologies (such as just-in-time or lean manufacturing) to be effective. Just as these technologies are integrated into an existing system, and guided by an over-arching methodology, in all areas of contemporary lean job design human workers are supplemented by technology and integrated into an interconnected system. Rates of workflow, continuous monitoring, and constant real-time feedback characterize job roles as human agents interact with upstream and downstream processes and feedback loops. These technological interventions are radically reshaping job functions and alter the ways in which employees interact with their organizations, their peers, their managers, and with their work. While purported benefits such as "enhanced data collection, ease of communication between different productive actors, information processing capabilities, and data display" (Pereira, 2019, p. 819) seem to be beneficial for organizations, it is unclear whether these will benefit individuals within the new systems and structures.

Birkel et al. (2019) explored the implementation of Industry 4.0 in German manufacturing organizations and found that flat hierarchies, flexible job structures, and decentralized settings that form an agile organization are important when implementing Industry 4.0 technologies within existing concepts. The findings of the study examined the benefits of the implementation from the perspective of the organization, conceding that "research has not dealt with the interplay between humans, organization, and technology" (p. 16). Despite the limited research on the experience of workers in such an environment, Birkel et al. (2019) suggest that employees should receive more expansive education with an emphasis on scenario-based learning; hierarchies should be flattened; decision-making should be decentralized; and organizations should strive to be open and entrepreneurial. There is an implicit assumption that the positive organizational benefits of these technologies will also benefit those within the organizations.

Similarly, research conducted by Frank et al. (2019) and Stock et al. (2018) explored the implementation of Industry 4.0 technologies on organizations, noting that 'smart working,' or the use of technologies to support worker tasks "enable[d] them to be more productive and flexible to attend the manufacturing system requirements" (Frank et al., 2019, p. 8) without considering whether those system requirements were detrimental to the workers themselves. An examination by Oesterreich et al. (2016) of the implications of Industry 4.0 on the construction industry, they conclude that while the adoption of Industry 4.0 technologies has far-reaching implications for employees, particularly as they "have to handle with increasing job requirements and a higher level of mental stress due to the fear about job losses" (p. 137). The impetus for technological implementation is driven by a desire to "transform to a technology-driven industry and to keep up with other manufacturing industries in terms of performance improvement" (Oesterreich et al., 2016, p. 137) to the benefit of organizations, rather than individuals within them.

IV) Industry 4.0 in a Contemporary Context

An examination of the moderating role of Industry 4.0 technologies on the relationship between lean manufacturing and operational performance improvement by Tortorella et al. (2019) concluded that without the systematic process improvement and design derived from lean manufacturing principles, investment in Industry 4.0 technologies did not result in better operational performance or outcomes. Importantly, it is noted that the empowerment of employees in lean systems, a "paradoxical scenario where high-tech applications and human-based simplicity exist concurrently" (p. 875) is instrumental in ensuring that organizations derive value from the high level of investment in these technologies. While it is acknowledged that by creating value for people and processes (Liker et al., 2006) organizations are better able to integrate technology into flow and pull processes, the specific means of increasing employee value (presumably by creating and sustaining ideal working conditions and circumstances) is not well understood in this context. However, the implication that employees play a meaningful role in the implementation of Industry 4.0 is significant.

Research by Thun et al. (2019) explored the impact that Industry 4.0 had on employees, and the consequences that the ubiquity of digital tools within the organization had among operators and "in the interfaces between human, machine and organization" (p. 40). Within a Norwegian industrial context, researchers found that if the aim is to increase work performance and ensure more effective working hours within the production area, the accessibility and use of digital communications (i.e., devices used to provide real-time information to operators which supports decentralized decision making) were instrumental if employed as a resource, and not as something that created an exhausting demand on workers. The centrality of their involvement in the implementation of new technologies and the feedback generated from their use of the tools, and an organizational commitment to providing digital assistance, helped ensure that they could function as decision makers and problem solvers. Organizations needed to fully understand their processes and value chains before attempting to implement new technologies to ensure that workers were not overwhelmed with the large amounts of data and information that are generated from complex systems. Organizations that emphasize "enhancing job attractiveness, facilitating continuous improvement and innovation, and developing human skills and abilities" (Thun et al., 2019, p. 44) find that employees had high levels of motivation and job satisfaction when digital tools were tailored for their roles, and supported their specific tasks. Research findings suggest that while "digital tools can help operators improve the quality of their work, complete work more quickly, experience new job content and contribute to safety in work routines" (Thun et al., 2019, p. 51), more study is needed to understand the interplay between technology and the experience of work. While it is clear that Industry 4.0 implementation can have a tremendous impact on industrial value creation, it is important to understand the underlying dynamics of that implementation, and to explore the ways in which social design of processes and systems should precede technical implementations in processes.

Much of the research on Industry 4.0 describes general conditions, and little has focused on how Industry 4.0 actually alters the role of employees within organizations and how "task range, task depth and task content actually change due to Industry 4.0" (Schneider, 2018, p, 829). The complex interplay between organizational social structures, technological interventions and individual subjective experience has not been explored in the literature. Schneider (2018), in that regard, suggests that "in-depth, qualitative case studies may enrich our understanding of sociocultural aspects of the changing role of humans in manufacturing, thus addressing calls for anthropocentrically motivated studies" (p. 830).

The statement that "the future of human labor has been rendered uncertain recently, due to the emergence of artificial intelligence and robotics" (Mfanafuthi et al., 2019, p. 13877) captures the sentiment of what Industry 4.0 enabled workplaces may mean for workers. Although it has been described as a fourth industrial revolution, it is important to consider that the term implies a radical departure from an existing order, in favour of a newer one. Revolutions must be widely embraced by large numbers of people to be sustained (Mfanafuthi, 2019). With studies like the one conducted by Bakhshi et al. (2013) indicating that the adoption of AI and robotics has resulted in a decline in employment and incomes, anxieties around the widespread adoption, and the rapid changes in the nature of work are certain to arise. With rapid change and a rise in fear and anxiety as a result, a critique of technologically enabled lean organizations is timely and practical. The impetus for change necessitates an understanding of that change, particularly when the potential exists for negative outcomes for so many.

iii. Technology and Work

I) The Organization of Work

From a socio-technical perspective, it is acknowledged that the adoption of emerging technologies associated with industry are not supported by themselves, but rather, by there are at least three complementary socio-technical dimensions to the technological one to consider: (1) organization of work; (2) human factors; and (3) the external environment (Dalenogare et al., 2018).

The introduction of new technologies in the workplace requires that organizations re-design how they will operate (Brettel et al., 2014) in relation to the design and purpose of the technology. There is wide evidence that technological changes often fail due to organizational misalignment, such as lack of employees' empowerment to exploit and use new technologies to their full extent (Kolodny et al., 1996).

Technology alignment occurs at both the micro-(i.e., work design) and macro-organizational (i.e., organizational structure) levels. The socio-technical perspective considers organizations as systems which are characterized by both technological and social variables, and include people, culture, and organizational structure. According to Trist et al. (2013) both types of variables must be taken into account when designing an effective Industry 4.0-enabled organizations. Considering the pervasive nature of networked information-based technologies throughout the manufacturing process and supply chain, organizations face a new manufacturing paradigm which is different from previous ones (Frank et al., 2019). The difference is rooted in the complexity and interconnectivity of the technology. Empirical evidence on how these technologies interact with organizational design are limited, however (Cagliano et al., 2019). The theoretical perspective of socio-technical theory posits that workplaces are comprised of opportunities and constraints (Parker et al., 2017), which, when considering technological and social variables, allows for analysis from a work organization and design perspective. This involves looking at how both micro- and macro-levels provide opportunity for both individuals and the organization as a whole, and how process constraints are addressed. This allows for a complete understanding of the ways in which technology interact with each component, and each level, of the organization. At the micro-level, job breadth, the number of tasks that individuals perform, job autonomy, cognitive demand, and social interaction are all affected by technological intervention (Wall et al., 1990). At the macro-level the ways in which decision-making authority and hierarchical structures are arranged will be affected by, and respond to, technological intervention (Mintzberg, 1980). According to Cagliano et al. (2019) organizations will adopt one of four configurations (process-automated factories; partially integrated factories; fully integrated factories; or smart factories) depending on the level of technology investment, and the sophistication of their technical systems. Each will interact with micro- and macro-level organizational processes differently. Notably, the smart factory configuration, characterized by a highly integrated smart manufacturing approach, integrated production processes with larger organizational processes, and integration of supply chains, is synonymous with Industry 4.0. In smart factories operators engage in mainly cognitive tasks which involve supervising machines and making decisions on the basis of available data and information. This involves working in formal teams, with intra-, inter-team and cross-hierarchical interactions. Moreover, since work is decentralized at the team and operator level, organizations that subscribe to the smart factory model tend to be characterized by "an organizational re-design toward a flatter organization [which is] considered a necessary requirement for the implementation of such technologies, in order to simplify and optimize operations and decision-making processes" (Cagliano et al., 2019, p. 927). Much of this shift in operator-level and macro-level structure occurred as a result of the adoption of lean manufacturing principles, which has contributed to managing technological complexity and realizing customer-defined value.

II) Human Factors

The socio-technical dimension that humans bring to technological intervention in organizations cannot be overlooked. According to Stein et al. (2020) human issues tend to follow the narrative of social determinism with social shaping and social construction of technology. Ultimately, people and their corresponding societal needs are drivers of technological changes, in that they attribute meaning to technology and its usage (Kranzberg, 1996). As work processes become automated, the way people work, and the role people will play in smart factories will change. Consequently, people will have to understand the necessity of these changes. Organizational sense-making addresses the question of how to deal with the realities of automation by addressing the way people attribute individual, as well as collective meaning to their experience, therefore "reducing ambiguity in mutual communication" (Stein et al., 2020, p. 395). How individuals perceive the positive effects of ongoing changes related to technological intervention and automation will ultimately decide if, and how, organizations will implement Industry 4.0 technologies. The 'buy-in' from individuals will inform a broader consent to technological changes, and inform the collective creation of a joint identity, and an "ongoing process of retrospection and enactment in order to build a new narration on real developments, and a process of shared acceptance of plausible explanatory patterns" (Stein et al., 2020, p. 395). Organizations cannot ignore the subjective realities of technological intervention in the daily work of individuals, nor can they expect that there will not be necessary changes to allow for meaningful adoption. According to Rosenthal et al. (2012) a fundamental shift in new technologies involves the way humans communicate with machines: since machines communicate with one another and have the ability to learn, machines are increasingly teaching humans, and are interacting with them in a synergistic manner. This disruption in traditional communication will undoubtedly create a number of issues, from anxiety, to having to learn a new way of communicating. Human factors and the organization of work can enable the potential benefits of technologies for business performance (Westermann et al., 2014).

III) The External Environment

The external environment is an important socio-technical dimension that helps inform the extent to which organizations are able to acquire and implement new technologies. Industry 4.0, for instance, can be regarded as matter of technology diffusion and adoption. Emerging technologies of the contemporary industrial age tend to flow from developed countries to developing countries, where the competitive environments of suppliers, customers, and those in the adopting industry create differences in the perception of the value of these diffused technologies (Kagermann, 2015). These differences are related to the maturity of the economies where they are implemented (Schumacher et al., 2016). According to Dalenogare et al. (2018) organizations in emerging economies face a gap in Industry 4.0 adoption due to the low maturity of prior industrial stages, and many companies are investing in technology to automate their operational routines instead of seeking advanced ICT tools that could provide a real competitive advantage in innovation development on a global scale. Market behaviors tend to influence decisions to invest in technology (Frank et al., 2016), and vary with socio-economic conditions. For instance, companies in developing countries tend to be focused on making investments in technologies that allow for low-cost production, while companies in developed countries tend to favor investment in technologies that facilitate the differentiation of products (Dalenogare et al., 2018). Customer needs, social trends, and changing realities of supply chains also impact how organizations invest in technology.

iv. The Adoption of Technology

I) Background

The adoption and extent of use of advanced manufacturing technologies is closely related to the cognitive beliefs, dispositions, and perceptions of the employees that use them. Technologies and technological systems in companies and organizations ultimately rely on employees to engage meaningfully with them over time to produce desired outcomes. In this way, while the adoption of new technologies creates opportunities for business, the adoption may have unintended detrimental effects, caused by disruption of routines and processes (Dube et al., 2020). Adopted technologies are unpredictable and can have a negative impact on organizations and intended outcomes if misused, or if not implemented in a systematic and thoughtful way. The successful adoption of technology relies on both organizational and individual, or user, factors.

Technology adoption has been widely studied in information systems (IS) research. The aim of many studies on technology adoption has been “identifying, predicting, and describing variables that affect adoption behavior both in individuals and in organizations to embrace and implement technological innovations” (Dube et al., 2020, p. 207). Several frameworks and conceptual models have been developed which assist in understanding the association between technology adoption, employee acceptance, and continuance of use. Of the proposed frameworks, the most significant and widely cited are the technology acceptance model (TAM), the technology-organization-environment (TOE) framework, and the unified theory of acceptance and use of technology (UTAUT).

The technology acceptance model (TAM) has been extensively used and studied for predicting the adoption and use of the adopted technology in organizations. TAM (Davis, 1989) speculates that technology adoption is determined by perceived usefulness and perceived ease of use by employees. Perceived usefulness is defined as “the degree to which an employee of an organization believes that using a particular system would enhance their job performance” (Au et al., 2008, p. 4) and perceived ease of use is defined as “the degree to which an employee of an organization believes that using a particular system would be free of effort” (Au et al., 2008, p. 4). In TAM, an employee’s perception of the usefulness of a new technology and its ease of use informs their attitude towards use, and importantly, whether they intend to use the technology, and continue using it. TAM is based on the theories of reasoned action and planned behavior, which differentiates between principles, attitudes, beliefs and intentions (Dube et al., 2020). It speculates that perceived ease of use influences perceived usefulness—

the simpler new technology is to use, the more useful it is perceived to be. Although TAM was originally developed to explain users' initial IT acceptance, some researchers have assumed that factors affecting initial acceptance would be similar to those affecting continued usage (Mathieson, 1991), and TAM is often used to predict the behavior of employees in the future.

The technology-organization-environment (TOE) framework developed by Tornatzky et al. (1990) explores the technology adoption of numerous technological systems and products at the organizational level, and provides an extensive theoretical viewpoint on IT adoption (Zhu et al., 2004). TOE considers a variety of organizational, technological, and environmental variables, and can be applied to businesses of any size. As a result, it offers a comprehensive perspective of the user's adoption of technology, its execution, expected obstacles, its effect on organizational value, post-adoption dissemination, and how organizational capabilities can be optimized to utilize the investment in the technology (Salwani et al., 2009; Zhu et al., 2004). According to Dube et al. (2020) there are three different contexts that effect technology acceptance, creativity, and implementation: (1) the technological context; (2) the organizational context; and (3) the environmental context. The technological context includes the variables that affect a person, an organization, and the adoption of innovations by a business (Claybomb et al., 2005). The variables considered in the technological context include system integration, complication, perceived intended benefits, perceived unintended benefits, and standardization. The organizational context refers to measures relating to organizations, including size, scope, and executive principles (Salwani et al., 2009). The adoption of technologies is affected by organizational structure and hierarchy, the creativity of the company, and the assets at its disposal. Organizations will have very different levels of access to assets such as capital, administration support, operational ability, innovative structure, and importantly, firm size. The environmental context emphasizes areas in which a company leads its business tasks, with the emphasis on external elements affecting the business, such as government policy , competition, relationships with purchasers and providers, and phases of the business cycle (LeRouge & Webb, 2004). While TOE is an effective framework for classifying variables, it does not represent an integrated theoretical framework by itself.

The unified theory of acceptance and use of technology (UTAUT) is extensively used in IS research, as it “enables the analysis to evaluate a users intent to use an information system, as well as the behavior resulting from using an IS or technology” (Dube et al., 2020, p. 210). UTAUT refines the key factors and contingencies which relate to expected behaviors regarding the intention to use a technology or system. These factors include quality expectations, effort expectations, social impact, and conditions facilitating (Dube et al, 2020). It is a broad and encompassing theory that integrates features of eight known models (Anderson & Schwager, 2003). There are, however, questions about the validity of the model as a predictive instrument.

According to Mohr (1982) there are two fundamentally different types of theoretical approaches, or models, that can be used to investigate technology adoption: *variance* models, and *process* models. Much of the research on technology adoption has been from a variance perspective, typically focused on large samples of organizations and focused on identifying the environmental, organizational, and managerial factors that distinguish adopters of technology from non-adopters. Process models, such as those proposed by Langley & Truax (1994) differ in that, rather than simply identifying the characteristics that, on average, distinguish ‘non-innovative’ from ‘innovative’ firms, they allow for an understanding of how firms may transition from one type to another. Process models track activities over time and come in three forms: (1) sequential models; (2) political models; and (3) serendipitous models (Langley & Truax, 1994).

Sequential models decompose technology adoption into a certain number of phases, each which are made up of different types of activities (Rogers, 1971). Empirical research has supported this model generally, although it has been criticized for assuming that technology adoption follows the stages in a prescriptive manner. Moreover, it fails to address social and political phenomena (Schroeder et al., 1989).

Political models, such as that by Dean (1989) explored manufacturing technology adoption decision processes, and identified the importance of individual champions within the organization to promote adoption (Langley & Truax, 1994). The focus of a political model is on how advocates of technology convince managers to accept their ideas “through a process of persuasion, salesmanship and negotiation in which ‘approval components’ such as personal credibility and political support carry as much or more weight than financial or strategic criteria” (Langley & Truax, 1994, p. 621). The model has been criticized for failing to address the unique needs of smaller firms, as barriers to technological adoption may be related more to a lack of skills and financial resources, rather than to politics and bureaucratic maneuvering.

Serendipitous models suggest that innovation in organizations is easiest when standard operating procedures or organizational routines compel the organization to consider new technology as part of its business process. According to Mohr (1987) a variety of different routines operate, either independently or in groups to bring new technologies into an organization. The greater the number of routines set in motion, the greater the likelihood that an organization will adopt a new technology or system. The interaction between organizational routines and resistance to change negotiate the adaptation process.

The various models and conceptual frameworks used to explore the adoption of technology in organizations help provide an understanding of continued or extended use— that behavior that goes beyond typical usage and can potentially lead to better results and returns for organizations that invest in advanced technological solutions. According to Hsieh & Wang (2006) while companies spend billions of dollars annually on technological systems, such as enterprise resource planning (ERP) systems, the results of often very expensive initiatives are often disappointing: nearly half of ERP system projects experience failures, and few organizations use their systems to their full potential. There is little to suggest that adoption of Industry 4.0 technologies do not, and cannot, face the same rates of failure. The production paradigm brought by Industry 4.0 requires organizational changes under high levels of uncertainty (Kamble et al., 2018), and ultimately, a variety of different barriers that similarly endanger them.

Numerous studies have focused on identifying barriers to specific Industry 4.0 technologies such as blockchain or IoT (Kamble et al., 2019), or to a specific context within manufacturing (i.e., automotive manufacturing), or a specific set of companies (Horvath &

Szabo, 2019). According to Senna et al. (2022) an organization's internal processes, as well as its strategy, culture, and workforce should be considered when undergoing the adoption process of Industry 4.0 technologies. Adoption requires a "shift in the human resources' mindset" (Senna et al., 2022, p. 3) to address the lack of a skilled workforce and the natural resistance to changes in the work environment. As such, there is an increasing need to continuously promote the retraining of staff to adapt to ever-changing circumstances (Moeuf et al., 2020). Industry 4.0 interventions, like other technologies and systems, require organizational and process changes to overcome a variety of barriers, including financial constraints, lack of expertise or knowledge, lack of clear comprehension about the benefits of the technology, and the lack of a sufficient digital strategy, among others. Senna et al. (2022) identified fourteen specific barriers to successful Industry 4.0 adoption, and address both organizational and individual factors.

Thie widespread underachievement of technological interventions can ultimately be attributed to underutilization by users, resulting from the complex interaction of barriers and enablers in organizations (Stornelli et al., 2021). The literature suggests that simple and superficial understanding of usage behavior is inadequate to sufficiently account for this underutilization. Rather, a deeper and more sophisticated understanding not only of the organizational barriers, but of the dispositions and perceptions of employees is required to understand technology acceptance and use, particularly over time.

II) Acceptance vs. Continuance

Cooper & Zmud (1990) introduced a six-stage model of IS implementation: initiation, adoption, adaptation, acceptance, routinization, and infusion. The last three stages refer to different levels of technological implementation. Acceptance, the fourth stage, reflects users' commitment to meaningfully engage with and use a system (Hsieh & Wang, 2006). Continuance generally refers to the extension of acceptance, or the continued use of a technology or a system over time. Continuance acknowledges the existence of a post-acceptance stage when technology use transcends conscious behavior and becomes part of normal, routine activity. While many theorists assume that continuance is an extension of acceptance behaviors, implicitly assuming that continuance co-varies with acceptance, it is clear that some users discontinue technology use after accepting it initially: the acceptance-discontinuance anomaly (Bhattacherjee, 2001). Users' dispositions, motivations, and perceptions that emerge after their initial acceptance can influence subsequent continuance decisions, but not necessary their prior acceptance decisions.

The distinction between acceptance and continuance behaviors is important in technological adoption due to the practical consequences of failure (i.e., cost, competitiveness, etc.). Properly identifying and promoting both acceptance and continuance behaviors among users requires different interventions, which has obvious management implications. Employees for whom new technologies become routinized have the potential to use them in a more comprehensive and sophisticated manner, and may achieve an even higher level of usage, allowing them to exploit the full potential of the technology, resulting in more positive organizational outcomes (Hsieh & Wang, 2007). The application of a number of different theories and models, such as the IS-continuance model (Hsieh & Wang, 2007), the Technology Acceptance Model (TAM) and the Expectation-confirmation theory (ECT) have been applied to understand continuance. The application of the expectation-confirmation theory (ECT) (Oliver, 1980) is particularly salient as it holds that consumers' intention to continue use is determined primarily by their satisfaction with prior use. Satisfaction, then, can be regarded as the key to building and retaining users of a technology. Satisfaction, in this context, is defined as "the summary psychological state resulting when the emotion surrounding disconfirmed expectations is coupled with the [user]'s prior feelings about the [use] experience" (Oliver, 1981, p. 29). This conceptualization of satisfaction "underscores a psychological or affective state related to and resulting from a cognitive appraisal of the expectation-performance discrepancy (confirmation)" (Bhattacherjee, 2001, p. 354). Lower expectations and/or higher performance lead to greater confirmation, which, in turn, positively influence satisfaction and continuance intention. In addition, Bhattacherjee (2001) indicates that in addition to satisfaction, perceived usefulness of the technology is a very important predictor of continuance behaviors. While perceived usefulness is more crucial for acceptance intention and satisfaction is more dominant for continuance intention (Bhattacherjee, 2001), organizations implementing advanced manufacturing technologies should adopt a two-fold strategy: inform new or potential users of the potential benefits of technology use, and educate existing or continuing users on how to use the technology effectively, so as to maximize their confirmation and satisfaction.

III) Adoption of Industry 4.0 Technologies

The adoption of Industry 4.0 technologies in manufacturing is less well understood than information systems (IS) due to the nature of the technology itself. According to Pedota et al. (2023) Industry 4.0 technologies "display remarkable dynamism and complementarity, but they have yet to become fully-fledged general purpose technologies, and their conjoint evolutionary pattern is still rather unpredictable" (p. 1). As a result, there has been far less research into the adoption of Industry 4.0 technologies specifically, but a reliance on adapting existing scholarship on information systems (IS). In such a dynamic context, adaptation strategies need to anticipate the coevolution of Industry 4.0 technological trajectories, reorganize facilities and employees as needed, improved coordination across organizational units, gather knowledge and know-how about the technologies, overcome potential organizational resistance, and develop the skills necessary to use the technology effectively (Kiel et al., 2020). Successful adoption relies upon similar principles as IS research has revealed, but adapted to the unique demands of Industry 4.0. A focus on the provision of training aligned with either acceptance or continuance behaviors is an important consideration when implementing new technologies, and leveraging them to create long-term value.

v. The Subjective Experience of Work

I) Background

Subjective experience can best be described as an individual's articulation of an episode, including the sights, sounds, feelings, thoughts, motives, and actions over a specified duration of time. These are closely knitted together, stored in memory, labelled, relived, and communicated to others. Experience can be conceptualized as a story "emerging from the dialogue of a person with her or his world through action" (Glanznig, 2012). Experience is a complex construct which emerges through the interaction between individuals and the external world. According to Dewey (1934) experience is constituted by the relationship between the self and the external, where the self meets different situations with personal interests, ideologies and biases, and the resulting feelings, meanings, and knowledge are not available *a priori*, but are achieved dialogically through reflection and introspection.

Until recently, subjective experience was excluded from scientific investigation, as it did not fit within the classical boundaries of experimental psychology. However, a number of researchers studying cognitive science have concluded that in order to fully study cognition, it is essential to take into account the subjective dimension, as it is lived from inside (Petitmengin, 2006). As a result of the cognitive processes being described in the first person, it is far more precise and provides richer detail than an indirect description, or account of observation. Describing one's subjective experiences is not a trivial activity, however. It is extremely difficult as "a substantial portion of our subjective experience unfolds below the threshold of consciousness" (Petitmengin, 2006, p. 230). Individuals are unaware of many of the cognitive operations that take place in the mind, and describing one's most immediate and most intimate experience, that which we live here and now, is also that most foreign and the most difficult to assess (Schwitzgebel, 2004). As a result of these challenges, researchers have devised a number of interview methods which enable individuals to be conscious of subjective experience, and describe it with precision. This first-person data gathering expresses the viewpoint of the individual in the grammatical form 'I.' The data can also be gathered through another person in the grammatical form 'You,' and is referred to as a 'second-person' method.

To explore subjective experience, it is important to specify what that means within the context of work (specifically, within contemporary organizations), to identify the practical difficulties of gathering and interpreting that information, and the processes that can be implemented to counter those difficulties. The seminal works in the study of subjective experience include Husserlian psycho-phenomenology, Piaget's theory of becoming aware, Ribot and Gusdorf's "affective memory" theories, and the clinical research of James and Titchener. According to Petitmengin (2006) these researchers, and others, have provided a basis for describing and understanding lived experience by:

- Highlighting the pre-reflective dimension of subjective experience
- Describing inner gestures enabling the awareness and the description of subjective experience
- Developing processes which can help others perform these gestures over the course of an interview
- Establishing precise terms to reference these gestures

Understanding the subjective experiences of individuals is important in that it is instrumental in how meaning is constructed and ascribed, it informs perspectives, it develops or reinforces new values and beliefs, and it facilitates the regulation of psychological needs. According to Faustino et al. (2020) humans make meaning of inner and external experience "thanks to a series of concepts, which may be expressed as cognitions—including ones about values or interests—or emotions" (p. 320). This concept was extended by Horowitz (1987) who noted that consciousness constructs tend to cluster together in recurrent forms of subjective experience, which are *states of mind* or *mental states*. States of mind are forms of subjective experience which cluster or activate together mental elements such as cognitions, emotions, needs, desires, or somatic sensations which enable action tendencies and behavior. The term *state of mind* encompasses different forms of mental elements, and as a result, different conceptualizations may be employed to organize how these elements are described. States of mind and schemas are two constructs that psychologists use to describe the interplay between cognition, emotion, and memory. Both constructs are similar in that they encompass some mental elements, however, while schemas tend to be associated with operant and external behaviors, states of mind are more concerned with experiential and internal subjective experience. According to Faustino et al. (2020) the notion of schema is "one of the most used conceptualizations for cognitions with a trait perspective and is used in different theoretical models" (p. 321). Schemas are comprised of cognitions, memories, emotions and beliefs that have a trait predisposition, and represent moment-to -moment emotional states. States of mind are forms of subjective experience that involve cognitions, emotions, needs, desires, and physical sensations that manifest together in consciousness (Horowitz, 1987). When examining the subjective experience of work, states will be the focus of the analysis.

II) States of Mind

Dimaggio et al. (2015) proposed three states of mind: (1) painful and fearful states, or those that are filled with suffering and distress; (2) coping states, or those for the purpose of coping with suffering; and (3) ego syntotic states, or those for the sake of value and identity. Painful and fearful states reflect vulnerable, suffered, weak or painful aspects of the self which people attempt to avoid, coping states are associated with individuals dealing with distressful thoughts, sensations, feelings, and interpersonal situations, and ego syntotic states are actively pursued because they are pleasant, or are central to defining identity or preferred goals (Dimaggio et al., 2015).

There are several competing theories regarding states of mind, from the perspective of clinical psychology. For instance, the paradigmatic complementary metamodel (PCM) suggests that psychological needs are states of mental disequilibrium caused by a deficiency or excess psychological stimuli, is signaled emotionally and informs behavior. Emotion-focused therapy (EFT) similarly explores the concept of emotionally-laden states of mind, and suggests that mental states are end-points of processes based on interventions. From a clinical perspective, identifying recurrent patterns of subjective experience is an important part of case formulation and is helpful when evaluating the therapeutic process and outcomes.

According to LeDoux et al. (2018) there are four contemporary views of subjective emotional experience in the brain: (1) the Neuro-Darwinian approach; (2) the Neuro-Jamesian approach; (3) the Neuro-Behaviorist approach; and (4) the Neuro-Cognitive approach. The Neuro-Darwinian approach views emotions as subjective feelings that emerge from a subcortical neural circuit that is highly conserved, and is centered on the amygdala and related subcortical areas. In this view, the amygdala circuit, when activated, gives rise to feelings and controls innate behaviors and supporting physiological responses. While this perspective suggests that emotions are the inherited mental state arising from the subcortical circuit, research has shown that the amygdala circuit does not seem to be responsible for subjective experience of emotional states, as the amygdala can respond to external stimuli without triggering emotional response. The Neuro-Jamesian approach suggests that emotional experiences result by way of feedback from the act of responding. This perspective is somewhat counter-intuitive as it suggests that emotional feelings are the result of activity in the body sensing circuits in the neocortex. Cognitive elaboration by higher-cortical circuits allows for introspection and self-reporting. However, LeDoux et al. (2018) point out that there is little evidence to suggest that these mechanisms are the main cause of emotional experience. The Neuro-behaviorist approach eliminates mental states from the causal chain between external stimuli and behavioral response. In doing so the approach satisfies the behaviorist constraint against using subjective explanations of behavior, and focuses on brain physiology. This allows proponents to argue that subjective experience is an “inaccurate social construct” (LeDoux et al., 2018, p. 68) that can be replaced with a more rigorous scientific notion of emotion as a non-subjective state of the amygdale-centered circuits. The widely observed lack of correlation between verbal reports of subjective experience and amygdala activity in the human brain bolsters the appeal of this perspective. What is lacking, however, is the capability of this perspective in addressing the question of how conscious fear comes about. The Neuro-Cognitive approach addresses this issue, as it emerged from the inability of the Neuro-Jamesian approach to overcome restrictions on inner explanations of subjective experience. The approach suggests that emotional experiences result from the individual interpretation of physiological arousal in the brain and/or body in addition to cognitive assessments of social context. Recent theorizing has emphasized that emotional experiences are cognitive constructions based on conceptualizations of situations, or “higher-order states that emerge as a result of the cognitive integration in working memory of diverse sources of information from within the brain and body" (LeDoux et al., 2018, p. 69). Emotional theory suggests that cognitive and emotional states are differentiated by the kinds of inputs or stimuli that are processed. Emotions result from neural circuit activation, by cognition, or by a combination of the two. While these four approaches can be conceptualized within the context of psychotherapy and clinical psychology, understanding the underlying mechanisms of subjective experience is important when examining it in an organizational context, and when evaluating associated research methods and tools.

Subjective experience has been difficult to examine, and challenging to study. According to Petitmengin (2006) individual awareness of subjective experience is difficult due to dispersion of attention, absorption in an objective, and confusion between experience and representation. Dispersion of attention refers to the observation that when engaged in a task, an individual's thinking often drifts from information readily observable in the current environment (task unrelated thinking) and tends to lapse. According to Smallwood et al. (2004) when considering subjective experience, individual inattention can contribute to the ambiguity of responses when reflecting upon situations, and important information regarding the situation, the context, and the environment could be missed. Absorption in the objective refers to the idea that individuals are often entirely absorbed in the results to be achieved (the 'what') while ignoring the ways in which that objective is achieved (the 'how'). This applies to many cognitive processes, particularly routine ones, and seems to be proportional to an individual's level of expertise (Petitmengin, 2006). With respect to subjective experience, individuals may not be aware of certain steps, processes, events, or decisions. Lastly, not only do individuals not know what they do not know (how cognitive processes function), but individuals often believe that they know, meaning that in many cases, individuals have a mistaken representation of their cognitive ability, a representation most hold firmly, which makes it difficult to become conscious of how that activity has taken place. In many cases, this mistaken representation is learned, and corresponds to beliefs that are informed by a variety of factors, notably language. According to Petitmengin (2006) the tenacity of representations and beliefs has two different effects: (1) a deforming effect in which individuals substitute their descriptions for experience; and (2) a concealing effect, where “when certain dimensions of our experience do not match up with our representation or our understanding, they are discarded from the field of our consciousness, or ‘repressed’” (p. 235). When an individual tries to describe the way in which they carry out a cognitive process, it usually begins with describing a representation, including what they believe they are doing, or what they imagine they are doing, framed by judgments, assessments, or comments on how the process was carried out, or by theoretical explanations about the process. While there is some value in this, it does not provide any information regarding how an individual actually carries out the process, and different techniques are required to gain access to the experience itself, and what lies beneath individual “representations, beliefs, judgments, and comments” (Petitmengin, 2006, p. 235).

III) Implications for Work

The study of subjective experience, despite challenges in doing so, is important because all individuals according to their health conditions, social roles, personalities, and idiosyncratic styles of interaction with environmental opportunities, and develop personal evaluations of what a good quality of life means (Delle Fave, 2006). Quality of life is a broad construct that involves areas and activities of daily life—including work—and is influenced by multiple dimensions, from cultural norms and beliefs to individual values and opinions. Different individual can be more or less effective in actively exploiting the environmental opportunities for action available to them, and the degree to which quality of life is rated is informed by a multitude of factors, including the extent to which individuals enjoy opportunities for growth and development, the degree to which individuals build an inner sense of coherence (Antonovsky, 1993), and the extent to which people engage in goal setting and associated completion (Prochaska, 1994). The subjective experience of work, within a culturally defined context, and within an organizational frame of reference, is sought to be optimized. This optimization can be from an organizational perspective, where workers, by optimizing working conditions, maximize productivity, and ultimately, improve return on investment (ROI). Alternatively, optimization can be examined from the perspective of the workers, where a high quality of life in all domains of life, of which work constitutes a significant portion, is realized. According to Deci et al. (2000) optimal experience is characterized "by the perception of high environmental challenges matched by adequately high personal skills and by high levels of concentration, involvement, enjoyment, control, and intrinsic motivation" (Della Fave, 2006, p. 172). Understanding optimal experiences and the developmental trajectories of individuals with regard to their working environment can thus be beneficial in understanding the conditions under which both workers and organizations benefit. This is particularly relevant in contemporary organizational forms in which the implementation of new technologies accompanies new paradigms of organizing people and processes (notably Industry 4.0).

Paid work occupies a great deal of daily life for many people. According to Biskup et al. (2019) employed Americans work on average 60-70% of their days, and on those days, spend about half their waking time working. Given the amount of time spent working, individual well-being during that time is an important consideration, for both organizations and workers. Much of the early literature on the nature of work and classical economic theory regards work as 'disutility' or obligation that is an inherently unpleasant activity that individuals engage in solely for instrumental financial purposes. Contemporary organizational theorists offer a different perspective, one in which employees realize numerous well-being benefits from working, including a sense of achievement and belonging, the provision of structure, and positive social interaction. Eudaimonic perspectives such as Self-Determination Theory highlight the potential benefits that work can provide in the form of meaning, personal growth, and intrinsic motivation (Biskup et al., 2019).

IV) Contemporary Perspective

Contemporary literature on employees' emotional experiences of work have shifted from an organizational perspective that framed it in terms of engagement, job satisfaction, employee well-being, performance and retention (Steger et al., 2009) to an employee perspective where concepts such as meaningfulness of work and the role of potential have become the focus (De Boeck et al. 2019). Existing literature offers mixed results on whether work is experienced positively, where some researchers have suggested that the positive affect of work is at least as high as leisure activities (Snir et al., 2008) while others have concluded that work ranked second lowest in happiness among 39 daily activities (Bryson et al., 2017). As work continues to change with the adaptation of new technologies, the role that new technology has in shaping tasks, informing workload, and changing the way employees cope with new occupational demands. Existing research on interactive technologies in the workplace have largely neglected the experience of work as a measurable construct, and instead focused on the extent to which technology acts as a stressor, without analyzing its relation to any negative or positive well-being states (Mäkiniemi et al., 2020). The integration of technology and work has the potential for both negative and positive outcomes, with a positive state of mind being divided into three dimensions: vigor, dedication, and absorption (Schaufeli et al., 2002). Vigor refers to high levels of energy, mental resilience, and a willingness to put in effort, and to persist. Dedication is characterized by enthusiasm, inspiration and pride, while absorption involves full concentration on tasks, and in one's work (Schaufeli et al., 2002). The concept of worker engagement describes how employees feel in relation to their work in general, whereas techno-work engagement, a concept proposed by Mäkiniemi et al. (2020) is a more specific state of work well-being in relation to the use of digital technology at work. Work engagement is a well-known, established, and validated concept (Kulikowski, 2017). In prior studies on technology-related well-being at work the focus has been mostly on negative experiences with technology, focusing on four types of feelings: anxiety, fatigue, skepticism, and beliefs concerning inefficacy related to the use of technology (Salanova et al., 2014). According to the framework established by Day et al. (2010), employees can experience the use of technology related to working life as either a demand (framed as a negative aspect) or as a resource (framed as a positive aspect). Technology can be regarded as a means of assisting in effective information transfer, a means of improving work performance, and can offer more flexibility to employees in terms of working places and work-life balance, ultimately contributing positively to employee well-being (Bordi et al., 2018). In this way, it is important to understand the claims made by organizations and proponents of the technology, and to measure subjective experience against those claims. In the context of Industry 4.0 stated claims about the benefits of technology can be examined with respect to autonomy, social/collegial support, self-efficacy, and value congruence (Mäkiniemi et al., 2020). It is important to consider that the technology may be beneficial, detrimental, or a combination of the two. Employee subjective experience will help identify the extent to which technology is regarded as a job demand, or a resource, and whether that aligns with the stated intentions of the technological intervention.

V) Operationalizing Subjective Experience

Exploring and ultimately measuring subjective experience can be accomplished in a number of ways. Retrospective questionnaires, questionnaires, focus groups, and interviews all rely on memory to collect data. Human memory is less concerned with accurately recording experiences than with integrating them into an individual narrative and making meaning of them (Constantino et al., 2021). The idea that individuals store memories to confirm biases and those that fit prior experiences supports the need to employ several different data-gathering techniques. The Experience Sampling Method (ESM) allows researchers to sample human experience as close to the moment of experience as possible by collecting data about actions as well as feelings about their actions in naturally occurring situations (Csikszentmihalyi & Larson, 1987). The Utrecht Work Engagement Scale (UWES-9) captures three dimensions of work engagement and is typically used to measure the level and factorial structure of work engagement (Schaufeli et al., 2006). Although there are some inconsistent findings concerning the factorial validity of UWES, it fits empirical data better than most alternative structures, and is considered the standard when exploring engagement (Kulikowski, 2017). The Subjective Work Experiences Scale (SWES) is a four-item scales that uses a five-point Likert type scale to measure global self-perceived life satisfaction, job/career satisfaction, happiness and the perception of work as a valuable activity (Bergh, 2009). Examining subjective experience using these methods, or a derivation of them in order to understand the role of technology in contemporary organizations will help form a complete assessment. The use of a mixed-methods perspective allows for the combination of empirical evidence for the relationship between technology and job characteristics with subjective interpretation to inform a comprehensive understanding of the role technology plays in the everyday experience of work. Importantly, this allows for the evaluation of claims made by proponents of Industry 4.0 technologies, while providing insight into the rapidly changing nature of work.

vi. Critical Realism

I) Background

A practical aim of critical management studies is the empowerment and emancipation of disadvantaged or otherwise disenfranchised individuals and groups within organizations through the critique of management ideology. This critical-emancipatory aim, within a broad managerialist framework, is aligned with what Fleetwood (2005) describes as a "cultural, linguistic, post-structural or postmodern turn" (p. 1), reflecting a broad ontological shift from realism to social construction within organizational scholarship. Three key approaches utilized by critical management scholars are feminism, critical realism, and postmodernism (Duberley et al., 2009). Notably, critical realism, defined by ontological realism and epistemological subjectivism, represents an approach that is concerned with providing both descriptions of human subjective experience, and explanations of the various forms of those interpretations. It is often regarded as a "more fruitful alternative to the social constructionist ontology associated with postmodernism—and, incidentally, to the empirical realist ontology associated with positivism" (Fleetwood, 2005, p. 197). Critical realism offers a suitable means of exploring the changing nature of work in contemporary lean organizations as it is well suited to exploring changing organizational structures, and understanding whether there is an inherent oppression within lean organizations.

Of the critical approaches favored by scholars within critical management studies, critical realism is beneficial to the study of organizational change (Fairclough, 2005), as it is concerned with providing both descriptions of human subjective experiences and explanations of the varying forms that those subjective interpretations might take. Through the application of a stratified ontology in which there is a differentiation between reality, actuality, and experience, critical realism allows management researchers to engage in a reflexive and dialogical interrogation of their own understanding, cognizant of the notion that there is "a lack of a neutral observational language through which [they] can conduct [their] research" (Duberley et al., 2009, p. 443). While critical theorists generally assert that management researchers can use socially derived inferences and assumptions in sense-making, as well as the resulting social constructions which allow for the interpretation of an external social world, postmodern scholars assert that researchers "create the social reality that [they] see, in and through the very act of perception itself" (Duberley et al., 2009, p. 443). Critical realists are not limited to the study of either the subject or the object, and are not bounded by either a strictly realist, or a strictly postmodern ontology, allowing for the existence of conceptually mediated entities. According to Fairclough (2005) the critical realist critique of postmodernist research in contemporary organizational studies "focuses on two interconnected issues: the view of organizations as consisting of only discourse, and a 'flat ontology' which makes no ontological distinction between process (and agency) and structure" (p. 902). This is a clear advantage of applying a critical realist perspective. Postmodernism is limited in its methodological examination of the conditions necessary for organizational change, as the causal powers of social agents to act on and transform organizational structures, social conditions, and the relationships with other agents are impossible to analyze if there is no clear distinction made between agency and organizational structure. Furthermore, postmodernism's view of organizations as consisting of a single discourse limits the ability of postmodern scholars to assess the relationship between competing discourses (i.e., those that have an organizing effect, and those that have a disorganizing effect), other social elements, organizational process, and structure (Fairclough, 2005). A critical realist perspective posits that there is an ontological distinction between agency and organizational processes, and the structures that support those processes. In this way, critical realism positions itself as an alternative to both positivism and postmodernism in organization and management studies. This is useful when examining the application of Industry 4.0 technologies and lean processes, as they can be examined separate from individual agency, accommodating a case study approach.

Critical realism is a relatively new approach to the field of management research. According to Fleetwood et al. (2004) organizational and management literature is plagued by the association of an “unqualified realism with positivism” (p. 6) in which researchers attempt to uncover natural laws that exist in the social world. Critical realism rejects this notion. In providing a critique of contemporary lean manufacturing, this rejection emphasizes the social construction of work, offering a rebuttal to the scientific management or Fordist assessments of work historically associated with manufacturing organizations, recognizing that there is an objective reality and real entities that exist, even without knowledge of them. A critical realist approach does regard entities such as organizations, people, relationships, attitudes, and ideas (such as the ideas associated with lean manufacturing) as the foundations of explanation, which stands in contrast to many social research perspectives. This is important as it requires the researcher to understand and acknowledge the fundamental nature of the objects being studied, rather than simply the measurable properties of those objects. In the case of lean manufacturing research, it requires understanding lean tools and concepts, how they are applied, and why organizations use them. Moreover, understanding the technologies utilized by Industry 4.0 and how they are complemented by, or how they complement lean methods is an important aspect of critical realist inquiry, since, as Easton (2007) points out, the benefit of conceptualizing entities is that it focuses attention on three key questions: “what are the entities that define our research field, what are their relationships, and what are their powers and liabilities” (p. 120). In studying the changing entities and structures within organizations (i.e., the implementation of new technologies) critical realism provides an understanding of the foundational entities that inform the subjective experiences within organizations.

Part of the appeal of critical realism to management research is that in addition to positing the existence of a world independent of researchers’ knowledge of it, it “holds to a fallibilist epistemology in which researchers’ knowledge of the world is socially produced” (Miller et al., 2011, p. 144). Since the philosophy holds the existence of an external or ‘real’ reference, claims of knowledge can be challenged and their merits assessed empirically. The role of the researcher within a critical realist framework is to identify organizational culture, and distinguish structures from mechanisms. In exploring the subjective experience of work within lean organizations, structure would consist of three classes of objects: (1) social structure, which includes both individual and organizational actors; (2) material artifacts with which the actors involved in the social structure interact (i.e., the Industry 4.0 technologies that have been embedded in the activities of work; and (3) the rules and practices that define the relationships and organization among actors and artifacts (Porpora, 2015). The identification of culture, which is interrelated but ontologically distinct from structure, involves characterizing the "shared assumptions, meanings and interpretations with which we approach the world in which we live" (Patterson, 2014). Culture affects both the meaning attached to the entities in a given structure, as well as the mechanisms available.

II) Critical Realism and Organizational Change

Exploring contemporary lean manufacturing from a critical perspective allows for flexibility in research design. Specifically, the application of a critical realist perspective with its transcendental realist ontology, an eclectic epistemology that combines realism and interpretivism, and a generally emancipatory axiology, accommodates quantitative, qualitative, and mixed methods approaches to the study of management questions. Since critical realism 'confronts the complexity of social phenomena by espousing explanations stated in terms of mechanisms that generalize, with empirical effects that are contingent" (Miller et al., 2011, p. 153), the subjectivity of experience can be explored while ontological realism provides a means of testing assumptions empirically. For organizations deploying advanced lean programs the ability to test the causal effects of technological interventions (generative mechanisms) and link them to subjective, lived experiences and observed events.

The application of critical management studies to the concept of organizational change is important, especially when considering change as a result of technological implementation (i.e., Industry 4.0), or operational methodology (i.e., lean manufacturing). According to

Fairclough (2005) the perspective that change is inherent in social process, and that organizations—as products of social process—inherently change as well, is "consistent with the dialectical-relational version of critical realist ontology" (p. 210). Bhaskar (1989) proposed that the existence of a dialectical relationship between individual human agents and social structures (where those structures exist independently of the conceptualization of them) are created and reproduced by the actions of individual human agents. Changes, such as those related to operational methodology (i.e., the implementation of lean manufacturing) can be considered institutional, rather than ongoing changes, and are the product of the actions of agents (i.e., organizational managers), in order to achieve desired outcomes such as reduced waste, increased productivity, or reduced cost. The ensuing social structures to support those aims can be considered the product of such a dialectical relationship. The distinction between ongoing and institutional changes is important in that one is related to process, and the other to structure. The basis of transformational ontology favored by critical realists posits that agency and structure are internally related, implying that structural changes reproduce particular power relationships between groups of social agents. A critical realist perspective allows for the exploration of the relationship between these structural changes, and the impetus of the agents involved.

III) Critical Realism, Technology, and Work

Critical management studies (CMS) have the potential to broaden the study of technological intervention in organizations. As Howcroft (2009) observes, critical Information Systems (IS) research is opposed to technological determinism and instrumental rationality: a critique of the determinist tradition highlights "both its inadequacy and its ideological function of furthering the vested interests in technical change" (Howcroft, 2009, p. 486). It is useful to draw a parallel between CMS and critical IS research, as it allows management researchers to question and deconstruct assumptions inherent in the status quo of organizations, marking a departure from a managerialist, or positivist, perspective from which IS has typically be considered. According to Howcroft (2009) the notion that a positivist perspective prevails within the field of IS is "supported by the provision of statistical evidence from a questionnaire of IS research journals, which revealed that while just over 3 percent of the articles were classified as interpretivist, there were no publications in their empirical analysis that were critical in orientation" (Howcroft, 2009, p. 491). Mainstream research within IS examines the deployment of technical solutions to support the managerial philosophy of increased productivity and gaining competitive advantage. This desire for lowering costs, increasing productivity and reducing waste in operations are the over-arching goals of an Industry 4.0 implementation, and are typically framed from a perspective of instrumental rationality. A critical approach will allow researchers to question the development and implementation of systems and explore the social consequences. Critical management studies, or CMS, offers a means of exploring broad social structures beyond either a positivist or an interpretivist perspective.

Critical research takes on a variety of different forms, none of which draw on a single philosophical foundation. Myers et al. (2011) identify three different streams of social critique: (1) those informed by Foucault; (2) those informed by Harbermas; and (3) those informed by Bourdieu. Bourdieu emphasizes the asymmetric distribution of symbolic and social assets in society, which causes and reproduces social stratification. He focused on exploring forms of behavior that are socially conditioned and reproduced by social and cultural practices. Foucault emphasizes the concepts of "discourse, archaeology, and genealogy of knowledge, and panopticon" (Myers et al., 2011, p. 21), and explores discursive practices from the perspective of history of epistemology. Meanwhile, Habermas focuses on the concepts of cognitive interests, communicative action, lifeworld, and systems, exploring the means by which people, collectively, could be emancipated from their current state. Informed by these various critical traditions, Alvesson et al. (2000) suggest that critical research is comprised of three different elements: critique, insight, and transformative redefinition. These three elements suggest that a critical analysis must include a comprehensive and insightful understanding of the current circumstances, before any meaningful social change can be suggested. As well, critical researchers must essentially adopt a more critical stance than interpretivists: "the purpose of critique is to reveal the normative basis of the current situation found in the research site and the forms of legitimation that justify the current social order" (Myers et al., 2011, p. 23). The element of transformative redefinition implies that critical research produce relevant knowledge and practical understandings that can be applied to organizations, and inform new ways of operating or working. Similarly, Howcroft (2009) contends that contemporary research within the field of IS is being explored from a broad range of experience, and from a more diverse range of criticality, namely from a Foucaultian, a structuration, or a gendered (or feminist) perspective. This does not exclude other perspectives, such as critical realism, however. Extending the field of IS to include the study of the adoption of Industry 4.0 technologies reveals that there have been no substantial critical studies undertaken, revealing a significant research opportunity. This aligns with the shared belief among critical theorists that there is a need for scholarly praxis (Prasad, 2017) and a constant need for ideology-critique. As IS and its applied technology become increasingly pervasive within organizations, issues such as powerlessness, loss of control and autonomy, and the proliferation of an instrumental rationality need to be examined. Moreover, the normative assumptions made by organizations to justify Industry 4.0 adoption ought to be critiqued. While some management scholars such as Fatorachian et al. (2018) have addressed the rise of Industry 4.0 technologies and issues of organizational integration, it has been from a positivist—in this case, a systems theory—perspective. Others, such as Mfanafuthi et al. (2019) raise concerns about the organizational impacts of automation, albeit again, from a positivist perspective rather than a critical one. This reflects the dominance of frameworks within IS studies such as the Technology Acceptance Model which is rooted in psychology literature and assumes that technological advancement is not only universally accepted as beneficial, but is centered on individual psychology, rather than being rooted in broader social structures (Howcroft, 2009).

Although this review does not explore the vast literature that exists within the tradition of critical theory, it does offer insight into how critical realism is being applied to the study of contemporary managerial practices, and its potential to critique organizations that are pairing the methodology of lean manufacturing with the tools of Industry 4.0. As a larger number of individuals work under these circumstances, the imperative for understanding both the functional and dysfunctional consequences of modernity and why the study of technological implementation in practice takes on a new urgency.

vii. Case Study Research

The exploration of the subjective experience of individual workers is well suited for case study research. According to Guetterman et al. (2018) case study involves the investigation of one or more real-life cases to capture its complexity and details. A mixed methods case study in this context will "address broader or more complicated research questions than case studies alone" (Yin, 2014, p. 67).

Mixed methods refer to the process of integrating qualitative and quantitative research to more completely address a study's research question, and can be categorized as one of three core designs: (1) exploratory sequential; (2) explanatory sequential; or (3) convergent (Plano Clark et al., 2016). In exploratory sequential designs, the study begins with a qualitative exploration followed by a quantitative phase to test findings or attempt to generalize the findings by applying it to a larger sample. In an explanatory sequential design, the study beings with quantitative data collection and analysis, and then proceeds to a follow-up qualitative phase for the purpose of enriching the explanation of the first phase. A convergent design involves a single phase in which qualitative and quantitative data are collected, analyzed, and integrated typically for the purpose of comparing or relating results from the two forms of research" (Guetterman et al., 2018, p. 903). This dissertation will be following a convergent design.

Integration is a critical feature of mixed methods, and can take place at many levels, and at many stages in the research process. Fetters et al. (2013) focused on three common approaches to the integration of mixed methods: merging, connecting, and building. Merging refers to the comparison of qualitative and quantitative results in order to examine patterns and themes, while connecting refers to the process of using results from either qualitative or quantitative methods to inform the sampling of the other. Building refers to the use of the results of one type of research to inform data collection of the other. This dissertation will employ a merging approach to the integration of the mixed-methods.

Since the logical structure of explanation is always implicitly or explicitly distilled from an ontological perspective, there are constraints upon the use of methods for particular purpose. The realist call for explicitness in research design (Bhaskar, 1997) is based upon the argument that mutually implicative chains of reasoning bind ontological, epistemological, and methodological choices (Baskar et al., 1998). Recognizing the existence of these chains of reasoning can provide lucidity to the design and implementation of a study, particularly when implementing mixed methods. This is because not only do logical relations exist between ontic, epistemic, and methodological concepts, irrespective of their acknowledgment, but logical coherence is more difficult to maintain in mixed-methods designs (Lipscomb, 2008).

In order to explore the subjective experience of work, a critical realist ontology supports the use of case studies. One goal of critical realist research is to identify the sequences of causation or causal mechanisms at work. Case studies are suitable for this purpose, as they provide an authentic context within which the behaviors of individuals are observed. Since critical realism posits that organizations (and ultimately, the social world) is an open system, explanatory power is to be found in understanding how different entities are related as parts of a greater whole. In contrast to a closed system such as a laboratory, social mechanisms cannot be isolated or repeated in an identical matter. According to Elder-Vass (2010) the concept of the laminated system refers to a system "whose internal elements are necessarily 'bonded' in a multiplicity of structures" (Bhaskar, 1993, p. 142). Lamination refers to systems, comprised of mechanisms and entities which, when considered together, can be separated, to an extent, broader society in order to be studied. Organizations can often regarded as laminated systems, in that while they cannot be separated in any way from society broadly, or exist without external forces or influences, they can be studied. The use of case studies suits this perspective.

The centrality of identifying sequences of causation or causal mechanisms means that critical theory puts theory first. The aim of realist research design is "to produce explanations (theories) about the essences (properties) and exercise of transfactual, hidden, and often universal mechanisms" (O'Mahoney et al., 2018, p. 7). Case studies facilitate the identification of context in which a specific causal mechanism is identified and explored. In the case of exploring the subjective experiences of employees in Industry 4.0-enabled organizations in relation to stated claims about the role technologies are expected to play, the objective is to bring to light formative processes which cause particular outcomes, when they operate, and which are best conceived in their totality. The case study design represents an opportunity to identify the operations of mechanisms in whole, or in part, through empirical observation.

viii. Critical Realism and Case Study Research

I) Background

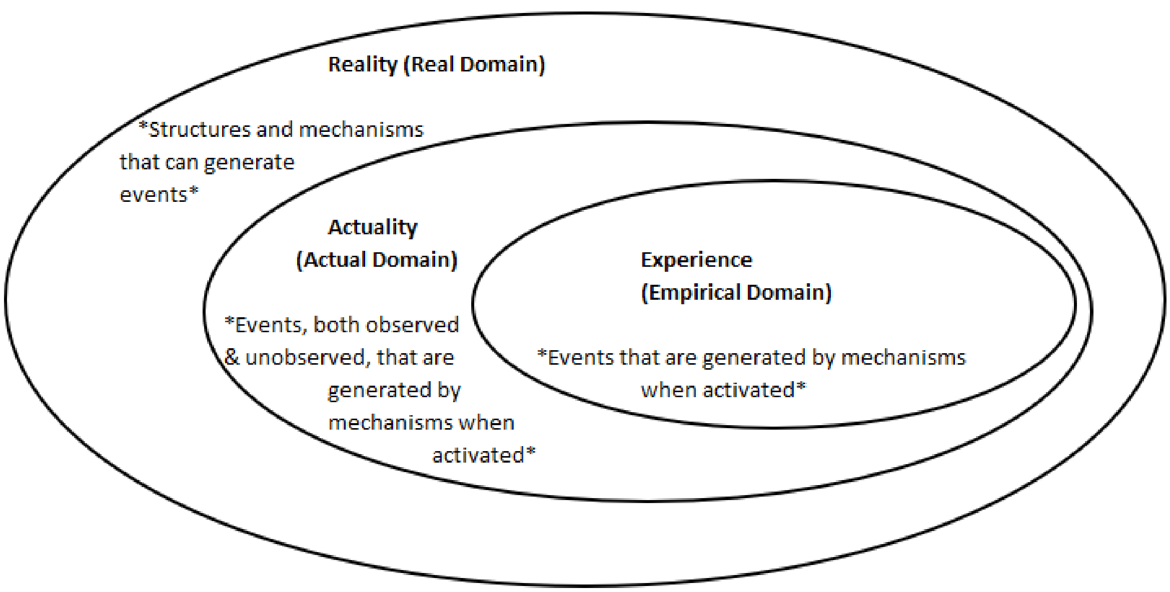
Critical realism (CR), which is based on the writings of Bhaskar (1975, 1978, 1989) and others (Archer et al. 1998; Collier 1994 Fleetwood 1999; Lawson 1997; and Sayer 1992) can be regarded as a nuanced version of a realist ontology, occupying a middle ground between empiricism and interpretivism. In addition to offering a realist ontology it is characterized by epistemological relativism and judgmental rationalism. It embraces a variety of methodological approaches from different philosophical positions by taking 'a critical stance towards the necessity and validity of current social arrangements' (Mingers, 2001, p. 248) without following 'the extant paradigms' assumptions at face value' (p. 248).

While realism assumes that reality is composed of entities that exist independently of perception, interpretivism asserts that reality is constructed from perception. Critical realism is a form of postpositivist philosophy that asserts that reality exists independently of perception, and that the underlying entities may not be observable or empirically measurable (Wynn et al., 2020). Critical realism posits that theories about reality are dependent upon beliefs and knowledge, both of which are fallible and dynamic, and the structural entities that comprise reality "generate and interact with emergent causal powers known as mechanisms, which have observable effects when enacted" (Wynn et al., 2020). In this way, it is a realist philosophy.

The original argument of critical realism was for a separation of ontology from epistemology. That is, that a reality consisting of causally efficacious entities, whether they are social or physical, exist independently of human knowledge of them (i.e., that there is a real, observable world that exists independent of human knowledge of it). However, unlike empiricism which limits causality to observable events, critical realism suggests that entities have causal powers, which may be exercised through the actions of generative mechanisms. These mechanisms, according to Armstrong (2018) are, in turn, “conditioned by physical and social structures, which may vary by context and produce differing outcomes” (p. 467). This creates a stratification of reality consisting of three domains: (1) the domain of the real, where structures and mechanisms generate events; (2) the domain of the actual, where events, both observed and unobserved, are generated by mechanisms when activated; and (3) the domain of the empirical, where events are experienced (Bhaskar, 1989).

Figure 1.

The Domains of Critical Realism



Mechanisms are triggered by structured things—physical objects or social processes—that generate the actual phenomena of the world (Lawson, 1997). Because mechanisms are not necessarily observable in an empirical sense, their potential to generate phenomena exists, whether they are exercised or not (Bhaskar, 1978). Critical realism's stratified ontology suggests that even though there is one reality, it does not follow that researchers "have immediate access to it or that we are able to observe and realise its every aspect" (Zachariadis et al., 2013, p. 857).

By maintaining a strong emphasis on ontology and supporting the idea that a reality exists independently of one's knowledge or perception of it (the intransitive domain), critical realism characterizes the generation of knowledge as a human activity (the transitive domain), which depends upon the specific details and processes of its production (Bhaskar, 1989). New knowledge can be articulated in these two dimensions as "it is a socially produced knowledge of a natural (human-independent) thing" (Archer et al., 1998, p. 65). In this way, critical realism allows for a degree of epistemological relativism.

II) Application to Case Study Research

The application of critical realism to case study research (Wynn et al., 2012) has highlighted the value of it as an underlying theoretical framework for mixed methods inquiry (Venkatesh et al., 2013), and offered a set of methodological principles for conducting such research. While Wynn et al. (2012) focused on research in the field of Information Systems (IS), the principles they outline can be adapted to researching the role of technology in organizations, specifically, to its role in everyday work. Case study research is an abundant methodology for using critical realism to explain organizational phenomena. According to Volkoff et al. (2007) the main objective when pursuing critical-realism-led research should be to "use perceptions of empirical events [those that can be observed or experienced] to identify the mechanisms that give rise to those events" (p. 835). In this way, studying the experience of work with respect to Industry 4.0 through the lens of critical realism allows for the perception of empirical events to help identify the underlying mechanisms that inform them, providing a thorough understanding of employee experience. Since reality is an open and complex system where a myriad of mechanisms and conditions exist and interact, it is important to identify not only structures, powers and liabilities, but also the conditions in which generative mechanisms are experienced. The application of case study research supports a retroductive approach, which embraces a variety of qualitative and quantitative methods, and can be well integrated to hypothesize and identify the generative mechanisms that cause organizational phenomena.

III) Retroduction

The conduct of critical realist-based research, in general, is based on the concept of retroduction. According to Wynn et al. (2020) this research can be distilled into two phases: first, the researcher describes the phenomenon in terms of the entities that interact to cause events to occur and employs retroduction to theorize alternative sets of mechanisms; and second, these hypothesized outcomes are compared to observed outcomes in order to eliminate alternatives. Retroduction, according to Danermark at al. (2002) is characterized by a researcher moving from beyond a specific ontic context to another, generating alternative explanations that embrace ontological depth. The process of abduction, whereby specific phenomena are recontextualized as more general phenomena, is part of this process.

Retroduction is employed as a means of achieving mixed-methods triangulation. Triangulation, sought to enhance validity, uses quantitative analysis to test the validity of qualitative insights, and uses qualitative work as preparation for quantitative work, elucidating a phenomenon in as much detail as possible. According to Zacharisis et al. (2013) the role of quantitative methods is largely viewed as descriptive, since "quantitative summaries are correlations between variables alone cannot uncover evidence on the causal mechanisms that generate the actual events we observe or predict future incidents" (p. 862). Downward et al. (2006) suggests that qualitative methods reflect an interactionist epistemology in that the researcher and the research subject engage in a dialectic which reflects social relationships which are inherently subjective and are intrinsically meaningful. Meanings must be understood, and that the interpretation of an object or an event is informed by its context. In this way, the justification for combining methods requires an explicit analysis of the ontological bases of various logics of inference. Critical realism can provide a basis for rethinking mixed-methods triangulation.

According to Downward et al. (2007) from the perspective of critical realism, there exists an 'epistemic fallacy'—that there is a conflation of the subject and the object of analysis through the invocation of covering laws. This invocation refers to a model of explanation in which an event is explained by referencing another event, which presupposes an appeal to laws, or a set of general propositions. Cruickshank (2016) argues, however, that the epistemic fallacy of critical realism is erroneous because the problem is with justification, not epistemology *per se*. This is because critical realism attempts to justify empirical explanations by basing them on what is taken to be a justified ontology of structure and agency. As a means of triangulation, critical realism is useful because it engages in sustained iteration of ideas which ultimately replace fallible ideas over time. Since critical realism posits that reality is a structured, open system, the real, the actual, and the empirical domains are organically related (Downward et al., 2007). The 'real' refers to the intransitive dimensions of knowledge which exist independently of our understanding of the world, and in which actual structures and causal powers reside. The 'actual' domains refers to what actually occurs if causal powers are activated. Causes act transfactually, and because society and organizations alike are open, causes, though operating consistently, may not reveal themselves in empirical regularities because of countervailing forces. In the empirical realm, therefore, the real and actual are observed and experienced. Since the empirical domain is the access point to the transitive dimension of knowledge, knowledge is expressed and informed by subjectivity. Under these ontological circumstances, adequate explanation required ontic depth, and retroduction is an appropriate means of achieving it.

Since different methods can be seen to be necessary to reveal different aspects of the constituency of phenomena (i.e., the subjective experience of work), the concept of cause (as in cause-and-effect) is tied to the emergence from the interaction of human agency and structure (Danermark et al., 2002). The process of retroduction provides a means of exploring the various dimensions of interaction, and allows for the elucidation of a phenomena in as much detail as possible.

IV) Contemporary Perspective

As a relatively new philosophy, many ideas within critical realism have yet to be developed in practical, applied settings (O'Mahoney et al., 2014). This was noted by Frederiksen et al. (2020), who point out that management and organizational researchers face two challenges when conducting critical realist research: (1) researchers must balance the theoretical-empirical divide based on research aims; and (2) researchers must balance the scientific theoretical-empirical divide by acknowledging how 'paradigmatically ingrained the research is' (p. 18).

Balancing the interaction between theoretical explanations of underlying mechanisms against the contextually-situated empirical events through which phenomena are investigated (Lawson 1997) is achieved through the selection of methodology. From a constructionist perspective, critical realism finds some common ground with interpretivism in that social phenomena are concept-dependent and need interpretive understanding (Giddens, 1979). However, critical realism also acknowledges the existence of a relational intransitive domain in social structures, meaning that the behaviors of individuals and groups are influenced by underlying social structures, related to the groups in which they are embedded. In this case, since the aim is to understand how employees subjectively experience work in relation to the stated claims about the role of Industry 4.0 technologies in the workplace, it is important to explore the meanings and behaviors attributed by, and displayed by employees, who are influenced by the social structures of the organizations of which they are a part, and which facilitate the implementation of new technologies. Balancing the theoretical-empirical divide in the context of the dissertation research will involve researching the organizational impetus for the introduction of new technologies in the workplace, and how that relates to the overall strategic objectives of the organization. Once a broad understanding of the objectives is established, determining how the technologies are implemented in specific circumstances, and at the local level will determine the rationale for change at the local level, and the expectation for positive outcomes. Within this context, the qualitative research component—the interview—will provide background on the social structures that existed prior to the technological change, and how they changed as a result. The thoughts and feelings of individuals about how their social interactions, and the meaning they assigned to their work and their daily tasks will provide empirical understanding of the change that Industry 4.0 technologies is having, or has had. The theoretical explanations of the underlying mechanisms of change will be informed by details of the specific cases and the organizations chosen for research.

The critical realist perspective differentiates between the empirical (the perception of technology) and the actual (the technology itself) and seeks to discover the causal mechanisms that relate Industry 4.0 technologies with the individual, identifying the causal relations that must exist in order for the empirical events, or perceptions, to occur, and how the subjective experience of work is manifested.

Acknowledging how 'paradigmatically ingrained the research is" (Frederiksen et al., 2020) involves acknowledging which systems of belief guide the research, and how they inform the generation and interpretation of reality. According to Wynn et al. (2012) critical realism is based on the following basic assumptions: "existence of an independent reality; a stratified ontology comprised of structures, mechanisms, events, and experiences; emergent powers dependent upon but reducible to lower-level powers; and an open systems perspective" (p. 789-790). The dissertation research is firmly ingrained in the critical realist paradigm, rather than a positivist or interpretivist paradigm for two primary reasons. First, the use of two distinct explanatory logics, abduction and retroduction, allow for employees to describe the sequence of causation that gives rise to observed regularities in the pattern of events, while also allowing to ascertain what the world (i.e., the broader context) ought to be like in order for the mechanisms (as identified through the subjective interpretation of work) to be as they are, and not otherwise. The use of retroduction and abduction in the context of the dissertation research will provide a richer and more nuanced perspective than other approaches may. A successful realist study, according to Edwards et al. (2014) involves a reconceptualization of the subject and the processes in which it is connected. Reconceptualizing the effect that the introduction of technology has on the subjective experience of work, and understanding the processes that inform that experience, within the context of lean manufacturing, is part of the novelty of the dissertation, and will provide a meaningful contribution to the management literature.

According to Frederiksen et al. (2020) critical realism can be beneficial in applied research in five ways:

> 1. Applied critical realist ontology enables the researcher to delineate the phenomenon under study.
> 2. Critical realism provides a meta-theoretical framing of the interplay between structures and actors that unfolds over time.
> 3. Applied critical realist methodology offers explanatory value through the interplay of multiple empirical aspects.
> 4. Applied critical realist epistemology accentuates the interpretative role of the researcher in developing knowledge.
> 5. Critical realism bridges the gap between local and general knowledge (p. 19).

Specific to this dissertation research, the first two benefits answer to what is studied empirically. Narrowing the focus to concentrate on structure, entities, and their relationship over time allows for easier delineation of the phenomenon of Industry 4.0 technological intervention in organizations. In a critical realist understanding of the world, entities are understood in terms of their causal powers, and the exploration of the relationships between entities provides an understanding of how Industry 4.0 technologies exist in relation to the people that are tasked with its use, and how the process of work, and the subjective meaning ascribed to it, is informed by technology.

Explanatory value is established through the interplay of multiple empirical aspects, notably interviews and questionnaires. Since critical realism is founded on a methodological openness that is inherent in epistemological relativism, the use of mixed-methods helps capture the complexity of the role technology in lean organizations, and the impact it has on the nature of work. Data collection, according to Frederiksen et al. (2020), is a means for the researcher to approximate the underlying ontology. In this case, qualitative interviews capture subjective interpretations, descriptions, perceptions, while quantitative questionnaires will be used to supplement and triangulate the data and provide an account of the generative processes at work in conditioning worker experiences of technological intervention and workplace change.

Critical realism, by stressing that our knowledge of reality is not the same as reality itself (the epistemic fallacy), provides a context in which the role of the researcher and the epistemological challenges inherent in conducting research can be elaborated and specified. In this case, data collection will be formed around descriptions of work experience and of personal accounts of how technology has changed daily tasks, and the experience of work. How those experiences relate to the stated claims about the expectations of the technology will form a critical narrative, and provide context for evaluating whether those claims are realized by individual employees. The role of the researcher, in this context, is to analyze the collected data in order to identify 'demi-regularities' that represent thematic patterns in the data through abduction (McGhee et al., 2017). The interpretive aspect of identifying data-driven events calls attention to the role of the researcher. According to Zacharidis et al. (2013) "social phenomena or structures are concept-dependent and thus are not independent from the agents' notion of them or the apparatus through which they became observable" (p. 863). The interpretive role of the researcher in working with empirical observations, and identifying underlying ontological domains, cannot be understated. The evaluation of the subjective experiences of work in order to synthesize and identify mechanisms affecting that work, with respect to the implementation of Industry 4.0 technologies within a lean manufacturing context, involves interpretation through abductive reasoning. A deliberate, robust abductive process, combined with an 'epistemological modesty' (Faulkner et al., 2010) acknowledges that while a thorough attempt to uncover all aspects of the relationships between entities and mechanisms will be the aim, there is an explicit acknowledgment that the researcher's knowledge of the intransitive dimension is limited, and that interpretation is both subjective, and approximated. Research is always the product of the research process, and the researcher's frame of reference will inform the discussion, and ultimately, conclusions.

Since critical realist research is "neither nomothetic nor idiographic" (Frederiksen et al., 2020, p. 30), meaning it seeks neither to develop a law-like understanding of the universe (positivism) nor seeks to simply describe the unique character of the social world (interpretivism). Rather, the aim of critical realist research is to obtain a deep knowledge of phenomena without generalizing the universality of the findings. The choice of a case study approach allows for the development of case-specific knowledge that can be generalized *analytically* (concerned with explanation of how empirical phenomena occur, or not), rather than generalized *statistically*, which is, in positivist tradition, concerned with prediction (Wynn et al., 2012). In applying the case study approach to the dissertation question, it is assumed that the mechanisms in one context will not necessarily provide similar effects in other contexts, however, by exploring the relationship between technological intervention and the subjective experience of the effects on work in different organizations, analytical generalization of the observed demi-regularities will contribute to the development of theory, and may represent a shared mechanism that occurs in different contexts.

d. Stated Claims of Industry 4.0 for Organizations

The objective of this dissertation is to understand how employees within manufacturing organizations experience work in relation to the stated claims about the implementation of Industry 4.0 technologies. Industry 4.0, the fourth phase of manufacturing and IT (Drath et al., 2014) has promised to "enhance and improve the efficiency of operations and, ultimately, the productivity of new business models, services and products that will have tremendous economic impact relative to other industrial revolutions" (Bauer et al., 2014). In narrowing down the broad category of Industry 4.0, Sangmahachai (2015) focuses attention on Cyber-Physical Systems and the Internet of Things (IoT), as well as virtualization, modularity, and real-time operation and interoperability of services, while several researchers including Schuh et al. (2015), Rosa et al. (2020) and Schweer and Sahl (2017) studied Industry 4.0 components and focused on the primary technologies of CPS and IoT systems capabilities, and how they were integrated into workflows. When assessing the claims made by theorists and practitioners with regards to Industry 4.0, consideration of how those claims relate to the everyday lived experiences of employees, and how they influence work will be imperative to the study. Claims about the perceived advantages or benefits of Industry 4.0-enabled technologies without context provides little upon which to base a meaningful evaluation. A review of both academic and practitioner-oriented literature on Industry 4.0 makes, among others, the following claims about the changing nature of work:

1. Industry 4.0 will enable connected workflows in intelligent technological environments to give workers not just the tools, but the freedom to adapt and solve problems in creative ways (Hoey, 2018);
2. Industry 4.0 will require organizations to actively invest in their workforce through retraining efforts and upgrading employees' current skill sets so they can manage automated processes or take on "creative" jobs that are less likely to be replaced by automation. As automated tasks are phased in, simultaneously training existing workers with the incremental skills needed for higher-level jobs (e.g., data analysis, process improvements) can help mitigate the perceived threat of automation (Navales, 2018);
3. Industry 4.0 leads to higher productivity (elimination of errors and risks, production of larger quantities of products, reduction of working hours); higher flexibility (individualized products, more efficient production, wide variability in control processes); higher competitiveness (lower production costs, implementation of innovations and innovative solutions, flexible responses to fluctuations in demand); higher profitability (mass production, process optimization, lower stocks, more

economical production); and superior safety outcomes (limiting defects and errors—software, protection of workforce safety by sensors, immediate reactions and interventions) (Grenčiková et al., 2020); and

4. The emerging technologies of Industry 4.0 have made flexible working arrangements more accessible and transparent, which are becoming more important to staff attraction and retention (O'Brien, 2018).

These selected claims address changes in workflow, task assignment, training, and job design. The claims are bold and promise positive outcomes for employees, who benefit both immediately, and over time as a result of technological integration. Whether these claims hold true (from a subjective perspective), and whether employees in lean organizations reportedly experience positive outcomes will be assessed by the research.

e. Summary

The review of the literature on the topics of lean manufacturing, Industry 4.0, technology and work, the adoption of technology, and the subjective experience of work indicate that to date, there has been little critical research conducted that explores the relationship between the implementation of technology and the experience of work within an Industry 4.0 context.

Broadly, existing research on lean manufacturing has focused on the implementation and outcomes of organizational practices, but largely from a positivist, organizational perspective. The extent to which research related to how lean manufacturing, broadly conceptualized as a methodology and set of practices, contributes to the subjective experience of work, is limited. The work-related outcomes for employees in lean manufacturing environments can be positive, negative, or neutral. The relationship between lean manufacturing and Industry 4.0, specifically related to employee use of Industry 4.0 technologies within a lean manufacturing environment is also limited.

There is little academic literature that has explored how employee experiences and outcomes are influenced by the use of Industry 4.0 technologies within lean manufacturing environments, despite claims that Industry 4.0 offers a promising suite of technologies that will bring about positive technological, economic and social effects (Hirsch-Kreinsen et al., 2016). The positive benefits purportedly associated with the implementation of Industry 4.0 technologies may be only fully realized when situated within a lean system.

The adoption of technology has been studied extensively in the field of information systems, and although many of the existing models and learnings can be applied to Industry 4.0 technologies, little research has been done in the area specifically. As 'smart' and increasingly interconnected technologies are adopted by manufacturing companies, it is imperative to understand how the unique and dynamic nature of these technologies differs from other information systems, considering the beneficial claims made regarding their use.

The relationship between technology and work, particularly the interaction between the organization of the work setting, human factors, and the external environment, has been explored by numerous researchers, and will benefit from an exploration within a contemporary, Industry 4.0 context. Much of the existing literature on the relationship between technology and work is related to the widespread adoption of lean principles, which contributes to managing technological complexity in organizations to fulfill customer-defined notions of value.

The adoption and extent of use of advanced technologies in manufacturing is closely related to the cognitive beliefs, dispositions and perceptions of the employees that use them. A better understanding of Industry 4.0 technologies will require an examination of these factors. An evaluation of employee subjective experience will help identify the extent to which technology is regarded as a resource, and whether it aligns with the stated objectives of the technological intervention.

The literature review provides an examination of methodology, informing the approach best suited to answering the research question. The use of a mixed-methods perspective allows for the combination of empirical evidence for the relationship between technology and job characteristics with subjective interpretation to inform a comprehensive understanding of the role technology plays in the everyday experience of work. Importantly, it allows for the evaluation of claims made by proponents of Industry 4.0 technologies, while providing insight into the rapidly changing nature of work. Paired with a critical realist approach, where the interaction between entities, structures, agency and empirical outcomes are systematically assessed, the question is explored with sufficient depth, while offering unique insights. By relying on multiple case studies, the critical realist approach is strengthened, as it allows for the attainment of deep knowledge of phenomena—Industry 4.0 technological interventions—without generalizing the universality of the findings.

The literature review reveals significant deficiencies in the understanding of how advanced technologies interact with, and inform, the subjective experience of work in manufacturing companies. It also reveals that while there has been significant scholarly exploration of technology adoption, lean manufacturing, industry 4.0, and the experience of work in isolation, and needs to be expanded upon. This creates a space for the dissertation research, and further exploration of the topic in future work.

Chapter 3: Methodology

a. Introduction

Assessing the subjective experience of employees to better understand the lived experience of work in Industry 4.0-enabled organizations is accomplished using the quantitative analysis of questionnaire data and qualitative analysis of semi-structured interviews within a case-study format. The overall findings are assessed within the context of critical realism.

b. Approach

The following question is the focus of the dissertation research:

Q: How do employees in organizations with a formal lean manufacturing program experience work in relation to the stated claims about the implementation of Industry 4.0 technologies for organizations?

To answer the research question, the stated claims are be explored in six hypotheses:

H1: Employee Autonomy (EA) is a significant component of a composite index, Overall Employee Satisfaction (OES).

H2: Training Effectiveness (TE) is a significant component of a composite index, Overall Employee Satisfaction (OES).

H3: Employee Productivity (EP) is a significant component of a composite index, Overall Employee Satisfaction (OES).

H4: Job Control (JC) is a significant component of a composite index, Overall Employee Satisfaction (OES).

H5: Safety Awareness (SA) is a significant component of a composite index, Overall Employee Satisfaction (OES).

H6: The presence of a formal lean program will have a positive moderating effect on the relationship between the five dimensions and Overall Employee Satisfaction (OES).

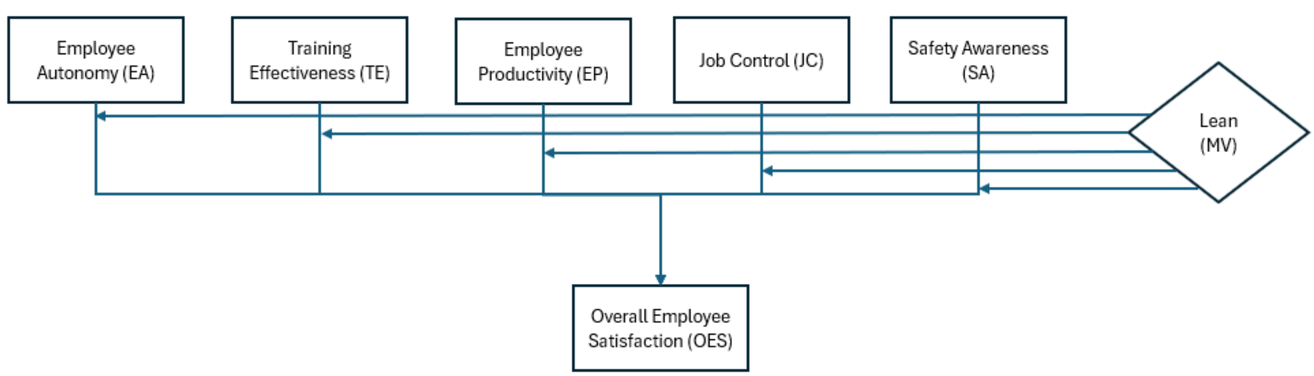
To test, each hypothesis is treated separately as a dimension of satisfaction, and evaluated using a quantitative questionnaire. The dimensions are examined using a Confirmatory Factor Analysis (CFA). Emergent themes are explored with a qualitative analysis, and the findings are subjected to a critical inquiry.

Each of the hypotheses tests a dimension of subjective experience of Industry 4.0 implementation. They are aggregated to construct a composite index measure of satisfaction, Overall Employee Satisfaction (OES).

Conceptually, (OES) is constructed as follows:

Figure 2.

Dimensions of Overall Employee Satisfaction (OES)



The development of the questionnaire to test the hypotheses is based on existing scholarship.

H1: The degree to which employees feel that they have the freedom to adapt to changing circumstances and the freedom to solve problems in creative ways, or job autonomy, can be measured with three items from a scale developed by Bacharach et al. (1990) measuring job formalization, and three items from a scale by Karasek (1979) measuring decision latitude.

Together, they measure the degree to which an employee has discretion to make work-related decisions on the job. This measure has been used by Naus et al. (2007). Job autonomy can be measured on a five-point scale with a demonstrated acceptable internal consistency.

H2. The degree to which employees feel as if their organizations' investment in retraining has allowed them to upgrade their skills, enabling them to manage automated processes and take on 'creative' jobs. This can be measured with five items from a scale developed by Santos et al. (2003) measuring perception of training performance. The scale measures the degree to which an employee perceives that their manager supports the training initiative(s), the perceived benefits of the training, and the perceived importance of, and satisfaction with, pre- and post-training activities. Training effectiveness can be measured using a five-point scale with a demonstrated level of internal consistency.

H3: The degree to which employees feel as if their level of individual productivity has changed, and the nature of that change as it relates to the introduction of Industry 4.0 can be measured with a workplace performance scale. According to Ramos-Villagrasa et al. (2019) the Individual Work Performance Questionnaire (IWPQ) meets the three criteria for measuring job performance. It is an 18-item scale developed in The Netherlands to measure the three main dimensions of job performance: task performance, contextual performance, and counterproductive work behavior.

H4: The degree to which employees feel as if their organizations' investment in Industry 4.0 has increased task flexibility can be measured through 'job control' (Glavin et al., 2012). Job control is captured through measures of autonomy over: (1) job tasks; (2) the pace of work; (3) ways of completing work; and (4) task order. Ganster et al.'s (1989) 22-item control instrument measures job control by asking how much control individuals have over the various facets of their jobs. The items in the instrument are similar to the 'decision latitude' items used by Karasek. A similar scale was utilized by Wheatley (2020) who demonstrated a sufficient level of internal consistency.

H5: The degree to which Industry 4.0 affects employee perceptions of organizational safety awareness and an increased focus on positive safety outcomes can be measured using the Integrated Organizational Safety Climate Questionnaire proposed by Brondino et al. (2013). Safety climate reflects the surface features of the safety culture found in employees perceptions, and is an indicator of the underlying safety culture of an organization. It corresponds to workers perceptions about safety level (policies, procedures and practices) in the organization.

H6: The presence of a formal lean program, that is, one that is documented and is reflected in company policy, will be tested to determine the extent to which it moderates the relationship between the five dimensions and OES. The presence of a lean program to support Industry 4.0 implementation is hypothesized to have a positive effect. The presence of a lean program will be captured as one of two binary alternatives (either one exists, or one does not).

c. Research Methods

i. Designing Mixed-Methods Research

Critical realism does not commit to a single type of research but endorses a variety of qualitative and quantitative methods. This pluralism preserves a strong link between meta-theory and method (Danermark et al., 2002). With this in mind, the best research design to explore the subjective experience of work is a mixed-methods retroductive design, using a case study methodology. Critical realism serves as the underlying philosophy. This dissertation utilizes a case study-mixed methods approach (CS-MM) characterized by a multiple case study that includes a nested mixed methods design. It is instrumental in nature, in that the cases represent an underlying phenomenon to be explored.

An explanatory-sequential mixed-methods design is utilized, which involves two phases where qualitative and quantitative data are collected and analyzed separately. The explanatory-sequential design involves gathering quantitative data first, and then qualitative data is collected as a follow-up to the quantitative phase. This differs from a convergent design, which relies on an interactive approach, where iteratively data collection and analysis drives changes in the data collection. For instance, initial quantitative findings may influence the focus and kinds of qualitative data that are being collected, and vice versa. In this case, the qualitative and quantitative data collection occurs in sequence, and analysis of the qualitative component occur after the quantitative analysis to provide insights into the findings. The two forms of data are analyzed separately and then the findings discussed together, informing a comprehensive analysis. The explanatory-sequential mixed-methods approach supports a case study framework as both the quantitative and qualitative data help build a comprehensive understanding of specific cases (Fetters et al., 2013). Since the study design involves exploring three organizations in-depth, an analysis of each organization's data facilitates a strong comparison between cases.

The dissertation employs the technique of retroduction in the analysis of the questionnaire and interview data. Retroduction, in a critical realist research process, is rooted in the question 'what must be true for events to be possible?' (Belfrage et al., 2017). Retroductive arguments move "from a description of some phenomenon to a description of something which produces it, or is a condition for it" (Bhaskar, 1997, p. 141). It oscillates between describing observable phenomena and possible explanations for that phenomenon, in an endeavor to gain deeper knowledge of complex reality, making use of both qualitative and quantitative data, depending on their "practical adequacy" (Sayer, 1992) for answering the research question posed. Possible explanations are drawn from analogies with already studied and understood phenomena, and with pre-existing theories (also referred to as 'proto-theories'). The stratified conception of causation (between the empirical, the actual, and the real)—which is characteristic of critical realism—facilitates a more adequate understanding of how powers which operate in different locations and at different hierarchical levels, are related. With retroductive reasoning, multiple causes can be teased out from detailed explorations of the setting, and various potential mechanisms that inform the subjective experience of work can be assessed.

As aforementioned, the dissertation employs a qualitative analysis. An investigation using semi-structured interviews examining the experience of work complements the quantitative examination of the five hypotheses, informing a more complete understanding of the experience of work. As previously outlined, retroduction is employed in the context of the dissertation by examining how employees subjectively describe their experience of work in relation to the stated claims about the benefits of Industry 4.0, and seeking possible explanations for them.

The use of mixed methods helps triangulate findings, and prompts a deeper understanding of how technological intervention affects the subjective experience of work.

d. Study Design

Three exploratory case studies were conducted for the purpose of answering the dissertation research question. Case studies are often employed in applied research. Since organizations are diverse, complex, and consist of changing social phenomena, it is difficult for management researchers to precisely state the conditions on which different types of behavior depend, or the contingencies that make particular theories relevant to certain contexts (Miller et al., 2010), making case studies an ideal approach. This allows for a comparative study between cases, which provides ontological depth to the exploration of the research question by providing multiple examples of how entities and mechanisms interact. In the case of exploring the subjective experience of work, the causal mechanisms that inform either a positive, negative, or neutral experience of work are examined within the context of Industry 4.0 implementations in lean manufacturing environments. The case study approach also allows for institutional analysis, which provides valuable context into how mechanisms have interacted in the past with specific organizational characteristics. The extent to which workers describe their experiences using older technologies, for instance, or the outcomes of past change initiatives helps enrich an understanding of current circumstances.

The three case studies focus on three different organizations that share common characteristics:

- They operate in Canada;
- They are at approximately the same stage in their Industry 4.0 implementation journey;
- And have implemented Industry 4.0 technological solutions as part of an overall strategic vision to achieve greater efficiencies, cost savings or grow market share, or some combination of those objectives. The companies must have a formal plan of adoption.

Each of the three organizations represent a different case, facilitating the in-depth study of different organizational settings and different organizational characteristics. Each of the organizations are of similar size (in terms of number of staff and size of operations), and similar in structure. This dissertation sought organizations that are involved in manufacturing, as manufacturing organizations have tended to be Industry 4.0 pioneers—many have established lean programs, forming a foundation to support Industry 4.0 (Buer et al., 2018). As opposed to organizations primarily concerned with the provision of services, manufacturing organizations share common characteristics, goals and operational performance metrics, in particular improved productivity, reduced cost, reduced delivery time, and improved quality (Buer et al., 2018, p. 5). As lean manufacturing and Industry 4.0 have generally been easier to implement in organizations with repetitive production systems, manufacturing offers a potentially larger pool of organizations from which to study and enable a comparison between companies that are more similar in structure than if attempting to compare organizations focused on the provision of services.

Since the presence of a formal lean program serves as a moderating variable in the relationship between the five dimensions of satisfaction and the composite index measure, OES, the study intentionally sought organizations that have formal lean programs and those that do not, enabling a meaningful study of whether lean programs positively influence Industry 4.0 implementation.

There are numerous organizations in Canada that have formal Industry 4.0 strategies that are engaged in industrial manufacturing, including 3M, Siemens, Denso, ABB, Magna, Honda, Ford, FCA, General Motors, Toyota, Dow, Dupont, P&G, GE and John Deere, according to Invest Canada. These organizations are similar in size and share similar objectives in their use of Industry 4.0 technologies. These formed the basis for initial contact. It took several months and multiple attempts to contact different organizations before any agreed to participate in the dissertation research.

i. Method, Data Collection, Organization, and Management

The design of this dissertation is comprised of a questionnaire for the quantitative study and semi- structured interviews for the qualitative component.

The quantitative design is comprised of a group-administered questionnaire with closed-ended questions. The appropriate sample size required to examine the relationship between employees and the influence of Industry 4.0 technologies is informed by Roscoe (1975). According to Roscoe (1975) sample size can be determined by specifying how much error is acceptable and how much confidence is required. In this case where the research is descriptive, a probability of 0.05 serves as a generally acceptable level of confidence, with a 7.5% error rate (Hill, 1998, p. 5). Based on this, a target number of completed questionnaires is approximately 15-35 for each of the three organizations (approximately 45-105 in total). The questionnaire is included as Appendix B.

Permission to conduct questionnaires was required from each of the organizations under study prior to any individual employees being approached. It was imperative that organizations provide consent to be studied, and understand what data was to be gathered and how the results are to be disseminated. Considerations were made and clearly communicated regarding the acquisition of organizational information, including proprietary knowledge of systems and processes. Organizations were anonymized and are referred to with non-identifiable labels. Confidentiality is of paramount importance.

The target sample of the respondents are organizational employees who are facing task modifications or other job-related changes as a result of the implementation of Industry 4.0 technologies. This offers a wide range of employees from front-line staff to middle-management. The organizations confirmed that selected employees are familiar with Industry 4.0 technologies, and indeed use them in the course of their daily tasks. The use of technology needed to be an explicit component of their daily jobs, and the implementation both intentional and well-documented.

The qualitative design is comprised of semi-structured interviews, where open-ended data were collected and transcribed. A thematic analysis was conducted. A target number of 6-12 interviews needed to be conducted, via electronic format (i.e., Zoom) across three organizations, representing three case studies.

The sample size was determined through point-of-saturation. The concept of saturation and sample size has been examined by several researchers through the application of systematic analysis, sampling theory, multivariate models, and simulations, among others. Saturation is defined as the point where less than one new item or piece of relevant information is expected for each additional person interviewed (Weller et al., 2018). Saturation is achieved when no new themes emerge from the data, and no new coding takes place. It is related both to domain size and the expected number of responses per person. It is important to note that across samples "interviews that gathered more information per person were more productive and obtained more unique items overall even with smaller sample sizes than did interviews with only three responses per person" (Weller et al., 2018, p. 10). In the case of this dissertation, where the domain number is relatively high and the interviews seek a relatively large amount of data (25 questions), a sufficient number of interviews should be approximately 6-12, based on the comparison of number of unique items obtained with full free lists (Weller et al., 2018). According to Francis et al. (2010) interviews that gather more information per person are more productive and obtain more unique items overall, even with smaller sample sizes, than a greater number of interviews with limited responses. The breadth of the qualitative questionnaires ensure that saturation will be achieved with a relatively small sample size. This will help ensure that the research can be practically completed.

The semi-structured Interview Guide is included as Appendix A. Whether some questions needed to be omitted, and whether the order of the questions need to be changed was assessed after a small number (2-4) interviews had been conducted and the responses analysed. Analysis of the quantitative and qualitative data identified mechanisms and their interplay in actualizing events, and provided insights into the meanings and values that employees ascribed to their experience of work. The extent to which the stated claims about role that Industry 4.0 technologies are expected to have, and the expected outcomes they are sought to generate, are compared to the subjective experiences of employees.

ii. Defining Industry 4.0 technologies

Industry 4.0 technologies are comprised of a combination of digital and manufacturing technologies that can enable vertical integration of an organization's systems, horizontal integration in collaborative networks, and end-to-end solutions across the value chain (Klingenberg et al., 2019). According to Zheng et al. (2021) there is no agreed list of Industry 4.0 enabled technologies, and as scholars lack a mutual agreement, there are inconsistencies among different literature domains. Based on the fundamental design principles of Industry 4.0, which are decentralization, real-time support, modularity, inter-operability, virtualization and service-orientation (Alguliyev et al., 2018), technologies tend to be clustered based on similar physical characteristics and operating parameters: cyber-physical systems, internet of things (IoT), big data and analytics, cloud technology, artificial intelligence, blockchain, simulation and modelling, visualization technology (augmented and virtual reality), automation and industrial robots, and additive manufacturing (Zheng et al., 2021).

Industry 4.0 technologies are implemented to support at least one manufacturing business process:

- New product development

- Supply chain configuration
- Integrated supply chain planning
- Internal logistics
- Production scheduling and control
- Energy management
- Quality management
- Maintenance management
- Customer relationship management
- After-sales management

Cyber-physical systems are a collection of transformative technologies that connect the operations of physical assets and computational capabilities. The aim of doing so is to monitor physical systems while creating a virtual copy (Algullyev, 2018).

The Internet of Things (IoT) constitute a network of physical objects (i.e., sensors, machines, vehicles and other items) that enables the collection and exchange of data, allowing interaction and cooperation of these objects (Oztemel & Gursev, 2018).

Big data and analytics involve technologies involved in the collection and analysis of large amounts of available data using a series of techniques to filter, capture and report insights, where data are processed in higher volumes, with greater speed, and in greater variety. Advances in computer hardware and associated software enable big data and analytics (Buhl et al., 2013).

Cloud technology represents a system for the provision of online storage services for applications, programs and data in a virtual server, without requiring any installation. (Li et al., 2012).

Artificial intelligence, as an emerging technology, consists of a system that mimics human cognition, according to six main disciplines, including natural language processing, automated reasoning, knowledge representation, machine learning, and computer vision (Russell and Norvig, 2016).

Blockchain refers to a database that creates a distributed and tamper-proof digital leger of transactions, including timestamps of blocks maintained by every processing node (Ghobakhloo, 2018).

Simulation and modelling technologies include those that mirror physical assets such as machines, products and humans in a virtual world, allowing users to modify designs, iterate uses, and create, test experiments on system operations (Ghobakhloo, 2018).

Visualization technology consists of augmented and virtual reality technologies. Augmented reality technologies are a set of innovative Human-Computer interaction (HCI) techniques that can embed virtual objects to coexist and interact in the real, physical environment (Liu et al., 2017). Virtual reality, on the other hand, is the application of computer technology to create an interactive virtual world, allowing the user to control virtual objects in real time.

Automation and industrial robots comprise the machinery and equipment that automate operational processes. This includes collaborative robotics, which allows humans and machines to operate in a shared learning environment (Oztemel & Gursev, 2018).

Additive manufacturing, according to Esmaeilian et al. (2016), is the process of joining materials in successive layers to manufacture objects from 3D model data to realize design options and achieve the potential for mass customization. 3D printers, and the associated computer hardware and software applications comprise additive manufacturing technology.

Given the wide range of physical technological artifacts that fall under the broad definition of Industry 4.0, it is impossible to narrowly define which specific technologies or technology features or affordances the case study companies ought to have in place for study, as the case companies will be from different industry sectors. The vast differences in application, even of the same or similar technologies may have very different organizational outcomes, and consequently, inform the subjective experience of work differently. For instance, if the dissertation focused on manufacturing companies that used cartesian robots (a common style of industrial robot used for CNC machines and 3D printing), even similar manufacturing companies may employ them in different processes for different reasons. As the dissertation takes a broad perspective, focusing on specific technologies and narrowly defined use behaviors is not essential. Rather, by allowing the case companies to specify the Industry 4.0 technologies themselves as part of their overall strategy, the dissertation research can explore the outcomes of technology use within the case context, rather than focus on the comparative use of a specific technology. The technologies employed by each case company will be detailed in the case narrative, confirming the technology cluster and the business process addressed.

iii. Lean as a moderating variable

Whether organizations have an existing lean manufacturing system in place will serve as a moderating variable (MV) between the dimensions of employee satisfaction and the composite index measure, OES. As opposed to a mediating variable which explains the process through which two variables are related, a moderating variable affects the strength and direction of the relationship. To put it another way, the effect of the dimensions on the outcome shifts, depending on the value of the moderator variable. In this case, it is predicted that the aggregation of five dimensions (job control, training effectiveness, job autonomy, safety awareness and employee productivity) comprise job satisfaction, but it is moderated by the presence of a lean program: if lean is present, overall employee satisfaction increases. If it is not present, overall employee satisfaction is reduced. The underlying assumption is that a lean program will enhance the efficacy of the manufacturing technology, leading to higher reported values for the five dimensions (improving the antecedents of job satisfaction).

Moderating processes can be examined through the use of interaction terms: new variables that are the product of a predictor variable, and a moderator variable. This interaction is included in a regression output as a predictor, alongside its component predictor and the moderator variable itself. This involves running a moderating multiple linear regression (MMLR) using calculated interaction terms. The moderating variable (L) is tested in the data analysis.

iv. Sampling

It is imperative that the population to be sampled is correctly targeted. In this case, the population represents the employees of the three organizations studied who experience task modifications or changes that are the result of the implementation of Industry 4.0 technologies in their jobs. The combined population is not large, but is broad, ranging from front-line staff to management. As such, it is important to classify and separate the target sample for the questionnaire and the interviews:

1. Non-management employees, typically compensated hourly, who engage with Industry 4.0 technologies daily in the course of executing their tasks. The use of technology should be an explicit component of their daily jobs, and the implementation both intentional and well-documented.
2. Management employees, typically on salary, who engage with Industry 4.0 technologies on a daily basis, and supervise the workflows and tasks being completed by front-line, non-management employees. This group includes supervisors and coordinators in a manufacturing environment. The use of technology should be an explicit component of their daily jobs, and the implementation both intentional and well-documented.

Middle and senior managers are excluded from the sampling process as they do not face the same job-related changes that front-line workers will because of Industry 4.0 technologies. While senior management procures new technologies, analyzes the results of implementation, establishes and reviews processes, procedures, workflows and makes organizational decisions based on the use of Industry 4.0, they will not typically interact with those technologies on a daily basis. As the dissertation seeks to understand the implications of these technologies on employees, and whether the claims made by the proponents are realized or not, the perspectives and lived experiences of front-line staff will be more suitable than those of senior-level employees.

Permission to conduct interviews are required from each of the organizations under study prior to approaching any individual employees. The research design follows a 'gatekeeper' approach to the selection of suitable employees. According to Haque et al. (2019) gatekeepers are employees inside the targeted organizations who circulate the questionnaires and interview requests, but do not participate in the study responses. These employees "hold the emission of entering to the field for the researchers as they keep gate pass in the circulation of instrument" (Haque et al., 2019, p. 241). Gatekeepers are selected through networks and referrals, often recommended by senior management when contacted regarding participation in the research study.

It is imperative that organizations provide consent to be studied, understand what data will be gathered, and how the results will be disseminated. Considerations are made and clearly communicated regarding the acquisition of organizational information through the interview process, just as it is regarding questionnaires, including proprietary knowledge of systems and processes. Organizations are anonymized and are referred to with non-identifiable labels. Organizations will be provided with a copy of the final research findings once the dissertation is completed.

v. Data Analysis

A Confirmatory Factor Analysis (CFA) is a type of structural equation modeling that specifically addresses measurement models; that is, the relationships between observed measures or *indicators* (i.e., the dimensions of employee satisfaction) and latent variables, or *factors*. A factor analysis establishes the number and nature of factors that account for the variation and covariation among a set of indicators (i.e., among the dimensions of employee satisfaction).

A factor is an unobservable variable that influences more than one observed measure, and which accounts for the correlations among these observed measures. Observed measures are intercorrelated because they share a common cause, that is, they are influenced by the same underlying construct. If the latent construct is partialled out, the intercorrelations among the observed measures becomes zero. CFA, as a measurement model, provides a comprehensive assessment of the covariation among a set of indicators (in this case, the dimensions of the composite index, OES) because the number of factors will be less than the number of measured variables.

The presence of an existing formal lean program is examined through the use of a moderated multiple linear regression (MMLR).

Qualitative analysis involves thematic analysis with NVivo software. Interviews are transcribed, and the information anonymized. All data is stored securely and is accessible to the principal researcher only.

vi. Validity and Reliability

With respect to the critical realist approach, the research is completed in open systems where causality and mechanisms are contingent upon the context of the study. As a result, a contextual frame for discussing both validity and reliability of the study lies in the specific contexts of the organizations ultimately chosen for study.

Empirically, the research seeks to corroborate the extent to which the causal relationships hold within the context studied, and is impacted by the perceptions of both the researcher and the participants, who operate within various social structures, and are influenced by existing theoretical paradigms. The application of analytical methods, logic, creativity, and intuition to the empirical data, in order to assess causal mechanisms that inform subjective experience, requires a degree of subjective interpretation. While critical realist research seeks to explain rather than predict open-system outcomes, the underlying need for validation, through the comparison of the theory's observational consequences with observed evidence remains. The primary means of providing this validation is by identifying other events that should have occurred, related to a focal event, if the proposed mechanisms indeed existed. To the extent that the collected study data confirms the related events, the proposed causal mechanisms will be corroborated. In the case of the dissertation, the mechanisms that exist within lean manufacturing environments, and inform the relationship between the implementation of technologies and work, are corroborated by observing the extent to which the anticipated effects occur. The explanatory potential of proposed mechanisms is tested by observing how perspectives change over time.

The validity of the questionnaire is based on four components: (1) face validity; (2) content validity; (3) construct validity; and (4) criterion validity. Face validity refers to the researchers' subjective assessment of the presentation and relevance of the measuring instrument, and the degree to which the items in the instrument appear to be relevant, reasonable, unambiguous and clear (Oluwatayo, 2012). The questionnaire, found in Appendix B, meets this subjective assessment. There is no indication that it is not relevant to the objectives of the study: it is reasonable, unambiguous and clear to the reader. Content validity refers to "the degree to which items in an instrument reflect the content universe to which the instrument will be generalized" (Taherdoost, 2016, p. 30). The development of the questionnaire included questions and scales from the literature that had already been developed. Had the questionnaire been created specifically for this dissertation, the Content Validity Ratio (CVR) using Lawshe's Method would have been required. Construct validity refers to the degree to which an idea, concept, or behavior has been operationalized. In this context, the questionnaire has been designed to gather information from a large group on the degree to which technology has intervened in their daily work, how they rate their subjective interpretations of that intervention, and how they rate their happiness, quality of life and quality of work. These broad findings are then be explored in depth using qualitative interviews with a smaller number of participants, in order to understand the mechanisms at work. The findings are then compared to the stated claims about the implementation of technology for organizations to test alignment. Construct validity of the questionnaire involves assessing convergent and discriminant validity. Discriminant validity tests whether constructs that should have no relationship, do not, in fact, have any relationship. Convergent validity refers to the degree to which two measures of constructs that should be related, are in fact, related. Finally, criterion validity refers to the extent to which a measure is related to an outcome.

The semi-structured interview offers both a versatile and flexible means of exploring the research question. The development of interview questions is based on the ethical consideration that questions should provide a richer understanding of the issue at hand (i.e., the subjective experience of work), and not lead to the collection of data that is unnecessary, or unrelated to the research. Semi-structured interviews are suitable for studying people's perceptions and opinions, as well as complex and emotionally sensitive issues (Kallio et al., 2016). Well-formulated questions are participant-oriented, clearly worded, single-faceted, and open-ended, without being leading. The aim is to generate answers from participants that are spontaneous, in-depth, unique, and vivid. Semi-structured interviews need to be credible, confirmable, and dependable. Credibility refers to the accurate recording of the phenomena being studied. Confirmability refers to the researcher's objectivity, which is enhanced by making the research process transparent, and describing clearly how the data are collected. Dependability refers to repeating the interview in the same conditions, across case studies.

Issues of validity and reliability need to be considered in any realist evaluation, as interviews are used to identify mechanisms which suggest contingent causality. Marshall et al. (2006) refer to validity as the "criteria of trustworthiness" (p. 200). From a critical realist perspective, the notions of *trust* and *trustworthiness* found in the research outcomes will only be relative to the context of this dissertation, and not generalizable, or applicable in all contexts. It is imperative, however, that the findings still be well-founded and sound. According to Robson (2002) there are three "threats to validity" (p. 171): description, interpretation, and theory.

According to Robson (2002) the threat of description is caused by the inaccuracy or incompleteness of data. To counter this threat all interviews have been transcribed verbatim from online meeting software (Zoom) and all text coded, apart from identifying information or proprietary company information irrelevant to the questions asked. This approach reduces the possibility of data loss.

There are two considerations related to the interpretation of the qualitative data: (1) the potential imposition of a framework or meaning on what is happening (Robson, 2002); and (2) the influence the interviewer has on the knowledge creation process (King et al., 2010). The risk of imposing a particular framework or meaning on the interpretation of the data is mitigated through the research design: the positivist claims about Industry 4.0 are identified by examining the literature, and the responses are interpreted as either affirming (+), negating (-), or are neutral. Responses are examined systematically through a retroductive process. Although the research design is inherently critical, a critique of the findings is completed after the data is collected and analyzed. The data collection itself is meant to provide context and further details regarding individual thoughts, experiences, and perspectives in relation to a set of claims favored by practitioners. The threat of interviewer influence during the interview process is negated by remaining as neutral as possible and staying as close to the interview guide as possible. Remaining cognizant that researchers are contributors to the knowledge creation process, efforts were made to identify and eliminate leading questions, the expression personal opinions, or the imposition of values during the interview. It is imperative that the participants' perspectives should unfold as they saw them (emic perspective), not how the researcher saw them (etic perspective).

According to Robson (2002) the threat of theory involves privileging a single, or small number of theories in the analysis of the data to the exclusion of other possible theoretical approaches. The application of a critical realist analysis, specifically retroductive analysis, explores multiple theories when evaluating underlying structures and mechanisms. The novel application of critical realism in this dissertation helps reduce the potential threat of a singular, or narrow theoretical focus when evaluating qualitative data.

vii. Confronting Bias

With respect to this research there are several common types of bias that need to be addressed. Volunteer, or self-selection bias is the most problematic with questionnaires. Volunteers are often different from non-volunteers in ways that may affect the outcomes of the research. According to Palys (2003) people who choose to participate in studies "tend to be more highly educated, politically more liberal, less authoritarian, more in need of social approval, more intelligent, and more interested in the issue being addressed than those who don't" (p. 152). It will be imperative to ensure that the respondents are representative of the population, and that the gatekeepers being engaged are cognizant of the need to distribute the questionnaire widely. Self-reporting bias can occur in any context where random or systematic misreporting is conceivable. The bias is ubiquitous in survey data where cognitive processes, social desirability, and survey conditions can alter interviewee's responses.

To address and minimize self-reporting bias, several measures have been taken when designing the questionnaires. One approach involved introducing an honesty prime task to assess the role of goal states or social factors on self-report accuracy. This was done by requesting participants complete the survey form honestly, and with the assurance that all responses will be strictly confidential. Priming occurs when an individual's exposure to a certain stimulus influences their response to a subsequent prompt, without any awareness of the connection. These stimuli are often related to words or images people are familiar with, or relate to on a daily basis. Another measure taken was to ensure that an adequate number of responses across participants are collected to minimize compliance bias (the introduction of a systemic predilection into collected self-reports as the result of differences in response rate between participants). Additionally, the use of neutral questions to reduce social desirability bias, and the use of forced-choice items was used to ensure equal desirability in the responses.

Common method bias is normally prevalent in studies where data for both independent and dependent variables are obtained from the same person in the same measurement context, using the same item context and similar item characteristics. Some sources of common method bias include:

- independent and dependent variables are used with the same item
- the presence of errors in the measurement items
- the context in which the measurement instruments are obtained such as social desirability, leniency bias, etc.

Common method bias is addressed in the following ways:

First, add a temporal, proximal, or psychological separation when measuring the independent (predictor) and dependent (criterion) variables. By adding a time delay, increasing the physical separation of items, and/or adding a cover story to deemphasize any association between the independent and dependent variables, a researcher can reduce a participants' tendency to use previous answers to inform subsequent answers. A temporal delay achieves this by allowing recalled information to leave a participant's short-term memory before answering new questions. Proximal separation removes common retrieval cues and a cover story, or. psychological separation, decreases the perceived relevance of previously recalled information to newly recalled information. The study only directly measures dimensions of satisfaction, and does not indicate in the survey how the composite index is measured. This provides a psychological separation.

Second, steps can be taken to eliminate common scale properties such as response format. Researchers should consider switching up response formats for different questionnaires. According to Kothandapani (1971), who experimented with four different scale formats: Likert, Thurstone, Guttman, and Guilford, found quite remarkably, that the average correlation between the independent and dependent variables dropped by 60% from r = .45 to r = .18 when different response formats were used versus the same response format. The questionnaire in this study was designed with multiple response formats, in order to help reduce common method bias.

Lastly, efforts should be made to eliminate ambiguity in scale items. Ambiguous items increase participants' reliance on their systematic response tendencies (e.g. extreme or midpoint response styles) as they are unable to rely on the content of the ambiguous item. Ambiguity can be reduced by keeping questions as simple and specific as possible. Clearly defining terms that may be unfamiliar to participants and providing examples when appropriate help eliminate ambiguity. The questionnaire in this study was designed to reduce ambiguity in question wording, and efforts were made to ensure that language and intent were simple and clear.

Common method bias (CMB) can be tested using Harman's single-factor score. A total variance exceeding 50% for one factor may require a remedy (Podsakoff et al., 2014). A test will be included in the data analysis section.

Another bias that is considered in the study design is endogeneity. Endogeneity refers to the correlation between the independent variable and unexplained variation, or error, in the dependent variable. In a regression analysis, endogeneity occurs when there is a relationship between the predictor variable and the error term. It may lead to bias in the results of statistical tests. It is important, as the presence of endogeneity may undermine the validity of inferences and lead to incorrect conclusions. Endogeneity can arise in several ways:

- Omitted variable bias: occurs if researchers leave out a relevant predictor variable from the model.
- Measurement error: occurs when the values of the predictor variables are not measured accurately, leading to biased estimates.
- Sample selection bias: occurs when the predictor and dependent variables causally influence each other (i.e., education level and income may have a circular or bi-directional relationship).
- Simultaneity: the fact of something happening or being done at the same time as something else

When considering endogeneity in the study, efforts were made to ensure all predictor variables, or dimensions, were accounted for, and that consistent measurement techniques were applied to those variables. Sample selection bias is reduced by not measuring satisfaction (calculated, rather, as a composite index) directly, so the study will have limited, if any, potential to inform reverse causality (i.e., increased overall employee satisfaction leading to increased productivity).

When considering the qualitative component, researchers must be cognizant that the data-gathering process itself is informative, and that one must be open to any new directions that may emerge in the context of the interview due to the unique perspectives of the participants. This requires a thorough understanding of the research objectives so that interviews can flow freely without veering off into tangents or unrelated areas (Palys, 2003). Interviews are also subject to reactive bias, where interviewees can be very attentive to cues that the interviewer emits, since they want to know whether they are performing well as participants. Being aware of body language, cues, and evaluating the impact that questions are having are important to ensure that accurate information and genuine perspectives are being captured (Nagappan, 2001).

viii. Dissemination Plan

The data, the results of the analysis, discussion, and conclusions generated from the research will be presented in a final doctoral dissertation and will be defended to a committee and external examiner. The dissertation will be published, and a copy will be made available in the Athabasca University Library. In addition, the completed dissertation will be shared at academic conferences (i.e., the Western Academy of Management), and with practitioners through industry publications or events. The results of the study will also be shared with the participating organizations to disseminate the practical implications of the research. Since the research is applied research, ensuring that the utility of the findings is well communicated aligns well with the study's objectives.

ix. Study Limitations

This study is limited in its scope, focusing on multiple case studies of manufacturing organizations. The study assesses the stated claims of Industry 4.0 proponents and practitioners and explores whether those claims can be supported. The research also assesses whether the presence of a lean manufacturing program plays a significant role in moderating the role of Industry 4.0 technologies in organizations. By comparing cases in which the technologies are implemented within lean organizations to organizations in which they are not, the role of the technology can be explored in a meaningful way. The case study approach not only offers insights into the extension of a critical realist perspective to the study of technology in organizations, but offers a very practical means of addressing the dissertation question, while allowing for a timely completion of the project. Since the findings will be limited to a small number of case studies, they can not be broadly generalized without further study.

x. Ethical Considerations

All questionnaire and interview data are kept anonymous. All case companies are anonymized, and any propriety information gathered is removed from the company description. Participation is voluntary. Confidentiality is assured, and informed consent forms are signed and collected before interviews are conducted, and before any questionnaires are sent. All research participants are properly informed about the goals of the dissertation, how their responses will be used, how that information will be secured, and that they will be able to read the results once the project is completed. All data is anonymized, encrypted, secured, and will be accessible to the sole researcher only. Ethics approval was sought as part of the proposal defence, and was in place prior to conducting any research.

Chapter 4: Data Analysis

a. Introduction

The quantitative study was based on a representative sample of employees in three different manufacturing companies. The companies were anonymized and designated *Company X*, *Company Y*, and *Company Z*. *Company X* and *Company Y* had formal Lean Manufacturing programs in place, while *Company Z* did not. Participation in the study was voluntary. Of the sixty (60) employees selected for survey completion, forty-seven (47) submitted a response, for a 78.3% response rate. The survey was completed online via Google Forms. According to Hair et al. (2010) the interplay among sample size, the significance level (α) chosen, and the number of independent variables inform the detection of a significant R^2: the sample size n=47 with six independent variables, and a 0.05 level of significance will detect an R^2 value of 23 percent and greater 80 percent of the time it occurs (corresponding to a power of 0.80). This is an acceptable level of statistical significance and desired power.

The survey gathered employee responses related to the five separate dimensions—Employee Autonomy, Training Effectiveness, Employee Productivity, Job Control, and Safety Awareness—and the results were tabulated. The sum of the scores across the 82 total questions represents the Overall Employee Satisfaction (OES) score. Each dimension relies on summated scales, or the employment of multiple variables and questions to reduce the reliance on any single variable or question as the sole representation of the dimension. This helps reduce measurement errors.

The dimensions included in the survey were chosen based on a literature review and assessed five broad dimensions: (1) Employee Autonomy; (2) Training Effectiveness; (3) Employee Productivity; (4) Job Control; and (5) Safety Awareness. The dimensions of Overall Employee Satisfaction (OES) were measured using different scales. Employee Autonomy (EA) was evaluated by Naus et al. (2007) with a Cronbach's alpha of 0.71. Training Effectiveness (TE) was evaluated by Santos & Stuart (2003). Employee Productivity (EP) was evaluated by Ramos-Villagrasa et al. (2019) with a Cronbac's alpha of 0.83. Job Control (JC) was evaluated by Smith et al. (1997). Safety Awareness (SA) was evaluated by Brondino et al. (2013). The aggregation of the dimensions inform a composite index measure, or the measure of overall employee satisfaction (OES).

The presence of a formal lean manufacturing program, a non-metric independent variable, is represented by a dichotomous, or dummy, variable. Both Company X and Company Y have formal lean programs in place, and this is represented through the use of indicator coding, where a 1 represents presence, and a 0 denotes absence. The coefficients for the dummy variables represent differences in the composite index measure for each group of respondents from the reference category. The group differences can be assessed directly by the Confirmatory Factor Analysis (CFA).

The analysis of the quantitative survey data was conducted by way of a CFA. A CFA aims to reproduce the observed relationships among the dimensions of satisfaction with a smaller set of latent variables.

A Confirmatory Factor Analysis (CFA) is used, rather than an Exploratory Factor Analysis (EFA) as it evaluates how well the hypothesized model of satisfaction reproduces the covariance matrix of the measured variables. A CFA is useful for testing the underlying structure that has been established on prior theoretical grounds.

Discriminant validity was tested against the Fornell-Larcker criterion. Convergent validity was tested by examining the statistical significance of standardized factor loadings.

The analysis of the qualitative interview data was conducted by way of a deductive process of coding and thematic analysis that is consistent with Critical Realist ontology and epistemology. The process of Critical Realist analysis is not linear, but rather, involves several key steps: (1) identification of demi-regularities; (2) abduction, or theoretical redescription; and (3) retroduction.

b. Case Narratives

Critical realism is often used to analyze complex and dynamic social systems. Social phenomena, such as the introduction of Industry 4.0 technologies, are influenced by both observable actions and deeper social structures. Critical realism strives for explanatory theories that uncover causal mechanisms (causal powers). Uncovering causal mechanisms and their interaction with structural entities requires a detailed understanding of the cases studied.

i. Company X

Company X is a small manufacturing company located in Canada. The company is involved in aviation consulting and aerospace manufacturing. The manufacturing division is involved in machining and manufacturing of components and parts in the aerospace industry. The company is ISO 9001:2015 and AS9100 certified, and is an approved aerospace manufacturing facility.

Company X utilizes additive manufacturing, otherwise known as 3D printing, in additional to traditional machining, material testing, and inspection. It is a revolutionary manufacturing process that builds parts and components, layer by layer, using computer-aided design (CAD) data. As opposed to removing material from a solid block (as in traditional manufacturing), additive manufacturing adds material in a controlled manner to create a final product. This technology has gained significant attention across various industries due to its versatility, design freedom, and potential for cost and time savings. Additive manufacturing is popular in aerospace manufacturing because it allows engineers to design complex structures with optimized geometries, resulting in lightweight parts, it enables rapid prototyping, it facilitates customization, it reduces waste, it reduces the length of the supply chain, can be employed on-demand for aircraft operators, it reduces the cost of low-volume parts, and it allows for the use of innovative materials, such as high-strength composites and lightweight alloys.

Company X offers complements its aerospace and related manufacturing with metallurgical and mechanical engineering, enhancing its research and design.

Company X has a formal lean manufacturing program in place, and has implemented Industry 4.0 technologies in its manufacturing process. Industry 4.0 adoption is part of the company's strategic plan, enabling it to position itself as a leading manufacturer in the aerospace industry, and allow it to seek market expansion opportunities. The company meets all of the criteria for a case study in this dissertation. The company is located in Canada. The company is at the same stage of it's Industry 4.0 journey as the others in the study—Industry 4.0 has been formally adopted and been used for at least two years. The technologies are implemented at all levels of the organization, and affect both management and front-line staff. The company has adopted Industry 4.0 in order to achieve operational efficiencies, cost savings, and to gain market share.

Company X has a technology-intense operation and the cost of machining equipment, automated lines, control systems and an integrated ERP is significant. The company utilizes IoT infrastructure, real-time data monitoring, and machine learning to support its engineering and research functions. The company engages in substantial training for its equipment operators, engineers, and managers. The company has robust processes and procedures, and engages in deliberate continuous improvement efforts to maximize its efficiency and deliver customer value.

The industry 4.0 technologies employed by Company X include a variety of IoT-enabled 5-axis CNC machines, including large DMG270 U Deckel Maho machines, using CELOS ERGOline software. The company also uses ULTEM FX20 3D printers that can build with a variety of input materials, including continuous carbon fibre. 3D printing, an application of additive manufacturing, allowing for the development and manufacture of complex designs, and supporting rapid prototyping. All 3D printers are IoT enabled, allowing for continuous monitoring of machine conditions and manufacturing progress.

Company X also uses hardware and software to support its advanced simulation and modelling. Engineering aerospace components is supported by virtual prototyping, technical product assessment and digital product representation.

The business processes supported by the Industry 4.0 technologies include production scheduling and control, quality management, and new product development.

The company adheres to strict safety regulations, conducts regular safety meetings, and maintains a safe working environment.

With respect to organizational norms and practices, Company X is characterized by a strong emphasis on teamwork, innovation, and a focus on the customer. Management focuses heavily on attending to customer needs, empowers individual contributors, and emphasizes teamwork.

ii. Company Y

Company Y is a small manufacturing company located in Canada. The company is involved in the manufacture of Computer Numerical Control (CNC) machines, distributing, installing, and developing solutions for customers of those machines. The company provides sales and technical support, and distributes their machines globally.

Company Y has had a formal lean manufacturing program, coupled with a six-sigma program, for over 15 years which aided in their quality control and testing. Company Y strongly supports employee training and development. The company closely follows one of the key tenants of lean manufacturing—engaging front-line staff in process assessment and continuous improvement. Company X has been investing heavily in manufacturing technology since it was founded in the early 1980's and adopted a formal Industry 4.0 development strategy several years ago, and actively utilizes IoT connectivity, real-time monitoring, big-data and machine learning analysis, AI for scenario analysis and testing, robotics, and digital twins. It utilizes augmented-reality technology in operator training and uses digital twins to train its maintenance and field support teams.

Company Y uses a variety of Industry 4.0 technologies in its manufacturing process, including 5-axis CNC and milling machines, and notably, Okuma MCR-BV double-column machining centres. The company uses a variety of waterjets and gantry lasers as well. Most of the large machines are IoT enabled, and are linked to the company's ERP system. This allows for continuous monitoring of machining status, tracking of OEE (overall equipment efficiency), and real-time tracking of maintenance requirements and scheduling. The company also uses a variety of hardware and software, as well as cloud computing applications to track customer service requests, service completion, and to gather customer intelligence, informing service improvements, as well as product design improvements.

The business processes supported by the Industry 4.0 technologies include production scheduling and control, quality management, new product and service development, as well as integrated supply chain planning, maintenance management, and customer relationship management.

Company Y works closely with its customers to design equipment specific for their manufacturing operations, placing customer value at the heart of its decision making—another key tenant of a lean manufacturing system. Industry 4.0 has provided the ability to iterate solutions more quickly and respond to customer changes more rapidly than its existing technologies did.

The company has a robust health and safety program in place, reporting no Lost Time Injuries (LTIs) in over five years. The high level of automation used in its manufacturing and assembly helps reduce the amount of time employees spend lifting heavy components, manually changing machine tools, or intervening in the process.

Company Y is a Canadian manufacturing company that has a well-established Industry 4.0 strategy, and has successfully implemented Industry 4.0 across it's organization for at least two years. The company utilizes Industry 4.0 to improve it's manufacturing and design efficiency, drive cost savings, and grow its market share, both domestically and internationally.

iii. Company Z

Company Z is a small manufacturing company located in Canada. The company manufactures fertilizers, plant stimulants, and additives for the horticultural industry. The manufacturing business of the company is separate from its wholesale business.

Company Z does not have a formal lean manufacturing program in place, but it does have a formal Industry 4.0 pillar as part of its overall corporate strategy. The use of advanced manufacturing technology in its fertilizer manufacturing includes integrated ERP with real-time IoT connectivity, remote monitoring capability, automated mixing, bottling, labelling, and automated quality control testing. The company utilizes demand planning and automated inventory management systems, scheduling production using Just-In-Time (JIT) principles to minimize inventory costs. The Industry 4.0 system allows for easy changeovers between different products, and allows the company to rapidly customize product blends and even packaging to suit specific customer requirements.

The Industry 4.0 technology utilized by Company Z includes, notably, an advanced production line featuring flexible automation, allowing for the production of different product types in batches. The system is linked to the company's ERP system, and is IoT-enabled, allowing for in-process inspections of product material (allowing for real-time quality control and batch management), and automated packaging, ensuring consist fill rates and reduced losses. The company also uses cloud computing applications and big data analytics to capture customer purchasing trends and real-time inventory to automate production scheduling.

The business processes supported by the Industry 4.0 technologies include production scheduling and control, quality management, integrated supply chain planning, and customer relationship management.

Company Z has a strong safety culture with no recorded LTI's for four years. It has an engaged management that fosters teamwork and a cohesive organization.

Company Z has embraced Industry 4.0 as part of its evolution from a small, entirely manual manufacturer to an advanced manufacturer with customers all over the globe. The company maintains a relatively small staff, favoring automation in order to control costs, and maintain a high level of productivity per employee.

Company Z is a Canadian-owned and operated manufacturing company that has formally adopted Industry 4.0 as part of its competitive strategy for at least two years. It leverages its investment in a variety of Industry 4.0 technologies to increase efficiency across its company's functions and focuses intently on cost savings to remain competitive. The company utilizes Industry 4.0 to compete for market share with much larger international producers of fertilizers and crop protection products.

c. Quantitative Analysis

i. Summary Statistics

The survey statistics from the respondents (n=47) are summarized in Table 1 and in the correlation matrix, Table 2.

Table 1.

Survey Statistics

Variable	Observations	Obs. with missing	Obs. without	Minimum	Maximum	Mean	Std. Deviation
OES	47	0	47	260.000	296.000	278.213	11.634
EA	47	0	47	0.600	0.750	0.751	0.061
TE	47	0	47	0.333	0.800	0.549	0.136
EP	47	0	47	0.556	0.756	0.707	0.037
JC	47	0	47	0.590	0.876	0.726	0.092
SA	47	0	47	0.460	0.833	0.679	0.132
L	47	0	47	0.000	1.000	0.638	0.486

Table 2.

Correlation Matrix

		EA	TE	EP	JC	SA	L
Correlation	EA	1.000	-0.590	0.224	0.281	0.418	0.123
	TE	-5.900	1.000	-0.108	-0.048	-0.142	-0.044
	EP	0.224	-0.108	1.000	0.411	0.356	0.560
	JC	0.281	-0.048	0.411	1.000	0.704	0.552
	SA	0.418	-0.142	0.356	0.704	1.000	0.327
	L	0.123	-0.044	0.560	0.552	0.237	1.000
Sig. (1-Tailed)	EA		<0.001	0.065	0.028	0.002	0.204
	TE	0.000		0.234	0.374	0.170	0.384
	EP	0.065	0.234		0.002	0.007	0.000
	JC	0.028	0.374	0.002		0.000	0.000
	SA	0.002	0.170	0.007	0.000		0.012
	L	0.204	0.384	0.000	0.000	0.012	

Determinant = 0.117

The correlation matrix has a determinant value of 0.117, which > 0.00001, indicating that the correlations are significant.

The highest correlation is between Job Control (JC) and Safety Awareness (SA) at 0.704. The lowest correlation is between the presence of a formal lean program (L) and Training Effectiveness (TE) at -0.044.

ii. Construction of the Composite Index Measure (OES)

The exploration of the five dimensions of satisfaction— Employee Autonomy, Training Effectiveness, Employee Productivity, Job Control, and Safety Awareness—is achieved through the construction, and examination, of a composite index measure. Overall Employee Satisfaction (OES) is calculated by summating the survey scores for each of the survey respondents. OES, then, is a composite index.

A composite index is a useful means of summating multidimensional information, distilling a complex concept into a single measure. The underlying dimensions, or items, need to be conceptually related.

The calculation of a composite index requires a determination of the weightings of the composite indicators, representing the underlying dimensions. The composite index measure of OES uses an equal, or attributes-based weighting system, reflecting a summated scale construction.

iii. Confirmatory Factor Analysis (CFA)

Confirmatory Factor Analysis (CFA) verifies the number of underlying dimensions of the instrument (OES), and the pattern of item-factor relationships (factor loadings). The CFA assists in the determination of how the composite index (OES) is constructed, and which dimensions of satisfaction are statistically significant. In other words, it allows for the determination of the variation of the model and the relative contribution of each dimension in the total variance. The CFA allows for an analysis of the dimensions of a composite index measure of employee satisfaction, and how they have explanatory value. Each dimension is weighted to ensure maximal prediction from the set of dimensions. The weights denote the relative contribution of each dimension to the overall model, and facilitate interpretation of the influence of each. In this way, an analysis of the factor loadings informs a substantive understanding of the effects of the dimensions (constructs) on Overall Employee Satisfaction (OES).

Measurement error in Confirmatory Factor Analysis (CFA) is specified to be random, implying that the indicator unique variances are not correlated. CFA partitions the variance of each indicator into two parts: (1) common variance, or that attributed to the latent variable(s); and (2) unique variance, which is a combination of reliable variance specific to the indicator and random error variance. When measurement error is specified to be random, the assumption is that the observed relationship between any two indicators loading on the same factor is entirely due to the shared influence of the latent variable (Brown & Moore, 2012), and not due to *method effects* that reflect additional indicator covariation resulting from several potential causes:

- The use of common assessment methods (i.e., a questionnaire);
- Reversed or similarly worded test items;
- Differential susceptibility to other influences, such as response set, demand characteristics, acquiescence, reading difficulty, or social desirability.

The specification of non-correlated errors in the dissertation fits the theoretical construct of the OES model.

The following control variables have been identified and implemented in the factor analysis:

1. Tenure: All of the surveyed employees have been employed with their organizations for a period of at least six months, ensuring that not only do the employees have a thorough understanding of their jobs and related tasks, but have used the Industry 4.0 technologies in a meaningful way, and can reflect thoughtfully on its implications for their job.
2. Age: All of the surveyed employees were over the age of eighteen.
3. Significant exposure to Industry 4.0 Technology: All subjects are either front-line (non-management) or management -level employees that experience task modifications or changes that are the result of the implementation of Industry 4.0 technologies in their jobs. All were employed full-time. Senior managers and executives that do not interact directly with Industry 4.0 technologies were excluded.

The use of a CFA informs a structural model for the quantitative assessment, which specifies how the various factors are related to one another (i.e. direct or indirect effects, no relationship). The CFA model contains the parameters of factor loadings, factor variances, and unique variances. Factor loadings are the regression slopes for predicting the indicators from the underlying factor. Factor variance expresses the dispersion of the factor, including error covariances, while unique variance represents the measurement error.

For this dissertation, a single-factor model is posited in which the observed measures of Employee Autonomy (EA), Training Effectiveness (TE), Employee Productivity (EP), Job Control (JC), Safety Awareness (SA) and the presence of a formal lean manufacturing program (L) are conjectured to load on a latent dimension of satisfaction.

Measurement error is presumed to be non-systematic (i.e., there are no correlated measurement errors among indicators). This implies that for indicators loading on the same factor, the observed covariance among these measures can be explained entirely by the underlying construct, that is, there is no reason for these observed relationships other than the factor.

The factor analysis was run in IBM SPSS, using a Principal Components Analysis.
The factor analysis was run with loading on a single factor. The solution could not be rotated. An initial Component Matrix was run:

Table 3.

Initial Component Matrix

	Component 1
JC	0.819
SA	0.786
L	0.692
EP	0.687
EA	0.588
TE	-0.353

Extraction Method: Principal Component Analysis

a. 1 components extracted

An analysis of the KMO and Bartlett's Test indicates a KMO Measure of Sampling Adequacy is 0.638. This exceeds the desired value of 0.60. See Table 4.

Table 4.

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.638
Bartlett's Test of Sphericity	Approx Chi-Square	92.672
	df	15
	Sig.	<0.001

The Bartlett's Test of Sphericity < 0.01, which is a desirable result. This is a statistically significant value.

An examination of the communalities (Table 5) indicates the proportion of variance for each variable that can be explained by the factor. The variable with the lowest proportion of variance that can be explained is Training Effectiveness (TE) at 0.125.

Table 5.

Communalities

	Initial	Extraction
EA	1.000	0.346
TE	1.000	0.125
EP	1.000	0.472
JC	1.000	0.671
SA	1.000	0.617
L	1.000	0.478

Extraction Method: Principal Component Analysis

An examination of the Total Variance Explained (Table 6) indicates that a single factor explains 45.15% of the total variance. Two factors can explain 68.86% of the total variance. Three factors can explain 82.67% of the total variance.

Table 6.

Total Variance Explained

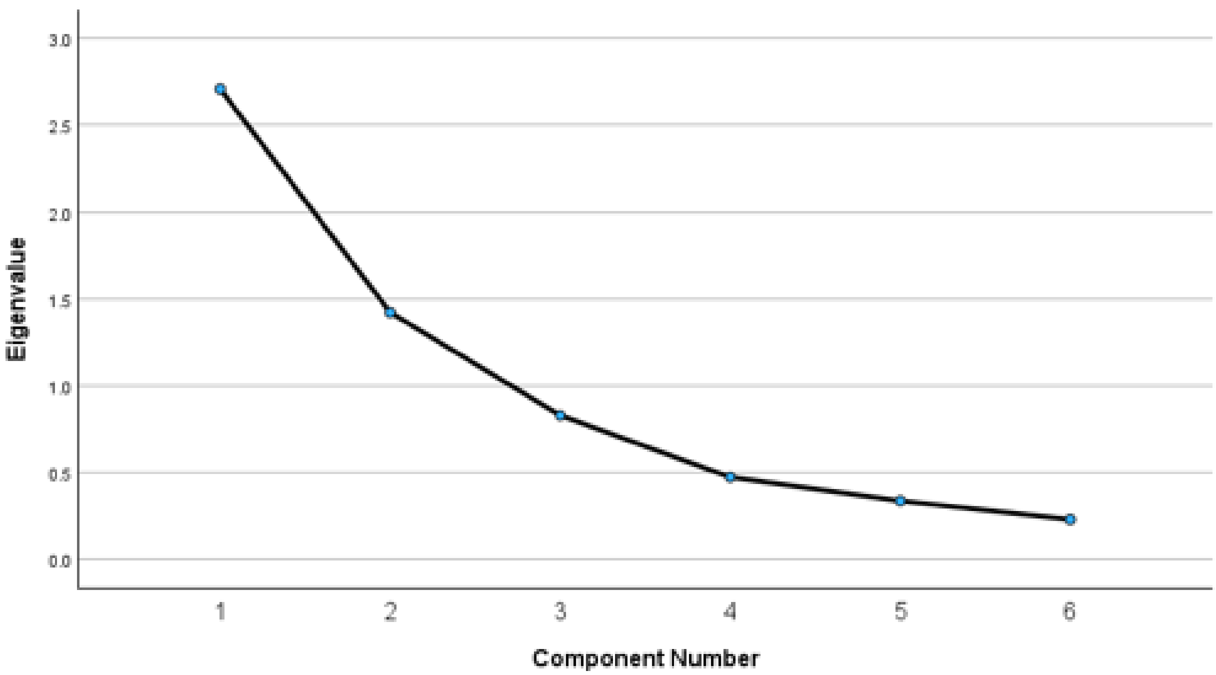
	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.709	45.152	45.152	2.709	45.152	45.152
2	1.422	23.706	68.859			
3	0.829	13.815	82.674			
4	0.473	7.887	90.56			
5	0.337	5.615	96.175			
6	0.229	3.825	100			

Extraction Method: Principal Component Analysis

An examination of the Scree Plot (Figure 3) indicates that the first two factors are above an Eigenvalue of 1.0.

Figure 3.

Scree Plot



The revised component matrix table (Table 7) values did not change during the analysis. An analysis of the values indicates that the factor has strong loadings from EA, EP, JC, SA, and L. It does not have strong loadings from TE.

Table 7.

Revised Component Matrix

	Component
	1
JC	0.819
SA	0.786
L	0.692
EP	0.687
EA	0.588
TE	-0.353

Extraction Method: Principal Component Analysis

a. 1 components extracted

Training Effectiveness (TE) has the lowest factor loading, and has an inverse relationship with the underlying factor. The component matrix indicates that JC, SA, L, EP, and EA inform the underlying construct (satisfaction), while TE does not contribute significantly to it.

Evaluating the Model

The acceptability of the fitted CFA solution can be evaluated on the basis of the overall goodness of fit.

Overall goodness of fit can be assessed by a calculation of RMSEA = 0.3355, where

$$\text{RMSEA} = \sqrt{\max\left(\frac{\chi^2 - df}{(N-1)df}, 0\right)},$$

This value indicates that the single-factor model is statistically acceptable.

A calculation of the covariance matrix can be found in Table 8.

Table 8.

Covariance Matrix

	EA	TE	EP	JC	SA	L
EA	0.004	-0.005	0.000	0.002	0.003	0.004
TE	-0.005	0.019	-0.001	-0.001	-0.003	-0.003
EP	0.000	-0.001	0.001	0.001	0.002	0.010
JC	0.002	-0.001	0.001	0.001	0.009	0.025
SA	0.003	-0.003	0.002	0.002	0.017	0.021
L	0.004	-0.003	0.010	0.010	0.021	0.236

Test of the Moderating Variable

A test of the moderating effect of the presence of a formal lean manufacturing program is accomplished using a moderated multiple regression (MMR) method. MMR analysis is the method of choice to detect moderator effects in field research and is superior to strategies such as comparison of subgroup-based correlation coefficients (The underlying theoretical assumption is that the effect of the dimensions (i.e., EA, JC, EP, SA) on a composite index measure (OES) varies with the presence of a lean program (i.e., job satisfaction increases, due to stronger antecedents of satisfaction resulting from a higher level of standardization, more effective implementation, and stronger execution).

The interaction regression equation for each dimension with the composite index can be represented as follows:

$$Y = \boldsymbol{b_0 + b_1(V) + b_2L + b_3(V),L + \varepsilon}$$

To improve the interpretability of results and to reduce collinearity between the predictor dimensions and the interaction term, grand-mean centering (the subtraction of the overall sample mean for a dimension from each case score on that dimension) is used.

Interaction terms are then calculated (the product of the grand-centered dimension value and the dichotomous moderator variable).

Assumptions of MMLR:

- Employees are randomly sampled from the underlying population
- The association between the dimensions and composite index is linear
- The data are free from multivariate outliers
- Average residual error value is zero for each level of the predictor dimension
- Variances of residual errors equal for all levels of the predictor dimensions (assumption of homoscedasticity)
- Residual errors are normally distributed for all levels of the predictor dimensions

Using null hypothesis significance testing (NHST), we interpret a p-value that is less than 0.05 to meet the standard for statistical significance (Table 9):

Table 9.

MMLR P-Values

	Coefficients	p-value	H0 (5%)
Intercept	277.6875	0.0000	
Interaction EA	72.2486	0.0455	Rejected
Interaction EP	104.0456	0.1310	Accepted
Interaction JC	9.5082	0.6035	Accepted
Interaction SA	100.0074	4.204E-10	Rejected

For the dimensions Employee Autonomy (EA) and Safety Awareness (SA), the p-values from the moderated multiple regression supports a moderating relationship with the presence of a formal lean program. Overall, the model supports a moderating relationship.

It can be concluded that the presence of a formal lean manufacturing program has a significant moderating relationship between the dimensions of satisfaction and the composite index, Overall Employee Satisfaction (OES).

Test for Common Method Bias

CMB was calculated using SPSS statistical software. An exploratory factor analysis was run where all variables were loaded onto a single factor, and constrained so there was no rotation (Podsakoff et al., 2003). If the sum of squared variance exceeds 50%, that typically indicates the presence of CMB. The data show 45.152. There is no evidence of CMB present in the model.

Table 10.

Test for Common Method Bias

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.709	45.152	45.152	2.709	45.152	45.152
2	1.422	23.706	68.859			
3	0.829	13.815	82.674			
4	0.473	7.887	90.56			
5	0.337	5.615	96.175			
6	0.229	3.825	100			

Extraction Method: Principal Component Analysis

Exploring the Nested Structure of Data

Given that the three companies explored differ in a number of key characteristics, such as geography and industry, there is a possibility that the data gathered exists within a nested structure: the research participants are nested within companies.

In this study design, clustering is used as a matter of practicality: the relative effect of technology use within specific companies is the objective. Simple random sampling of employees that use advanced technology would not only be difficult to accomplish, but the results wouldn't be able to analyzed within a case structure, leaving the findings unanchored, and impossible to explore from a deeper and more detailed level.

As a result, however, observations taken from within the same company may be more similar than observations taken from different companies. This necessitates separating within- versus between-company effects. If nesting is not addressed, the degree of independence may be overestimated, and may lead to erroneously concluding that effects are statistically significant (a type I error).

The effects of nested data can be inferred from the degree of relative similarity between observations obtained from the same company: this is expressed in the intra-cluster (intra-company) correlation (ICC), which ranges from 0 to 1. If clustering is absent (ICC = 0), all observations obtained from a research object are independent, that is, contribute fully unique information. In the extreme case of ICC = 1, that would indicate that all observations obtained from the same company are equal, and therefore convey the same information.

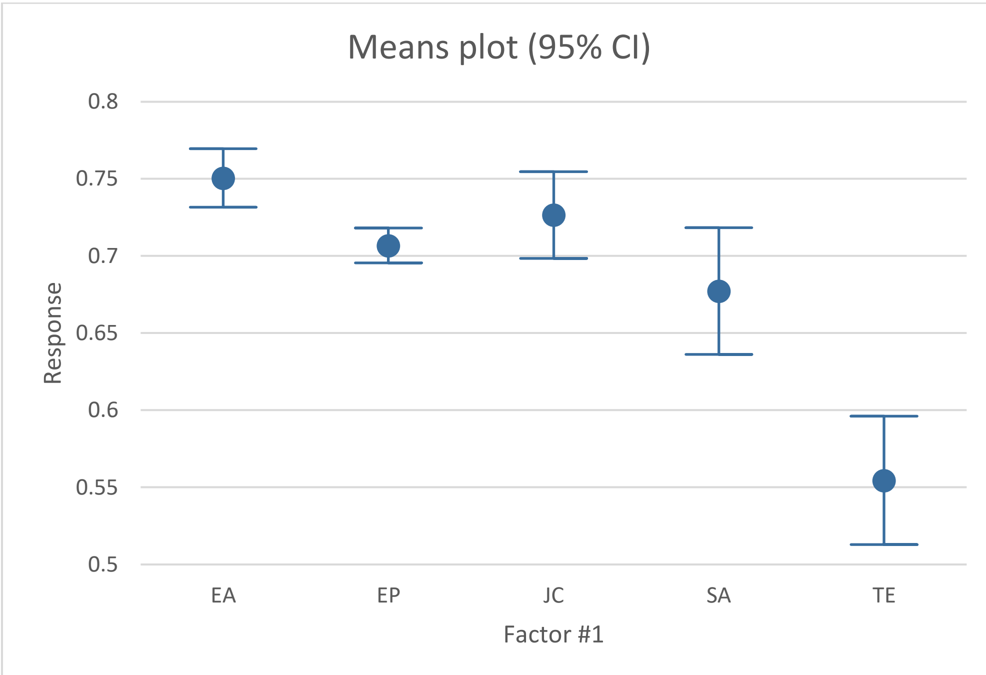
ICC is calculated from the variance between companies (clusters), calculated as the deviation of the cluster means from the grand mean, and the total variance, or the sum of the variance between clusters and the variance within clusters, calculated from the deviations of individual observations from their cluster mean.

The ICC for all observations is 0.3217.

The ICC for Company X is 0.954; Company Y is 0.429; and Company Z is 0.355

Figure 4.

Means Plot (Response Variance)



Clearly, clustering is not absent. Intra-company correlation is highest in Company X, and lowest in Company Z. There may be several reasons for this.

There is no evidence that the residuals in employee satisfaction are correlated. The Durbin-Watson statistic is 2.2330, indicating no autocorrelation.

Summary

It can be concluded that the companies with formal lean manufacturing programs (Companies X and Y, respectively) can expect a higher OES score than companies (Company Z), provided the other dimensions remain constant.

Based on the analysis of the survey results through a Confirmatory Factor Analysis (CFA) the hypotheses can be evaluated:

EA: Employee Autonomy (EA) is a significant component of the composite index, Overall Employee Satisfaction (OES). **Accepted.**

TE: Training Effectiveness (TE) is a significant component of the composite index, Overall Employee Satisfaction (OES). **Not accepted.**

EP: Employee Productivity (EP) is a significant component of the composite index, Overall Employee Satisfaction (OES **Accepted.**

JC: Job Control (JC) is a significant component of the composite index, Overall Employee Satisfaction (OES **Accepted.**

SA: Safety Awareness (SA) is a significant component of the composite index, Overall Employee Satisfaction (OES). **Accepted.**

L: The presence of a formal lean program will have a positive moderating effect on the relationship between the five dimensions and Overall Employee Satisfaction (OES). **Accepted.**

d. Qualitative Analysis

To gain a deeper understanding of the subjective experience of work and the complex realities faced by individuals, semi-structured interviews were conducted with nine different employees. This format provided the flexibility to explore the ideas from the existing literature, while allowing new ideas to emerge. Three employees each from Company X, Company Y, and Company Z participated. From each company, one individual at a managerial level, and two individuals at a front-line (non-management) level were interviewed. Each interview was anonymized, and the transcription was assigned a unique identifier, P1 through P9. Each interview transcript represents a unique case.

The interviews were conducted via Zoom, an online meeting software, and were recorded with permission from the interviewees. Those recorded interviews were then transcribed verbatim for analysis.

The transcripts were analyzed using NVivo software, and the entirety of the text coded based on analytical categories consistent with critical realist ontology. The data analysis began with the search for demi-regularities at the empirical level of reality. Although critical realism acknowledges that while ideas, social conventions, and decisions can have causal impacts, these social objects do not follow a conception of causal laws and the deterministic regularity of Humean constant conjunction—event 'x' doesn't always lead to outcome 'y.' The social world consists of open systems in which any number of occurrences and events can overlap and interact, and individuals are constantly learning, changing, and adapting (Danermark et al., 2002). As a result of this acknowledgment, critical realism seeks *tendencies*, not laws (Danermark et al., 2002, p. 70). These tendencies, or demi-regularities, are found in rough trends, or broken patterns in empirical data, and are identified through qualitative data coding.

The absence of literature on applied critical realism created a challenge for coding the transcripts. The scant literature that does address the issue described the process of coding in vague terms such as an "intensive grounding process in which concepts emerged" (Yeung, 1997, p. 69). The coding process that was used not only helped identify demi-regularities, but it informed the processes of abduction and retroduction, which were central to the critical realist analysis.

While some critical realists have employed a grounded theory approach to data coding (Yeung, 1997), there are several reasons why grounded theory is not ideal for a critical realist study, particularly: (1) grounded theory and critical realism engage with existing theory in different ways, and (2) the inferential processes associated with grounded theory are primarily inductive, while critical realism relies on abduction and retroduction (Fletcher, 2017).

Although grounded theory can be generally guided by existing theory or literature (Glaser et al., 1967) it does not actively engage with existing theory during the analysis process. Grounded theorists favor inductively coding each line of text to gradually develop higher-level theories that are grounded in data in a process called theoretical sampling, rather than in concepts drawn from elsewhere (Corbin et al., 2008). This early detailed coding is intended to "break open the data to consider all possible meanings" (Corbin et al., 2008, p. 59) with the goal of moving the researcher away from their preconceptions. Critical realism, however, seeks to find the best explanation of reality through engagement with existing theories about that reality while acknowledging that all understanding is partial, tentative, and temporary, or fallible (Oliver, 2012).

The inferential processes associated with grounded theory are primarily inductive, while critical realism relies on the use of abduction and retroduction. Grounded theory is data-driven while critical realism relies on a more theory- and researcher-driven analytical process (Fletcher, 2017). Grounded theory is, hence, more empiricist than critical realism. Since existing theory is such an important part of the critical realist analysis, relying on grounded theory, which is founded on the intentional avoidance of existing theory to build new theories, to examine the stated claims of Industry 4.0 made little sense.

Critical realist methodology embraces epistemic relativism, or the idea that there are many ways of knowing (Oliver, 2012). Critical realist studies tend to use mixed methods approaches, typically using statistical analysis to ascertain patterns or regularities in empirical phenomena, and then qualitative inquiry to probe for depth of explanation (Kazi, 2003). This enables triangulation for reasons that may appear contradictory within traditional paradigms, but which are coherent from a critical realist perspective. Triangulation allows for an examination of convergence on, and tentative confirmation or a real tendency. It offers a more complete understanding of a phenomenon by bringing together the information gained from different perspectives and prompting the interrogation of emergent contradictions (Olsen, 2004).

With the idea of triangulation in mind, a primarily deductive, yet flexible, directed coding process (Hsieh et al., 2005) that drew on existing theory and literature was used. A list of codes was based on the five central claims made regarding the benefits of Industry 4.0 integration, as well as a series of general statements about the impacts of integration. The interview transcript codes were assigned to each claim, and were changed, eliminated, and supplanted with new codes during the process, until every line of text was coded. The deductive codes were used to reformulate the existing model from which they were drawn.

The first round of coding was organized around claim-based categories, reflecting the dissertation hypotheses. By basing the coding categories on the general claims identified in the literature, the behaviors, attitudes, and observations identified in the interviews were coded as either supportive of a particular claim, neutral, or opposing a particular claim. In assessing this, references in the transcripts were assessed within the context, linking the behavior or attitude to one of the five specific claims (i.e., references to workload and stress are coded to the *Employee Productivity* cluster because the specific references in the interview transcripts are situated within a comment or a discussion about achieving productivity targets). Generalized statements that were not related to a stated claim but were broadly generalizable were clustered together. Through the process a total of 69 codes were created, grouped into 6 categories. Codes were then clustered within the categories, reflecting the flexibility of the deductive coding process. The complete NVivo codebook is attached as Appendix C.

i. Coding: First Round

1. **[Employee Autonomy – EA]** Claim: Industry 4.0 will enable connected workflows in intelligent technological environments to give workers not just the tools, but the freedom to adapt and solve problems in creative ways (Hoey, 2018);

Table 11.

Employee Autonomy – Coding Clusters

Cluster 1: Work is fulfilling (satisfies curiosity, stimulates interest, and is engaging)	Cluster 2: Enables use of skills (challenging, utilizes skills to address problems and solve)	Cluster 3: Requires learning (upgrading of skills and changing work)	Cluster 4: Tasks have changed	Cluster 5: Increased autonomy (freedom to adapt)
(+) Fulfilling (+) Tech informs creativity (+) Enjoy technology	(+) Skills used (+) Formal leadership (+) Enhanced Decision-Making	Need to learn (-) Difficulty of training	Tasks have changed (-) Change is difficult Tasks have not changed	(+) Enhances autonomy (+) Improved work-life balance (-) Limited autonomy (-) Declining work-life balance Unchanged work-life balance Static Autonomy

For example, for Cluster 1, all the transcript references regarding fulfillment, the extent to which technology requires or inspires creativity, or enjoyment were identified and clustered together. An example of a reference to fulfilment comes from P1: "Our capability to provide manufacturing engineering, inspection, material testing, additive manufacturing and precision machining offers significant fulfillment and interesting work." With respect to technology informing creativity, a reference again comes from P1: "The technology [software] is far more responsive to change, and allows me to rapidly adapt to changing variables such as changes to customer designs, or to complete last-minute orders far more easily than using older tech. It makes being creative easy, since the software can quickly extrapolate, and fill in the blanks for incomplete designs." An example of a reference regarding the enjoyment of technology comes from P9: "It [the use of technology] will definitely become easier. The longer we work with this technology, it will become second nature. I already enjoy using it. I'll never go back to the old way of production."

2. **[Job Control – JC]** Claim: Industry 4.0 will require organizations to actively invest in their workforce through retraining efforts and upgrading employees' current skill sets so they can manage automated processes or take on "creative" jobs that are less likely to be replaced by automation. As automated tasks are phased in, simultaneously training existing workers with the incremental skills needed for higher-level jobs (e.g., data analysis, process improvements) can help mitigate the perceived threat of automation (Navales, 2018);

Table 12.

Job Control – Coding Clusters

Cluster 1: Industry 4.0 leads to increased output; increased pride in outcome	Cluster 2: Change is difficult to manage and adapt to	Cluster 3: The growing role of AI; speculation about the future	Cluster 4: Automation	Cluster 5: Improved communication
(+) Increased output (+) Pride in work	(-) Increased Workload Static Workload	(+) AI will be beneficial	(+) Automate routine tasks (+) Tech eliminates errors	(+) Good communication (+) Increased team collaboration (+) Increased Transparency

For example, for cluster 4, all references to the automation of tasks, or indicate that technologies help eliminate errors in the transcripts were identified and clustered together. For instance, P4 refers to the automation of routine tasks in Company Y: "The monitoring and oversight of all phases of test automation, scenario testing, and the production of performance test scripts have all become much more advanced, much easier to run, and much more effective." An example of a reference to technology eliminating errors comes from P3: "New technologies in the manufacturing process have simplified the process, and reduced the need to intervene. The level of monitoring and smart, self-adjusting and self-correcting systems have helped address much of the variability [in the final product]."

3. **[Employee Productivity – EP]** Claim: Industry 4.0 leads to higher productivity (elimination of errors and risks, production of larger quantities of products, reduction of working hours); higher flexibility (individualized products, more efficient production, wide variability in control processes); higher competitiveness (lower production costs, implementation of innovations and innovative solutions, flexible responses to fluctuations in demand); higher profitability (mass production, process optimization, lower stocks, more economical production).

Table 13.

Employee Productivity – Coding Clusters

Cluster 1: Alignment	Cluster 2: Accessibility of work	Cluster 3: Flexibility	Cluster 4: Employee control over job/tasks
(+) Goals aligned with organization (+) Staying in role (-) Goals not aligned	(+) Accessibility (+) Office location	(+) Flexibility (+) Technology increases speed & adaptability (+) Technology frees up time (-) Flexibility (-) Constricted Focus	(+) Participation in management (+) Influence over policies and procedures (-) Workload increased (-) Stress is High (-) Tasks set by mgmt (no Involvement) (+) Stress is low, or well-managed Stress is moderate Workload unchanged

For example, in Cluster 4, all references to the increase in scheduling or work flexibility, the use of technology in increasing the speed of task completion and/or improvement in adaptability, or instances of technology freeing up time were clustered together. These instances all indicated positive references. The coding cluster also involved negative references related to workplace flexibility: references to instances where technology reduced flexibility in an aspect of work, or the constriction of focus. An example of a reference to increased flexibility comes from P3: “Remote work options exist and make it so we can take meetings and client meetings remotely.” A negative reference to flexibility comes from P6: “No, not really. I work on-site as an operator.”

4. **[Safety Awareness – SA]** Claim: Industry 4.0 leads to superior safety outcomes (limiting defects and errors—software, protection of workforce safety by sensors, immediate reactions and interventions) (Grenčiková et al., 2020); and

Table 14.

Safety Awareness – Coding Clusters

Cluster 1: Industry 4.0 leads to improved safety outcomes, and a higher degree of safety awareness and engagement	Cluster 2: Industry 4.0 has reduced the need for humans to intervene in manufacturing processes, and improved ergonomics (reducing the chances of injury)
(+) Improves Safety (+) Management Attention (+) Employees are consulted (+) Communication emphasized in training	(+) Less human intervention in process (+) Improved Ergonomics (-) Creates complacency

For example, in Cluster 2, all references in the interview transcripts to technologies reducing the need for humans to physically intervene in the manufacturing process, or instances where technology has contributed to improved ergonomics were recorded, and clustered together. Instances where employees referenced a negative situation in which technology contributed to complacency were included in the cluster. An example of reduced intervention come from P5: "It's [equipment] is newer, has better guarding, and doesn't need nearly as much maintenance. It takes our people away from it." The single negative referencing a situation in which technology creates complacency comes from P6: "I feel like management relies too heavily on technology to ensure we're safe."

5. **[Training Effectiveness – TE]** Claim: The emerging technologies of Industry 4.0 have made flexible working arrangements more accessible and transparent, which are becoming more important to staff attraction and retention (O'Brien, 2018).

Table 15.

Training Effectiveness – Coding Clusters

Cluster 1: Training and development is encouraged	Cluster 2: Continuous learning needs to be implemented, supported, and available to employees
(+) Training is encouraged (-) Limited Training	Continuous Learning

For example, Cluster 1 includes all references to situations where training is encouraged, and situations where training is limited. The opposing coding fall under the same Cluster, exploring the extent to which training is encouraged. An example of a positive reference can be attributed to P5: "Absolutely. Some days, I feel that's all we do. There's so much to learn with this new technology, and it's always being updated." An example of a negative reference can be attributed to P3: "We receive some training from manufacturers when integrating new equipment into our own manufacturing processes. It's ironic, however, that as an organization that puts together training for other companies of the use of their technology, we don't have a lot of training ourselves on the equipment we use. Most of our training, at least as far as my role is concerned, is self-directed."

6. General statements concerning the investment in, and integration of Industry 4.0 technologies in manufacturing operations:

Table 16.

General Statements – Coding Clusters

Cluster 1: Optimistic about the future of the company	Cluster 2: Overall positive experience informing employee commitment	Cluster 3: Optimistic about the role of the technology	Cluster 4: Organizational change (neither positive or negative)
(+) Future Outlook (-) Anxious about change	(+) Longevity in role (+) Relationship with coworkers (+) Relationship with manager (+) Good Morale (-) Longevity in role (-) Looking for new employment (-) Relationship with manager	(+) Optimistic about change (+) Successfully integrated (+) Customer Value	Significant organizational change Technology Interconnectedness

The coding of general statements includes references from all nine interview transcripts, and the codes are general, rather than specific to the five dimensions. Cluster 1 includes references related to optimism about the future of the respondent's company, either positive or negative. An example of a reference to a positive future outlook can be attributed to P3: "I think that the future is very good for us. Our machines are in high demand, and we're having trouble keeping up. Manufacturing is booming in Canada, and we're fortunate to be a domestic supplier of quality equipment. We've invested heavily into advanced technologies to support our own manufacturing, and leverage our own manufacturing." An example of a negative reference about anxiety related to change comes from P7: "I admit that I sometimes feel anxious about the pace of change, and wonder if I will be able to continue to keep up with all of the new advancements in the field."

A summary of most referenced (top) themes, a comparison between management employees, non-management employees, and by company are provided in Figures 15, 16, and 17, respectively.

Table 17.

Top Themes (Combined)

Top Themes (Combined)	References
24: (+) Increased Output	20
59: (+) Training is Encouraged	18
10: (+) Fulfilling	14
2: (-) Training is Difficult	14
67: (+) Future Outlook	13
60: Continuous Learning	13
12: (+) Skills Used	12
39: (+) Goals Aligned with Organization	12
54: (+) Improves Safety	12
70: (+) Optimistic about Change	11

Table 18.

Top Themes (Management and Non-Management)

Top Themes (Management)	References
14: Need to Learn	8
2: (-) Change is Difficult	7
10: (+) Fulfilling	7
39: (+) Goals Aligned with Organization	7
38: (+) Flexibility	6
24: (+) Increased Output	6
59: (+) Training is Encouraged	6

Top Themes (Non-Management)	References
24: (+) Increased Output	14
59: (+) Training is Encouraged	12
60: Continuous Learning	12
70: (+) Optimistic about Change	9
67: (+) Future Outlook	8
12: (+) Skills Used	8
2: (-) Change is Difficult	7
10: (+) Fulfilling	7
54: (+) Improves Safety	7

Table 19.

Top Themes (Company X, Company Y, and Company Z)

Top Themes (Company X)	References
12: (+) Skills Used	8
59: (+) Training is Encouraged	7
60: Continuous Learning	7
70: (+) Optimistic about Change	7
10: (+) Fulfilling	6
21: (+) AI will be beneficial	6
24: (+) Increased Output	6
45 (+) Technology frees up time	6
73: (+) Successfully integrated	6

Top Themes (Company Y)	References
2: (-) Change is Difficult	10
24: (+) Increased Output	6
39: (+) Goals aligned with organization	5
59: (+) Training is encouraged	5
67: (+) Future Outlook	5
54: (+) Improves Safety	5
25: (+) Increased team collaboration	4
37: (+) Fulfilling	4
54: (+) Accessibility	4
60: Continuous Learning	4

Top Themes (Company Z)	References
24: (+) Increased Output	8
59: (+) Training is Encouraged	6
60: Need to learn	5
10: (+) Fulfilling	4
22: (+) Automate routine tasks	4
34: (-) Stress is high	4
2: (+) Flexibility	4
39: (+) Goals aligned with organization	4
42: (+) Participation in management	4
69: (+) Longevity in role	4

ii. Coding: Second Round

The second round of coding involved re-organizing and combining the first round of 69 codes into critical realist-informed categories of *structure* and *agency*. Critical realism differentiates between structure—the social structures that are relatively enduring, and are reproduced and transformed over time—and agency—individual values, meaning, and ideas that are shaped, but not determined by structures, and can consciously or unconsciously shape social structures (Bhaskar, 1979). According to Carter et al. (2004) critical realist analysis “starts from the ontological claim that structure and agency each possess distinct properties and powers in their own right” (p. 5). Two categories were created: one each for structure and agency, and the codes were assigned. This distinction helped inform an analysis of the structural entities that comprise reality and generate and interact with emergent causal powers. See Appendix D.

iii. Sentiment

The sentiment of each of the nine cases was analyzed with NVivo. Sentiment analysis refers to the process of extracting information about how an individual or group reacts to a particular policy, event, or change. It indicates opinion by mining through text to methodically recognize, extract, evaluate, and examine emotional states and subjective information. Sentiment analysis, sometimes referred to as opinion mining or subjectivity analysis extracts opinions, sentiments and subjectivity in unstructured text, identifying whether expressions indicate positive (favorable) or negative (unfavorable) opinions toward the subject (Pang et al., 2008). Sentiment analysis normally deals with detecting polarity (i.e., positive or negative sentiment) as opposed to detecting discrete emotions (i.e., happiness or sadness). Table 18 summarizes the sentiments of the interviewees:

Table 20.

Sentiment

	Years at Company	Level	Company	Very positive	Positive	Moderately positive	Moderately negative	Negative	Very negative
1 : P1	5.5	Manager	X	12	40	28	3	3	0
2 : P2	2	Front-Line	X	21	40	19	5	5	0
3 : P3	7.5	Manager	Y	13	35	22	6	10	4
4 : P4	1	Front-Line	Y	7	26	19	5	9	4
5 : P5	11	Manager	Z	6	28	22	1	4	3
6 : P6	14	Front-Line	Z	5	13	8	2	6	4
7 : P7	3	Front-Line	X	15	38	23	3	8	5
8 : P8	4	Front-Line	Y	12	23	11	3	4	1
9 : P9	12	Front-Line	Z	13	22	9	1	4	3
				25%	70%	46%	8%	13%	5%

Based on the NVivo analysis, 83% of the responses across all the interviewees were ‘moderately positive,’ ‘positive’ or ‘very positive’.

A comparison between managers and front-line employees in Table 19 reveals slightly more negative sentimentality amongst the latter (18% of responses from front-line employees being either ‘very negative,’ ‘moderately negative’ or ‘negative’ compared to 14% for managers).

Table 21.

Sentiment (Management vs. Non-Management)

	Years at Company	Level	Company	Very positive	Positive	Moderately positive	Moderately negative	Negative	Very negative
2 : P2	2	Front-Line	X	21	40	19	5	5	0
4 : P4	1	Front-Line	Y	7	26	19	5	9	4
6 : P6	14	Front-Line	Z	5	13	8	2	6	4
7 : P7	3	Front-Line	X	15	38	23	3	8	5
8 : P8	4	Front-Line	Y	12	23	11	3	4	1
9 : P9	12	Front-Line	Z	13	22	9	1	4	3
				18%	41%	22%	5%	9%	4%

	Years at Company	Level	Company	Very positive	Positive	Moderately positive	Moderately negative	Negative	Very negative
1 : P1	5.5	Manager	X	12	40	28	3	3	0
3 : P3	7.5	Manager	Y	13	35	22	6	10	4
5 : P5	11	Manager	Z	6	28	22	1	4	3
				13%	43%	30%	4%	7%	3%

While front-line responses tend to be slightly more negative, there is no significant difference between the front-line employees and managers overall.

Comparing sentimentality between the three different companies (Table 20) reveals that Company X has more positive sentimentality (88% positive compared to 78% and 82% for Companies Y and Z, respectfully). Interestingly, Companies Y and Z are more similar, despite Company Z not having a formal lean manufacturing program in place. Company Y has the highest rate of negative sentiment (21%), but Company Z has the highest percentage of 'very negative' responses. Table 20 illustrates the comparison between companies.

Table 22.

Sentiment (Company X vs. Company Y vs. Company Z)

	Years at Company	Level	Company	Very positive	Positive	Moderately positive	Moderately negative	Negative	Very negative
1 : P1	5.5	Manager	X	12	40	28	3	3	0
2 : P2	2	Front-Line	X	21	40	19	5	5	0
7 : P7	3	Front-Line	X	15	38	23	3	8	5
				18%	44%	26%	4%	6%	2%

	Years at Company	Level	Company	Very positive	Positive	Moderately positive	Moderately negative	Negative	Very negative
3 : P3	7.5	Manager	Y	13	35	22	6	10	4
4 : P4	1	Front-Line	Y	7	26	19	5	9	4
8 : P8	4	Front-Line	Y	12	23	11	3	4	1
				15%	39%	24%	7%	11%	4%

	Years at Company	Level	Company	Very positive	Positive	Moderately positive	Moderately negative	Negative	Very negative
5 : P5	11	Manager	Z	6	28	22	1	4	3
6 : P6	14	Front-Line	Z	5	13	8	2	6	4
9 : P9	12	Front-Line	Z	13	22	9	1	4	3
				16%	41%	25%	3%	9%	6%

e. Demi-Regularities and Recurring Themes

i. Coding: Third Round

Recurring codes, identified by the number of files (case count) and specific references (code count), were used as a identify initial demi-regularities. The following demi-regularities were identified:

- Industry 4.0 technologies enhance output potential (+ Increased Output)
- Work was reported to be fulfilling, either personally, or professionally (+ Fulfilling)

- Employees are encouraged to take advantage of training and development opportunities (+ Training is Encouraged); There is an increasing need for continuous learning, and an increasing quantity of material to be learned (Need to learn)
- The outlook for the organization implementing Industry 4.0 is positive
- Industry 4.0 technologies facilitate a more accessible workplace (+ Accessibility)
- There is a shared perception that Industry 4.0 contributes meaningfully to a safe workplace (+ Improves Safety)
- Industry 4.0 facilitates a positive and constructive relationship between coworkers

The third round of coding identified codes that were shared among all, or the majority of, the interviewees. Those with a high number of files and a high number of specific references were designated as code clusters, and related codes were assigned to those clusters. The sentimentality of the interviews was referenced to accurately capture the prevailing attitude underpinning the demi-regularities. The specific transcription references were reviewed to provide context. See Appendix E.

The first demi-regularity identified by all interviewees was that the implementation of Industry 4.0 technologies contributed to increased productivity and output. Every interviewee responded positively in that the technology has either contributed to increased productivity, or has the potential to do so, and that was the shared expectation. For instance, an employee of Company X (P2) indicated that “monitoring the production process and monitoring machine status allows us to optimize our processes, limit downtime, and schedule maintenance and changeovers.” Similarly, an employee from Company Y (P3) indicated that “the technology that we use in manufacturing has made us far more efficient, safer, and more productive.” This idea was shared among both the managers and the front-line workers as technologies improved productivity in a variety of different ways, from decreasing the amount of time needed to run iterations for engineers to reducing tool change-over time for machine operators. As Industry 4.0 includes a suite of technologies including IoT connectivity, utilization of big data solutions, cloud computing and sensor-based technologies, the notion that employees in different functional areas all benefit from its adoption and integration is consistent with the literature. Increased productivity was driven, in part, by the automation of routine tasks, and the increased speed of task completion and adaptability to changing conditions and parameters. Interviewees indicated that technology was effective in freeing up their time by automating a variety of tasks, allowing more time to focus on essential tasks.

The second demi-regularity was that working in an Industry 4.0-enabled manufacturing organization was reported to be fulfilling, either personally or professionally. This was reported by all interviewees. The feeling of fulfillment—of happiness, satisfaction or contentment—is driven by the utilization of skills, enhanced autonomy, participation in management, the enjoyment of using technology, having a position with a formal leadership component, and having a moderate level of stress. For example, an employee of Company Y (P3) expressed that "I like my work. It's a challenging and interesting space. I think that the future of manufacturing is very exciting, and being a part of it, by designing the CNC machines that manufacturers use, and helping them install, service, and troubleshoot them is very rewarding." The notion that working in advanced manufacturing companies can be fulfilling is one that was described by all interviewees, regardless of age or position. Coding indicates that Industry 4.0 creates a challenging, albeit rewarding environment. The high rate of change and the ability of technology to adapt to that change informs a rewarding work experience. There are several references to the power that technology holds to respond to customer demands, and to help deliver customer value, an experience that four of the respondents mentioned. The reduced cycle times, high iterative capacity, and real-time data flows characteristic of advanced manufacturing technology create a fast-paced and responsive environment that all respondents found to be fulfilling.

The third demi-regularity identified by all the interviewees is that they all were encouraged to take advantage of training and development opportunities. This is driven by the pace of change, and the rapid development of technologies in the workplace. The transcripts reference the importance of effective and continuous training in order to understand and properly utilize technology in the workplace. For instance, an employee of Company Z (P6) said 'the investment in technology gives us all new opportunities to learn, grow and build out skills. We get a lot of good training." The fundamental need to engage in training seems well understood by organizational leaders, but it's also well understood by those that use the technology. There is a recurring theme that understanding is imperative, and that employees will quickly fall behind, or be ineffective, in their roles if they do not engage meaningfully in training. The complexity of the technology itself, coupled with the complexity of integrating new technologies in existing processes necessitates thorough understanding. The literature reflects this realization. According to Rangraz et al. (2021) employees in Industry 4.0 environments increasingly face a situation where they have to adapt to workplace transformations brought by digitalization, automation and robotics, or face lay-offs. It is in the best interests of employers and employees alike to ensure that organizations "realize appropriate training strategies and organization of work in a way that fosters learning, enables lifelong learning and workplace-based training and continues professional development" (Rangraz et al., 2021, p. 6). The acknowledgment that training is necessary, and that lifelong learning is quickly becoming a component of contemporary work is associated with high levels of stress and, often, difficulty managing the sheer volume of training that is required. The interviewees indicated that training can be internal (updated processes, procedures, or solutions) or external (equipment or software training provided by external manufacturers or OEM's, or customers).

The fourth demi-regularity identified is that there was a positive outlook for the future shared among all interviewees, in all three case companies. This positivity was characterized by a belief that the investments in Industry 4.0 technologies were helping to secure new business, support innovation, sustain new orders, and improve capabilities. To illustrate, an employee of Company Y (P4) posits that "I think that the future is bright. The company continues to grow, and the manufacturing space is strong. Canada is well positioned for smart manufacturing." The rosy outlook tended to follow a period of turmoil and change, and once in place, managers and front-line employees alike embraced it as a means of remaining competitive. This perspective is aligned with references to individual goals being aligned with those of the organization (i.e., the desire to learn, grow, and engage in challenging work), optimism that future changes will yield similarly beneficial results, that Industry 4.0 has improved morale, and in all but one case, interviewees reported an inclination to remain in their roles. In the exceptional case the individual indicated that retirement was their next career step, and the decision to retire was not influenced by Industry 4.0 in the workplace.

The fifth demi-regularity emerging from the coding is the acknowledgment that the adoption of Industry 4.0 facilitates a more accessible workplace. Employees with mobility issues face fewer barriers to engaging fully in work as work is not only more accessible as a remote option (i.e., real-time data, ERPs, and document sharing are widely available) but work on the plant floor is far easier and more ergonomic. Lengthy tool changeovers, for example, require less manual exertion, are simpler, and are required far less often. The use of advanced technologies improves maintenance outcomes leading to less downtime and less frequent large repairs. Advanced computer simulations optimize manufacturing line planning, so fewer changeovers are required, equipment designs are improved, and less human intervention is required in the manufacturing process. The reduction in intervention makes it far easier for operators with mobility limitations to monitor the process, and limits the amount of physical exertion required to operate equipment. For instance, an employee of Company Y (P4) indicated that “a lot of the office-related tasks we do can be done remotely, and collaborative software has come a long way, helping our team work together.” The increased accessibility afforded by Industry 4.0 adoption is closely related to increased job flexibility—the idea that employees can be engaged and productive from anywhere.

The sixth demi-regularity is that Industry 4.0 adoption leads to improved workplace safety. The interviewees shared a number of specific examples of improvements being driven by the adoption of advanced technologies in a manufacturing setting including a reduction in the number of tool changeovers, more ergonomic machine designs for operator controls, better machine optimization resulting in less human intervention, the use of robotics for lifting and moving heavy materials, better guarding, and fewer moving parts. A repeated theme was that Industry 4.0 enabled far better machine, line, and process monitoring because of real-time IoT data, resulting in earlier detection of problems, more rapid intervention, and fewer catastrophic failures. Maintenance activities, a key function in manufacturing, became easier and more predictable. Parts inventories have become automated, preventative maintenance scheduling is automated, and in one company machines could adapt to component failures and maintain a reasonable level of output. This is exemplified by an Employee of Company X (P7) who observes that "the machines require far less maintenance than the old ones, meaning less interaction between machines and people. We have fewer physical changeovers, and we don't change tools nearly as much. I think that yes, we are more safe [sic] as a company than we were even a few years ago." Improved safety is closely related to less human intervention in manufacturing processes (reducing the potential for harm), maintaining a static workload, and ensuring that organizational leaders and managers consult employees on changes to their tasks, workstations and processes.

The seventh and final demi-regularity identified through the interviews was that Industry 4.0 adoption was associated with a positive and constructive relationship between coworkers. Relationships were described as positive and cordial, with a high degree of collaboration. Transcripts reference the notion that cross-functional collaboration is increasingly important as technological solutions transcend traditional functions or departments. This is exemplified by an employee of Company X (P1) who stated that "My relationship with my coworkers is great. I work closely with our engineers and technicians in the design and manufacture of components, explore new capabilities, and consider new offerings. I work well with our senior leadership team." Insights can be quickly extracted from large amounts of data and shared widely necessitating open communication between operators and managers. Employees are expected to keep up to rapid changes and to be responsive to customer demands, which requires teamwork and collaboration. It was noted that teams in advanced manufacturing environments are smaller than they otherwise would be, and as such, employees form closer relationships to a relatively smaller number of people. The positive relationships between co-workers is associated with effective (good) communication, a positive relationship with one's manager, increased team collaboration, increased organizational transparency, increased and sustained management attention paid to issues raised, and close proximity of employees.

The interviews revealed relatively few negative comments: few case counts, and few references. However, it's worth exploring what those negative references are, and if there is any pattern to be discerned. The most prominent concern, raised by five of the nine interviewees is that they experience a high level of stress. This is attributed to managing several projects concurrently, a high number of issues to address, difficulty with change management, anxiety about the market their company operates in, the high costs of investment, and challenges that arise from setbacks and breakdowns.

Related negative references include concerns raised about the difficulty of managing change, and the difficulties associated with training. These countervailing conditions are often known as contrasitives (Lawson, 1997). With regard to managing change, multiple references were made to the challenges with designing and implementing new procedures, reviewing new technologies, and ensuring that entire teams were trained to the same level, or 'on the same page.' Significant challenges in the re-engineering of systems, addressing integration issues, and meeting customer expectations were also identified. Similarly, training, although widely available, heavily promoted, and highly sought after, posed several challenges to the interviewees. Namely, the vast scope and complexity of material and the pace of change were identified. In all three case companies, new software and new hardware (i.e., manufacturing machines, production lines, and associated equipment) have been implemented, necessitating learning entirely new complex systems. Sustaining the rate of change was described as fatiguing, and there was a shared hope among four of the interviewees that the pace would slow as the systems delivered on their promise.

It is worth noting that several observations were made among the interviewees that were neither positive nor negative, but were common characteristics of their experiences. These include:

- Tasks have changed;
- There is a need for continuous learning; and
- Industry 4.0 adoption has led to significant organizational change.

While these observations are not considered demi-regularities, they constitute a shared acknowledgment that Industry 4.0 is revolutionary in that it constitutes a revised approach to manufacturing, encompassing efforts to "make use of the latest technological inventions and innovations, particularly in merging operational and information and communication technology" (Gilchrist, 2016, p. 186). As a manufacturing philosophy it changes individual employee tasks, disrupts existing organizational structures and processes, and necessitates continuous learning.

f. Structure and Agency

Critical realism not only recognizes the causal significance of social structures, but also regards human agency as causally significant. Human agents are entities with emergent properties, and critical realism suggests that both individual agency and social structure can have causal power. The concept of multiple determination of events by multiple interacting causes "allows us to say that events are not determined by any single force, be it structural or agential but rather by the interaction of both structural and agential powers (and indeed the causal powers of non-social objects)" (Elder-Vass, 2010, p. 5). According to Archer (1995) the *morphogenetic cycle* allows for a greater understanding of both social reproduction and social transformation: Individuals, aware of at least some of the social structures they interact with, take actions that contribute to either reproducing or transforming those structures, which then provide either an unchanged, or new set of constraints and opportunities to be considered.

The recognition in critical realism of the causal significance of both structural and agential forces is important in the retroductive analysis of the qualitative interview data. Critical realism acknowledges the analytical dualism of structures and agency (Bhaskar, 1989).

g. Retroductive Theorizing

Retroduction is the logic of inference-making espoused by critical realism (Downward et al., 2007). According to Sayer (1992) retroduction is the "mode of inference in which events are explained by postulating mechanisms which are capable of producing them" (p. 107). Retroduction differs from other forms of logical inference such as induction, deduction and abduction in that it describes an overarching logical method that incorporates all three for its full performance (Chiasson, 2001).

Induction involves projecting from what one knows to what one doesn't know, and it begins with a specific observation. Inductive reasoning seeks to make broad generalizations and predictions from specific observations. Deductive reasoning involves moving from the general (theory) to the specific (observations). Abduction begins with an incomplete set of observations and the researcher suggests the most likely explanation for the set (Mukumbang, 2023). By interpreting and re-contextualizing observed actions and events, the researcher attempts to formulate the best explanation for the set of observations. According to Dobson et al. (2012) there are four types of abduction, each of which is useful at different stages of a critical realist retroductive analysis: over-coded, under-coded, creative, and meta-abduction. Retroduction is an empirical process of devising a theory and requires moving from an observation—an inference made by an observer in response to, or ideas about, an event—of concrete phenomena to reconstruct the basic conditions for a deeper causal understanding (Mukumbang, 2023). It is the application of inventive thinking employed systematically to imagine the existence of mechanisms with abductive conclusions underpinning retroductive inferences.

There are three stages to retroductive theorizing: (1) emergent/theory gleaning; (2) construction/refining; and (3) retrodiction.

1. Emergent/Theory Gleaning Phase

The first phase of retroductive theorizing utilizes over-coded abduction to identify underlying mechanisms, structures and agents, and conditions (i.e., social, political, and environmental) informing the demi-regularities. Over-coded abduction involves generating a hypothesis that explains more than what is observed, which will then be parsed down through a comparative process informed by judgmental rationality.

The structural and agential entities that comprise reality generate and interact with emergent causal powers (mechanisms), which have observable effects (empirical events). Mechanisms may or may not be observable, and have the potential to generate phenomena, whether they are exercised or not. Individual perceptions of empirical events (those that can be observed or experienced) are used to help identify the mechanisms that give rise to those events. Events are triggered by mechanisms acting within physical constraints and social circumstances.

The three companies that were examined operate in highly complex open systems, each influenced by distinct conditions. Following an over-coded abduction, an interpretation is made about possible underlying mechanisms, relevant structures, and circumstances that cause the observed events or phenomena.

The specific references to the seven demi-regularities from the interview transcripts were examined systematically: (1) the observable events and phenomena described in the references were identified; (2) the entities that were involved and interacted were identified; (3) emergent causal powers (mechanisms) that generated those events were identified; (4) a prediction about the structures (the unobservable, underlying features of the social world that shape and constrain mechanisms and entities) was made; (5) the theoretical foundations that inform those structures were identified; and (6) the unique conditions affecting each specific company or case were identified. The outcomes of the abduction can be found in Appendix F.

2. Construction/Refining Phase

Since the abduction process offers the possibility for multiple potential explanations of events, the researcher must adjudicate between rival theories—a process known as judgmental rationality (Bhaskar, 2009)—by evaluating and comparing explanatory value, and ultimately selecting those which best represent the 'real' domain. Greater explanatory power requires "having greater (but not final) epistemic credibility…and a greater ability to integrate knowledge" (Isaksen, 2016, p. 245). According to Bhaskar (2009) the application of the process of under-coded abduction, that is, the generation of the simplest and most minimalistic explanation for the observed events, allows for a comparison between competing theories for explanatory value (the theory that can explain more phenomena is preferable). The selected theory should be able to explain a deeper level of reality (the 'real' domain), or achieve a greater order of epistemic integration (Bhaskar, 2009). Since the ultimate goal of retroduction is to identify the necessary contextual conditions for causal mechanisms to take effect, or afford the observed outcomes, the construction/refining phase needs to consider the different cases separately as the application of theory will differ based on those contextual conditions.

i. Industry 4.0 technologies enhance output, and output potential.

a. Company X

An examination of the retroductive analysis reveals that the enhanced output, and enhanced output potential resulting from the investment in Industry 4.0 technologies in Company X was driven by (1) the highly regulated nature of the aerospace industry; and (2) the cost-competitive nature of that industry. The most significant causal mechanisms are a (1) focus on process optimization, and (2) an investment in advanced engineering software.

The contextual, or macro-social conditions that enable the causal mechanisms to take effect are, predominantly, the highly regulated nature, and highly cost-competitive nature of the aerospace industry. According to Tomic et al. (2012) "perhaps no other industry is as obsessively safety-conscious as the Aerospace industry…[it is] constantly under public examination, and with little margin for error, strict quality control standards are now considered standard in every aspect of the industry" (p. 11). The implementation and adherence by aerospace manufacturers to AS9100 standards in order to comply with internal, government, and regulatory standards focuses on quality, safety, and the use of technology (Tomic et al., 2012). Importantly, the standards addressing design and development activities ensure that quality controls are in place for designs, and that input data is maintained and properly detailed. This ensures that designs can be validated and tested. Additionally, manufacturers must demonstrate the integrity of the tools and machines they use and develop a process that will ensure adequate oversight of the entire manufacturing process (Tomic et al., 2012). The strict adherence to regulatory requirements informs the impetus to invest in efficient, effective technologies in order to do so, efficiently and effectively. Coupled with the reality that the aerospace industry is a highly competitive global industry in which technologies and innovations are sought to reduce costs (Altiparmak et al., 2021), Company X's focus on process optimization and investment in advanced design software are eminently reasonable. As causal mechanisms can be interpreted as *affordances*—action possibilities that link structures and events—the focus on process optimization affords increased output potential of the manufacturing activities, while the investment in, and use of advanced design software affords increased iterative capacity, improved models and designs, and more robust scenario analysis. The outcomes, or events, identified in the interview process include increased output, increased delivery speed to customers of high quality component, and improved computer models. The focus on optimizing the manufacturing process resulted in the use of real-time monitoring, improved maintenance scheduling, and less equipment downtime.

The relationship between the events described during the interview process, the structures that characterize the aerospace industry, and the causal mechanisms can be described by the Theory of Constraints (TOC). TOC can be summarized as a logical and pragmatic approach to assessing systems, one that emphasizes ongoing improvements and growth. It is characterized by five focusing steps: (1) identifying a systems constraint; (2) deciding how to exploit the system's constraint; (3) subordinating everything else to the above decisions; (4) elevating the system's constraint; and (5) not allowing inertia to become the system's constraint (Moore et al., 1998). Within the context of Company X, the two critical structural constraints of industry regulations and cost inform the organization's focus. First, the unique regulatory environment of aerospace manufacturing serves as a constraint, one which limits the organization's performance and throughput. Component design, material selection, equipment selection, manufacturing flow, quality control, and output are all aligned to support and accommodate the strict regulations and requirements imposed upon the company. Second, the cost-competitive nature of the industry is the other critical structural constraint. The focus on reducing costs of production and providing cost-competitive components to customers informed the focus on process optimization and investment in software. Coupled with a formal lean program that focuses relentlessly on the reduction of waste in the system, increasing uptime, and driving manufacturing efficiency, Company X increased both its output and output potential.

For Company X, the dual structures of regulations and cost competitiveness in the *real* domain generate and interact with the causal mechanisms of process optimization and investment in advanced software to give rise to *empirically* described real-time monitoring, reduced equipment downtime, improved computer modelling, and importantly, increased manufacturing output.

b. Company Y

The retroductive analysis exploring the increased output, and enhanced output potential in Company Y was driven by high customer demand, fundamentally structured as an economic imperative. The demand for machining equipment is strong, both in Canada and globally, valued at 354.92 Billion USD in 2022, and expected to grow at 6.5% during the period from 2023 to 2032 ("Machining market report", 2023). This strong demand for Industry 4.0-enabled (IoT compatible) machining equipment generates and interacts with two principle causal mechanisms: (1) investment in advanced software; and (2) a strategic focus on increasing manufacturing output. These mechanisms result in increased productivity and increased output.

The affordance of software investment and a focus on increasing output leading to increased productivity and, ultimately, output, can be conceptualized by the concept of Lean Manufacturing. Although the concept seems self-evident, increased demand for manufactured products, regardless of the source of that demand—whether the result of sales actions or not—

does not mean that companies can simply respond by increasing output to match. The application of lean manufacturing principles, as Company Y does with its formal program and strategy, is instrumental in reducing waste and improving process efficiency. The investment in Industry 4.0 technologies, in concert with a robust lean methodology enabled Company Y to realize output increases. Various examples in the literature support the notion that the application of lean manufacturing principles improves productivity in manufacturing applications (Das et al., 2014).

The empirically reported increases in task productivity and output can be attributed to Company Y's established lean manufacturing methodology interacting with the causal mechanisms of investment in advanced software and a strategic goal of increasing output to meet an increased demand. The existence of a formal lean manufacturing program, structurally, interacts with Industry 4.0 technologies to drive increased productivity and output.

c. Company Z

Company Z reported (1) improved monitoring; (2) improved productivity per capita; (3) increased output; (4) increased manufacturing capacity; and (5) the dissemination and embracing of a continuous improvement mindset as a result of their adoption of Industry 4.0 technologies in their manufacturing process. These empirical events were driven by two prominent causal mechanisms: (1) the application of a continuous improvement methodology; and (2) investing in technology to enable customization and increased throughput.

Examining the conditions that enabled these mechanisms to afford Company Z the various improvements and increased output suggests that the structural entities that interacted with the identified causal powers are (1) a growing market (and growing demand for Company Z's products); and (2) the cultural beliefs shared among those in the organization. Specifically, the shared beliefs that growth is beneficial, that manufacturing capacity can be a strategic advantage, and that efficiency can be achieved through investment in automation. It is worth noting that Company Z does not have a formal lean manufacturing program in place, meaning that the application of a continuous improvement methodology in its manufacturing was *ad hoc*, and limited just to that process.

It is useful to consider the relationships between structural entities, causal mechanisms, and empirical events within the context of Resource Dependence Theory. Like the Theory of Constraints (TOC) which aligns processes to address constraints, Resource Dependence Theory focuses on the adaptations of organizations to the contexts that confront them, but are not solely confined to changes in internal structure. Resource Dependence Theory suggests that Company Z, in aggressively seeking market share and investing heavily in new manufacturing capacity and automation, have defined those goals as 'strategic contingencies' (McKinley et al., 2003) and configured the company's operations to meet those goals. In doing so, Company Z increased its manufacturing output and capacity for future production.

For Company Z, the market conditions, specifically, the growth potential in their market segment and rising demand for products from customers, coupled with the cultural beliefs shared among those in the organization afforded the causal mechanisms of an investment in technology and an application of a continuous improvement methodology to drive the empirical events of increased output, and adoption of a continuous improvement mindset amongst the employees.

ii. ***Work was reported to be fulfilling, either personally or professionally.***

An examination of the retroductive analysis of individual fulfilment, either personally or professionally, reported by those who use and interact with Industry 4.0 technologies revealed that the two most significant causal mechanisms are (1) alignment of personal values with organizational values; and (2) the provision of autonomy and decision-making power. These two causal mechanisms appear to transcend Company X, Company Y, and Company Z.

All nine of the interviewees reported that they found their work in an Industry 4.0 enabled workplace to be fulfilling. Whether it was the challenge of working with new technologies, satisfaction in meeting customer expectations, or experiencing the reward in overcoming organizational changes, work was fulfilling. Within this context, the emergence of a sense of fulfilment can be examined through Self-Determination Theory. Self-Determination Theory suggest that individuals have three basic psychological needs: autonomy, competence, and relatedness. Autonomy refers to "the desire to self-organize experience and behavior and to have activity concordant with one's integrated sense of self" (Deci et al., 2000, p. 231). Competence is linked to the necessity of having "an effect on the environment as well as to attain valued outcomes within it" (Deci et al., 2000, p. 231). Relatedness can be described as the "desire to fell connected to others—to love and care, and to be loved and cared for" (Deci et al, 2000, p. 231). Self-Determination Theory suggests that as long as employees feel a sense of autonomy, competence, and being related to others, then their behavior will be intrinsically motivated. According to Vui-Lee et al. (2018) ensuring job characteristics align with employees' values or expectations results in work fulfilment, and that employees are keen to remain with a company if they find their job enriching. Well-designed jobs, clearly defined tasks, roles and responsibilities that are coupled with the values and interests that suit employees contributes to fulfilment and ultimately, employee retention.

The macro-social structure, or contextual conditions that enable the two causal mechanisms to take effect is the acknowledgment that "human operators will be a central part of [Industry 4.0] production systems, due to their cognitive abilities such as coordination, supervision and decision-making" (Rauch et al., 2020, p. 13), and as such, ensuring that jobs are well-designed, and that they are aligned with the interests and values of employees. The outcomes reported by the interviewees indicate that advanced technologies are deployed in such a way that employees derive intrinsic rewards and satisfaction from its use in their daily tasks, since companies are increasingly focused on addressing employee engagement and well-being (Salas-Vallina et al., 2020). The interaction between an employee-centric focus in the real domain and the alignment of values and emphasis on autonomy result in a feeling of fulfilment in the empirical domain.

iii. Employees are encouraged to take advantage of training and development opportunities.

a. Company X

An examination of the third demi-regularity for Company X reveals that there is a shared recognition that training and development initiatives are encouraged for employees. Moreover, there is an acknowledgment that training, a necessity in an Industry 4.0 organization, takes a considerable amount of time. The employee survey findings, an empirical measure, was driven by (1) the company's desire to expand into new international markets; and (2) the highly regulated industry that the company operates in. The likely causal mechanisms interacting with the real domain are (1) the extensive training provided to employees in order to satisfy regulatory compliance; and (2) the improved skills of those employees.

The dual conditions that exist in the real domain—Company X's focus on growth in new international markets for its manufactured products and the highly regulated nature of the aerospace industry—interact with the provision of training, and the resulting improved skills of employees to drive the empirical responses from the interviewees. According to van der Heiden et al. (2015) learning is inextricably related to working, and learning is therefore intrinsically embedded in ongoing work activities. Van der Heiden et al. (2015) argue that "professionals have to engage in continuous learning to apply existing knowledge to routine or innovation and to conceive of new knowledge in anticipation of a changing workplace situation" (p. 49). For Company X, manufacturing growth represented a changing workplace situation where Industry 4.0 technologies and equipment were deployed in order to meet customer demands in multiple international markets where new materials and new designs were required, and costs were prioritized. Adapting new technologies and methods such as 3D printing and machine learning required significant investment in training. According to van der Heiden et al. (2015) "the contours of transformative changes in aerospace engineering, education and learning are conspicuously emerging on the horizon…[and there is] need of a holistic approach towards aerospace education and training because of the rapid development and challenges of leading-edge technologies such as cloud and petascale/exascale computing, intelligent autonomous robotics, artificial intelligence, Big Data, virtual and augmented/enhanced reality and the blurring and widening of (inter-) disciplinary boundaries" (p. 50). The successful integration and optimization of Industry 4.0 technologies required cross-disciplinary collaboration where managers, engineers and operators needed to be sufficiently trained to safely operate equipment while being able to offer cost-effective, innovative designs for customers. Importantly, regulatory compliance necessitates learning in the industry as manufacturing specifications are strict, tolerances are very tight, and quality assurance and inspection protocols need to be well understood.

The skills acquired by the team at Company X, existing in the domain of the *actual*, act as a causal mechanism since employees are engaged in continuous improvement, continuous innovation with ever-newer equipment, and are tasked with developing the training materials, and participating in the training for their colleagues. Being engaged in continuous learning activities, a pillar of lean manufacturing methodology, affords employees ever-greater understanding of innovative technologies, methods, and processes and building valuable skills in the process. According to Chuang (2021) constructivist learning theory people construct knowledge from activities and reflections rather than passively absorb information. The theory emphasizes naturally cumulative learning in individuals by creating personal meaning through experiential learning, which focuses on hands-on and active learning events to enhance learners' engagement and learning retention. Constructivist learning motivates learners by giving them control on learning content, strategies and activities (Chuang, 2021). Company X relies on multiple modalities to engage employees, whether it's hands-on learning with the equipment, instructor-led demonstrations, self-directed learning and experimentation (i.e., design and testing software) to enhance learners' cognitive involvement and support positive learning outcomes. This allows employees to both learn about, and learn through, Industry 4.0 technologies, forming a self-reinforcing cycle.

For Company X, the dual structures of regulations and a growth strategy in the *real* domain generate and interact with the causal mechanisms of extensive training and skills development to give rise to *empirically* described extensive time spent training, culturally engrained continuous learning, and co-creation of training.

b. Company Y

Similar to Company X, Company Y's encouragement of its employees to take advantage of training and development opportunities stems from two related structural forces in the real domain: (1) the rapid changes required in equipment design; and (2) high customer demand for that equipment. The adoption of Industry 4.0 technologies by machining and manufacturing companies globally has led to an increased demand for machines that integrate into a DT-based CPS (Digital-Twin-based Cyber-Physical System) that constantly acquires, integrates, analyzes, simulates, and synchronizes data "across multiple stages of the product life cycle to provide on-demand predictive services to different users in both physical and cyber spaces" (Lee et al., 2020, p. 34). New CNC machines realize self-maintainability, self-configurability, and predictive services. Understanding these functionalities, their integration, and their implications requires significant investment and dedication to training. Considering Company Y designs and builds CNC machines, maintaining the level of knowledge and skill of their engineers and technical staff necessitates a high level of investment in developing their skills and knowledge. The high level of demand reported by the company suggests that a high level of knowledge about efficient manufacturing, cost control, and maintaining high levels of predictable output is also necessary.

With respect to the structural forces operating in the real domain, the extensive training required acts as a causal mechanism, affording operators the ability to develop the knowledge and skills required to innovate. The confirmatory feedback from the employees serves as the empirical outcome. According to the Oslo Manual published by OECD innovation is the "implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (Sartori et al., 2013, p. 2). Sung et al. (2014) suggest that training and development investments of an organization affect its innovative performance by promoting several learning practices. Comprehending the elements, factors and dimensions that facilitate innovation necessitates understanding the current state of the technology, industry trends, and the social processes (i.e., effective team cooperation and collaborative knowledge creation) that support it (Shipton et al., 2006).

The link between organizational training and innovation can be understood in terms of Organizational Learning Theory. Creating an environment that fosters a culture of innovation, such as that required by Company Y to effectively design and manufacture advanced machining equipment, is a dynamic process based on knowledge. It is "translated through the various levels of action, from the individual level to the group and organizational level, retaking the initial process" (Antunes, 2020, p. 143). Considering the internal environment of a company, learning is one of the main internal processes within organizations, contributing to mediate the relationship between dynamic capabilities and performance of the company (Antunes, 2020). Company Y's commitment to ongoing training—a tenant of a formal lean manufacturing program—helps foster an environment in which employees are able to experiment, learn from failures, and share insights, all of which contribute to generating innovative ideas and practices. According to Edmondson et al. (1998) organizations committed to individual learning and development "create a tension that elicits personal development by employees, and this individual learning contributes to a process of continual transformation of the organization" (p. 25). Increased knowledge and understanding of technologies contributes to the unplanned, ongoing adjustment and improvisation activities of organizational actors, helping drive process improvement, innovation, and organizational improvement.

For Company Y, the dual structures of necessary change in equipment design and rising demand in the *real* domain generate and interact with the causal mechanism of investment in training to give rise to *empirically* described effective training on systems, equipment and procedures.

c. Company Z

Just as Company Y empirically reported positive empirical feedback regarding employee training, employees of Company Z reported that training on new systems and new technologies was ongoing, was constantly updated, and took a considerable amount of time. The structural force in the real domain, a growth strategy focused on increasing the sales of manufactured products interacts with the investment in training, which serves as a causal mechanism.

Unlike Companies X and Y that have a formal lean manufacturing program in place, Company Z's training and development were implemented *ad hoc*, implemented as a result of the investment in, and use of advanced technology, but not prior to. While empirically all three employees of Company Z reported similar experiences and affirmed that training and development is indeed encouraged and they take advantage of the opportunities, it is unclear whether the difference in structure, support, and post-training activities will impact effectiveness from an organizational perspective. The shared causal mechanism does appear to afford employees similar empirical outcomes when interacting with similar structural forces.

The affordance granted by the causal mechanism, investment in training, can be considered within the context of Organizational Learning Theory. The training provided to individuals, whether they are managers or operators, provides practical knowledge. In order to turn this knowledge into values which can benefit the company, it must be transformed. This transformation, according to Jensen (2005), is an important task for management: coordinating the knowledge individuals possess and guiding the process of sharing information among individuals. The transformation processes also take place as "people continuously find ways to get around problems and solve difficulties when they are working and communicating while doing their jobs…[and] through this process they learn to do their jobs better" (Jensen, 2005, p. 61). Organizational Learning Theory suggests that by systematically structuring the organization to utilize knowledge, in part by ensuring that "work is organized in such a way that learning takes place as a natural and necessary activity" (Jensen, 2005, p. 62), both organizations and employees benefit from extensive training initiatives.

According to Pfeiffer (2015), besides the qualification requirements that arise in direct connection with the technical phenomena of change in Industry 4.0-enabled organizations, certain "transversal competency requirements play an ever more important role in an increasingly digitalized world of work" (p. 40). These competencies include the ability to work as a team, a capacity for inter- and trans-disciplinary collaboration, the capacity to link the material and the abstract, knowledge about the limitations of algorithms and the risks to data security, the capacity to think systematically and confidently in conditions of uncertainty, and the creative development of novel ideas (Pfeiffer, 2015). The implementation of new technologies to meet external requirements and demands requires training that addresses the competencies required by Industry 4.0 applications.

For Company Z the overall growth strategy, operating in the real domain, necessitated an investment in training and skill development in the actual domain. The employee feedback regarding the extent of the training and its effectiveness in meeting the demand for manufactured goods reflects the empirical experience.

iv. Industry 4.0 technologies facilitate a more accessible workplace.

An examination of the initial retroductive analysis reveals that all three companies agree that Industry 4.0 technologies facilitate a more accessible workplace. All three companies face a similar structural force in the real domain: a social awareness of the need to accommodate employees and provide accessible workplaces. Industry 4.0 technologies, specifically those related to remote and real-time monitoring, and telecommunications enable employees to connect to company systems, their teams, and their managers in a variety of settings. This emphasis on accessibility represents "an important strategy to address the challenges that can impact sustained and productive employment" (Jetha et al., 2021, p. 155). Enabling accessible workplaces encourages labor market engagement through scheduling flexibility, modified job duties and opportunities to informally modify work. According to Jetha et al. (2021) workers report personal responsibilities (i.e., child and eldercare responsibilities), health-related demands (i.e., attending healthcare appointments), and workplace factors (i.e., interpersonal conflict) that can interrupt employment engagement. The deployment of advanced technologies can help bridge these gaps in workplace accessibility.

The structural force in the real domain led to the implementation of both advanced technologies and the organizational systems to support them in the actual domain. The positive employee feedback confirming that workplaces have indeed become more accessible exists in the empirical domain.

The relationship between a broad social change and organizational use of technology to achieve positive accessibility outcomes can be conceptualized through the Social Model of Disability. The social model of disability conceptualizes disability as a phenomenon emerging from the interaction between a person and their environment. Disability is dynamic and external, emerging from situations and environments that contribute to a process of enablement or disablement (Newman-Griffis et al., 2022). The social model requires measuring and understanding an employee's capacities and needs (physical, cognitive and otherwise) with respect to functioning in different activities and roles, as well as the facilitators and barriers to that functioning in a given environment. The application of advanced technologies contributes to the process of enablement.

By designing technological solutions and adopting supportive norms and processes, organizations are able to support a diverse workforce and address a broad range of work limitations. Of course, organizations need to carefully consider how technologies are implemented, organizational norms around its use, and address employee perceptions of its effect on their role, paying close attention to a variety of factors beyond productivity, including mental health outcomes.

Responses from seven of the interviewees supported the notion that Industry 4.0 technologies positively contribute to a more accessible workplace. The interaction between technology, a casual mechanism, and a broad social focus on reducing barriers in employment informed the empirical outcomes.

v. The outlook for the organization implementing Industry 4.0 is positive.

The initial retroductive analysis revealed that interviewees in all three companies share a positive outlook for the future of their organizations within the context of Industry 4.0

adoption. In the real domain all three companies were experiencing opportunities for growth, and all seized upon them, investing in Industry 4.0 technologies to realize their growth potential. The increased alignment towards growth, and the implementation of technology to support it functioned as the causal mechanism. Empirically, the optimistic outlook shared by all interviewees for the future of their respective organizations was the outcome.

The relationship between organizational growth and positive employee outlook can be conceptualized by Expectancy Theory. Expectancy Theory suggests that individuals are motivated to act in a certain way when they believe their efforts will lead to desired outcomes. In the context of organizational growth, positive employee outlook may be derived from the expectation that the organization’s growth will result in better opportunities, job security, career advancement, or other rewards. According to Mathibe (2008) if managers understand where the organization wants to go and they develop adequate communication networks and channels for the dissemination of organizational vision, values, mandates and goals, they are able to sufficiently mobilize employees’ energy and enthusiasm. Moreover, Mathibe (2008) points out that employees that are skilled and well-trained for their jobs tend to be more resilient and generally have a more optimistic view of change. The use of incentives and extrinsic rewards help enhance motivation, as does a robust program for the recognition of performance (p. 13).

The alignment towards growth and the implementation of technology to support that alignment—real-time productivity monitoring, KPI reporting, automation and employee training—facilitates a link between employee efforts and the perception of organizational growth and the achievement of objectives. Technologies assist managers in communicating organization vision and goals, and improves reporting capability. Aligning individual performance with organizational performance contributes to positive motivation and a positive outlook for the future.

The empirical feedback supports the notion that Industry 4.0 technologies contribute, at least in part, to a positive perception of the future of the three organizations studied. The interplay of the pursuit of sales growth and the use of technology to align employees with the associated organizational objectives contributes to a positive outlook for the future.

vi. *There is a shared perception that Industry 4.0 contributes meaningfully to a safe workplace*.

All interviewees in all three companies, X, Y, and Z share the notion that Industry 4.0 contributes meaningfully to a safe workplace. All three companies share a common structural force in the real domain: a recognition of the importance of employee safety and well-being. Canadian workplaces, like those in the United States have made significant progress in addressing issues of health in safety since the 1970’s. During the past decades major safety improvements have been made through the widespread implementation of risk assessments, medical surveillance examinations, safety training, improved protective equipment, better mechanical safety engineering, as well as a host of other factors (Loeppke et al., 2015). The adoption of safety culture became ingrained in organizational culture and in organizational processes, which continues in contemporary organizations. It is useful to conceptualize safety culture as “those aspects of the organizational culture which will impact attitudes and behaviour related to increasing or decreasing risk” (Digmayer eet al., 2019, p. 2) what manifests in basic assumptions about the nature of reality, espoused values and attitudes, and artifacts, or observable behavior. The implementation of Industry 4.0 principles and technologies presupposes efficient communication (Digmayer et al., 2019), informed by both the technologies themselves and the digital communication skills of employees. Communication enables the sharing of basic assumptions, values, attitudes, and behaviors. In the context of Industry 4.0, the communication of risks, development of safety and security standards, terminology, documentation and training help create and reinforce a safety culture adapted to an advanced manufacturing organization.

The implementation of Industry 4.0 technologies in the actual domain, notably those that assist with efficient communication, interact with the prioritization of safety culture in the real domain, serving as a causal mechanism in all three companies studied. The implementation of other technologies for safety management purposes, such as IoT devices that monitor the environment, monitor employee vital signs for fatigue and stress, and risk monitoring systems help keep employees safe. The objective of ensuring employees are safe at work informs technology choice and guides application (Forcina et al., 2021).

The relationship between Industry 4.0 technologies and positive safety outcomes in the workplace can be considered within the context of Safety Culture Theory. Safety Culture Theory highlights the role of organizational culture in shaping safety-related behaviors and attitudes. Technology can contribute to a positive safety culture by providing tools for reporting hazards, tracking safety metrics, and promoting open communication (Reason, 1998). When technology supports a culture of safety, employees are more likely to engage in safe practices. According to Digmayer et al. (2019) occupational safety in Industry 4.0 organizations is embedded in a complex conditional structure of socio-technical systems, where employees share a common understanding of the importance of safety, management functions as a role model, and the self-perception of employees aligns with the established safety culture. The provision of advanced tools combined with a robust safety culture results in positive safety outcomes. The empirical feedback provided by the interviewees confirms positive outcomes and a shared perception that Industry 4.0 technologies contribute positively to a safe workplace.

vii. Industry 4.0 facilitates a positive and constructive relationship between co-workers.

The retroductive analysis suggests that the interviewees in all three companies shared the belief that Industry 4.0 contributed to a positive and constructive relationship between coworkers. Empirical feedback highlighted the collaborative nature of work in an Industry 4.0 environment, both within teams, and across different departments or functions. The collaborative interactions characteristic of the organizations studied reflect those of learning organizations: High levels of trust, open communication, a high level of engagement, the existence of challenges, competition and a creative atmosphere promote learning and enable knowledge to be shared (Stachová et al., 2019).

The shared recognition of the value of collaborative teams acts as a structural force in the real domain. The interaction with Industry 4.0 technologies, specifically those that enable effective and efficient communication, combined with organizational structures that facilitate collaborative work function as a causal mechanism, affording the empirical outcomes specified. The three organizations studied share a common structural influence—the value of teamwork and collaboration in the workplace—which is the number one global workforce trend (Lacerenza et al., 2018). Organizations, globally, are implementing networks of teams where projects are assigned to groups of individuals who work interdependently, employ high levels of empowerment, communicate freely, and either disband following project completion, or continue collaborating. Effective teamwork allows teams to produce outcomes greater than the sum of individual members' contributions (Stagl et al., 2006) and is driven by teamwork processes and emergent states, requiring both taskwork and teamwork competencies.

The interaction between the rise of collaborative work and technology can be considered within the context of Social Learning Theory. Social Learning Theory emphasizes how individuals learn from observing others and through social interactions (McLeod, 2011). Technology-supported teamwork provides opportunities for employees to learn from their colleagues, share knowledge, and collaborate on tasks. This theory highlights how technology can facilitate knowledge transfer and skill development among team members. Organizations rely on teams to develop the skills and knowledge necessary to use and leverage Industry 4.0 technologies, while simultaneously relying on the technology to assist teams and reinforce collaborative behaviors.

The interaction of collaborative values and teamwork in the real domain with technologies and organizational values in the actual domain result in the empirical outcomes that confirm the positive, collaborative relationships between employees.

3. Retrodiction Phase

Retrodiction is the systematic comparison of explanations obtained from different cases toward a more refined theory. In multi-case studies like this dissertation when demi-regularities and contrastives are explored for their causal mechanisms, a cross-case analysis should be done (Mukumbang, 2023). By searching for variations in the context accounting for the differences between cases, retrodiction aims to generalize across cases by examining how important outcomes were achieved. According to Yeung (1997) retrodiction should be focused on synchronizing the mechanisms that account for the emergence of the phenomena operating at the real domain, based on best explanation obtained from the different contexts within the individual case studies.

Table 23.

Demi-Regularities

Demi-Regularity (Event)		**Mechanism(s) - ACTUAL**	**Structure(s) - REAL**	**Theoretical Foundation**
Industry 4.0 technologies enhance output, and output potential (+ Increased Output)	X	(1) Focus on process optimization; (2) investment in advanced engineering software	(1) Highly regulated industry; (2) Cost-competitive nature of the industry	Theory of Constraints
	Y	(1) Investment in software; (2) Strategic focus on output	Strong customer demand	Lean Manufacturing Theory
	Z	(1) Application of CI methodology; (2) Investment in production technology	(1) Strong customer demand; (2) shared cultural beliefs	Resource Dependence Theory
Work was reported to be fulfilling, either personally, or professionally (+ Fulfilling)	X Y Z	(1) Alignment of personal values and organizational values; (2) Provision of autonomy and	Integration of humans into production systems	Self-Determination Theory

		decision-making power		
Employees are encouraged to take advantage of training and development opportunities (+ Training is Encouraged)	X	(1) Extensive training provided to employees; (2) Improved employee skill	(1) Focus on growth; (2) Highly regulated industry	Constructivist Learning Theory
	Y	Extensive employee training	(1) Rapid changes in customer design requirements; (2) Strong customer demand	Organizational Learning Theory
	Z	Extensive employee training	Focus on growth	Organizational Learning Theory
Industry 4.0 technologies facilitate a more accessible workplace (+ Accessibility)	X Y Z	Advanced technologies and organizational systems	Social awareness of accommodation and flexible workplaces	Social Model of Disability
The outlook for the organization implementing Industry 4.0 is positive	X Y Z	(1) Implementation of technology; (2) Organizational alignment to growth objective	Market opportunity for sales growth	Expectancy Theory
There is a shared perception that Industry 4.0 contributes meaningfully to a safe workplace (+ Improves Safety)	X Y Z	Implementation of technology	Recognition of the importance of safety and employee well-being	Safety Culture Theory
Industry 4.0 facilitates a positive and constructive	X Y	Implementation of technology		Social Learning Theory

relationship between coworkers	Z		Recognition of the value of collaboration	

The retrodictive phase of the analysis revealed several generalizable insights.

The complete retroductive analysis can be found in Appendix F. The analysis was captured in a Microsoft Excel table, where the demi-regularity is specified, and all of the specific references from the nine interviews are attributed to it. The Underlying structures, generative mechanisms, interacting entities, and empirical events that inform that reference are detailed. As well, the company-specific context and/or social conditions and theoretical foundations are noted.

For example, regarding the demi-regulatory 'Industry 4.0 technologies enhance output, and output potential, a comparison between the responses of two participants, P3 and P4, allows for an exploration of interacting entities, mechanisms, structures, and observed events (Figure 5).

Figure 5.
Retroductive Analysis Example

Participant	References
P3	From my perspective, yes. Collaborative software and advanced software used in design and testing have made us more productive. The technology that we use in manufacturing has made us far more efficient, safer, and more productive.
P4	Absolutely, one hundred percent. The amount that we can do in a day is dramatic. The technology is great at driving productivity.

Participant	Event(s)	Interacting Entities
P3	Increased productivity	Software; Computer Hardware; individuals; economic factors; communication between groups
P4	Increased output and task productivity (faster and more effective task execution)	Individuals; technology

Participant	Mechanism(s)	Structure(s)
P3	Investment in advanced software	Economic systems (focus on ROI); Technological infrastructure; organizational norms
P4	Focus on outputs	Economic systems (focus on ROI); Technological infrastructure; organizational norms

Participant	Theoretical Foundation	Context (Circumstances)/ Social Conditions
P3	Theory of Constraints (TOC); Lean; Total Quality Management (TQM); Continuous Flow	Company manufactures machining equipment, often integrating their own designs and equipment into the processes, giving it a unique ability to test integration.
P4	Economies of scale; Lean; TOC	Productivity is measured objectively by output (designs, iterations, tests, etc. completed; as well as parts machines and final assemblies completed)

Regarding the propensity of Industry 4.0 technologies to enhance manufacturing output, or output potential, all three companies studied share common causal mechanisms: (1) investment in advanced technologies; and (2) alignment of that technology and employees toward a common goal in a structured manner. The goals vary slightly in response to the environmental conditions and structural realities. While two companies (X and Y) have a formal lean manufacturing program in place, Company Z adopted several lean principles, including a systematic continuous improvement methodology to improve manufacturing processes and drive efficiency. According to Tortella et al. (2019) technological adoption by itself does not lead to improved organizational outcomes. Rather, lean manufacturing, or similarly structured practices help install organizational habits and mindsets that favor systemic process improvements: the "socio-technical organizational changes that coincide with LP [Lean Production] reinforce practices and behaviors which, when combined properly with today's technological advancements, enables companies to compete successfully under the, at first sight, paradoxical scenario where high-tech applications and human-based simplicity exist concurrently" (Tortella et al., 2019, p. 875).

The same two causal mechanisms afforded the shared positive outlook for the future. The implementation of Industry 4.0 technologies and alignment to a growth objective, even while varying slightly based on the company's specific manufactured output, aligns employee expectations with the organizational goals, and providing the tools to execute in an efficient and effective way.

The investment in various Industry 4.0 technologies—IoT sensors and tracking, integrated ERP systems, machine learning, advanced design software, and real-time monitoring—served as the causal mechanism affording safer workplaces and facilitating a positive and constructive relationship between co-workers. The implementation of technology, coupled with robust organizational systems, practices and policies also facilitate more accessible workplaces.

The alignment of employee values and organizational values, coupled with the provision of employee autonomy and decision-making power served as causal mechanisms for all three companies in facilitating employees' feelings of fulfilment.

Finally, the extensive investment of time and energy in providing training on the use of technology to employees facilitated the positive perceptions of training, and the willingness of employees to take advantage of it to develop their knowledge and skills.

The retrodiction process revealed a key insight that transcended the different case companies: that Industry 4.0 technology is, by itself, insufficient to drive improvements in either organizational or employee outcomes. Investment in technology must be coupled with specific organizational or employee-centric goals; organizational systems, processes, and procedures must be aligned with and support those goals; employee values must be aligned with organizational values, and employee development and training must be prioritized.

h. Data Saturation

According to Fusch & Ness (2015) data saturation in qualitative research is reached when there is enough information to replicate the study, when the ability to obtain additional new information and themes has been attained, and when further coding is no longer feasible. While Guest et al. (2006) note that data saturation may be obtained by as little as six interviews depending on the sample size of the population, saturation is dependent on the depth of the data. Bernard (2012) states that the number of interviews needed for a qualitative study to reach saturation cannot be quantified easily, but that researchers should, more or less, take what they can get. If interviews are semi-structured, in that multiple participants are asked the same questions, the researcher is able to establish goalposts, or a standard to which new information or themes can be assessed. In this way, it becomes readily apparent when no new themes emerge from the questions, and no new codes are required. Theoretical saturation, according to Lincoln et al. (1985) is the point at which the properties of categories and the relationships between categories are comprehensively explained, so that a theory can arise, drawing from grounded theory tradition. Since theoretical saturation is inextricable linked to the practice of theoretical sampling and concurrent practices of data collection and analysis in grounded theory (Hennink et al., 2017), saturation cannot be determined in advance of data collection, and at least some data analysis (Braun et al., 2019). With regard to the nine interviews conducted (three from each of the case companies), saturation was achieved at nine, as no new themes emerged from the semi-structured interviews, and no expansion to the coding of the transcripts was required. Each case company shared perspectives from management and non-management employees, with six of the nine interviews exploring the perspectives of front-line staff. The perspectives informed a sufficient depth of understanding of the impact Industry 4.0 had on the experience of work within the context of the case companies. Common themes were identified in the retroduction process, and there were no new or different ones that emerged following the conclusion of the nine interviews.

There is a direct link between data triangulation and data saturation: Denzin (2009) argues that triangulation, achieved via a mixed-methods approach, helps achieve saturation by ensuring that the data collected in the study is rich in depth. Triangulation allows for the extrapolation of meaning inherent in the data, first by identifying themes and patterns in the quantitative phase, then by exploring those themes in more depth in the qualitative phase. The combination of quantitative and qualitative approaches reduces the need to achieve a high quantity of responses in either, favoring depth and a richness of perspective instead. In the case the three case companies, X, Y and Z, the total combined number of employees was relatively small—less than n=120. Of the sixty (60) total combined employees that met the study criteria across the three companies, forty-seven (47) responded to the survey (a positive response rate of 78.3%). The high response rate was likely due to two factors: (1) the effective use of a gatekeeper approach to data collection, where the gatekeepers within the three companies distributed the surveys, provided time for completion, and followed up with respondents; and (2) the relatively small nature of the three companies studied meant the research study was highly visible, and broadly known about. The high response rate and the capture of so many perspectives within the case companies—close to 80% of all qualified employees—suggests that saturation was achieved as a function of widespread representation. The triangulation of the survey data with interview data allowed for a reflexive comparison between the two. The process of coding the qualitative data and identifying emergent themes reflected those themes that emerged from the quantitative data. The two types of data revealed consistent themes, and consistent outcomes. This use of mixed-methods triangulation, especially within the context of relatively small companies, helps achieve saturation. With such a high rate of response and the capture of such a high percentage of the target population, the sampling error is relatively low, and the probability of important themes remaining undetected or uncovered is also relatively low.

Data saturation is, as Braun et al. (2021) point out, nearly always a pragmatic activity, shaped and constrained by the time and resources available to the researcher. For this dissertation, the companies willing to participate in the research were relatively small, limiting the number of respondents. The quality and richness of the data generated from the participants was significant considering the extensive survey and semi-structured interview guide, capturing depth and breadth of perspective. This helped offset the smaller sample size and contributed meaningfully to achieving data saturation. With the achievement of both coding and thematic saturation, it is unclear whether any additional data, whether quantitative or qualitative, from a fourth case (as the majority of qualified respondents within the three case companies did respond) would offer any more meaningful insight, given the parameters of the dissertation, and the non-generalizable nature of a critical realist approach.

Chapter 5: Discussion

This section integrates the findings from the data analysis with the theoretical foundations established by the literature review to answer the research question. The section also explores how the adoption of a critical realist perspective provides new insights into Industry 4.0-enabled workplaces, and the implications for employees.

a. Examining the Hypotheses

The objective of this dissertation is to understand how employees within manufacturing organizations experience work in relation to stated claims about the implementation of Industry 4.0 technologies. These experiences are examined from a critical realist perspective to understand whether the subjective experience of work by employees within these organizations supports or disputes the stated claims, why that may be the case, and what the implications are.

Specifically, the research question posed was: *How do employees in organizations with a formal lean manufacturing program experience work in relation to the stated claims about the implementation of Industry 4.0 technologies for organizations?*

To answer the research question, the stated claims were explored in six hypotheses. Overall Employee Satisfaction (OES) serves as a composite index, representing employees' reported experience of work in an Industry 4.0-enabled workplace, where a higher OES score reflects more positive or affirmative answers to a higher number of survey questions. The extent to which each construct, or claim, contributes to the composite measure of workplace satisfaction reflects the extent to which the claims are supported within an Industry 4.0-enabled workplace.

H1: Employee Autonomy (EA) is a significant component of a composite index, Overall Employee Satisfaction (OES).

Employee Autonomy (EA) refers to the degree to which employees feel they have the freedom to adapt to changing circumstances and the freedom to solve problems in creative ways. Employees with a high level of autonomy enjoy independence and discretion in scheduling their work and determining the procedures and manner with which it is carried out. According to Naus et al. (2007) there exists a "large body of research showing that job autonomy is related to positive work outcomes and that it constitutes an effective buffer against negative impacts from the work situation" (p. 693), and that employees who have more job autonomy "show more positive affect, internal motivation , and self-confidence, more creativity, less mental strain, and satisfaction with different aspects of the work context, and less emotional dissonance compared with those who have little job autonomy" (p. 693). The adoption of Industry 4.0 technologies is claimed to provide workers the tools and the freedom to adapt and solve problems in creative ways (Hoey, 2018), supporting employee autonomy.

The quantitative analysis by confirmatory factor analysis (CFA) supports accepting the hypothesis that Employee Autonomy (EA) is a significant component of the composite index measure, Overall Employee Satisfaction (OES). This is significant because the respondents in Industry 4.0 enabled organizations affirm that they do indeed have autonomy, and that autonomy contributes positively to their subjective experience of work. An examination of the summary statistics of the survey responses (Figure 1) indicates a mean response of 0.751, the highest positive response rate of any of the five dimensions of Overall Employee Satisfaction (OES). Based on the quantitative analysis, it can be concluded that within the context of the three organizations studied, the claim that Industry 4.0 provides the tools and the freedom to adapt and solve problems in creative ways, or contribute to employee autonomy, is supported.

The qualitative analysis reveals that the adoption of advanced Industry 4.0 technologies informs work that is fulfilling, utilizes skills, and enhances autonomy. With respect to Company X, although the respondents reported that their daily tasks have changed, working with advanced technologies in the design and manufacture of aerospace components requires creativity, informs higher levels of autonomy, improves work-life balance, and utilizes employee skill. The employees of Company X provide several references confirming that working in an

Industry 4.0 environment is fulfilling, and that it is enjoyable working with technology. As individual employees who have more job autonomy show more positive affect and satisfaction with different aspects of the work context (Naus et al., 2007), fulfilment represents an important component of autonomy.

With respect to Company Y, the respondents too confirmed that their tasks had changed, and there was a need to learn new technologies and new systems. They reported that their skills were utilized, they found fulfilment in the work, and that they experienced mixed responses to the notion that Industry 4.0 informed enhanced autonomy. While all three respondents indicated that autonomy was enhanced in some circumstances, the manager in Company Y indicated that their autonomy remained static in another circumstance, while the non-management employees indicated that technology limited their autonomy since they were able to determine the pace of their work, but not the order of their tasks. The non-management employees provided several negative references, indicating that the changes associated with technology adoption were difficult to implement, and that training was often difficult due largely to the scope of it. On balance, while Industry 4.0 technologies generally led to increased autonomy, organizational hierarchies and job functions place structural constraints on the degree of autonomy, and it can be challenging for employees to become proficient with the tools necessary to facilitate flexibility and autonomy.

For Company Z, the respondents reported that working with Industry 4.0 technologies was fulfilling, but there was a significant amount of knowledge required to master the tools and technologies available. Job formalization and specific roles (i.e., management versus equipment operators) limited the decision latitude of the respondents. The management-level respondent confirmed that their level of autonomy was enhanced, while it remained static for the equipment operator. Similar concerns were raised by the operator regarding the challenges related to training and the amount of knowledge needed to fully understand and implement the technologies to realize an enhanced level of autonomy.

The degree to which employees feel that they have the freedom to adapt to changing circumstances and the freedom to solve problems in creative ways is informed by Industry 4.0

technologies. It is important that organizations consider roles, job functions, and the amount of knowledge and training necessary to leverage those technologies to achieve enhanced employee autonomy.

H2: Training Effectiveness (TE) is a significant component of a composite index, Overall Employee Satisfaction (OES).

Training Effectiveness (TE) refers to the degree to which employees feel their organizations' investment in training has allowed them to upgrade their skills, enabling them to manage automated processes and effectively complete 'creative' jobs. It measures the degree to which an employee perceives that their manager supports the training initiative(s), the perceived benefits of the training, and the perceived importance of, and satisfaction with, pre- and post-training activities. According to Santos et al. (2003) while "economic studies identify training and development investments as key determinants or organizational performance and economic growth…in practice, however, the issue of demonstrating the 'effectiveness' of training has proved extremely complex" (p. 27).

The quantitative analysis by confirmatory factor analysis (CFA) does not support accepting the hypothesis that Training Effectiveness (TE) is a significant component of the composite index measure, Overall Employee Satisfaction (OES). This is significant because the respondents in Industry 4.0 enabled organizations do not attest that the training they receive contributes meaningfully to a positive subjective experience of work. An examination of the summary statistics of the survey responses (Figure 1) indicates a mean response of 0.549, the lowest positive response rate of any of the five dimensions of Overall Employee Satisfaction (OES). Based on the quantitative analysis, it can be concluded that within the context of the three organizations studied, the claim that Industry 4.0 necessitates organizations to actively invest in their workforce through retraining and upgrading employees' current skills sets needed for higher-level jobs and to mitigate the perceived threat of automation, is not supported.

The quantitative survey explored the degree to which employees perceived that their manager supports training initiatives, the perceived benefits of the training provided, and the perceived importance of, and satisfaction with, pre- and post-training activities. Relatively low scores related to Training Effectiveness (TE) compared to the other dimensions of Overall Employee Satisfaction (OES) does not mean that training was not provided, but rather, the perception that it was fully supported by management, that it provided a clear benefit to the employee, or that pre- or post-training activities were important and satisfactory was not shared. There is a distinction to be made between the provision of training, and the provision of *effective* training that contributes meaningfully to the positive subjective experience of work.

An analysis of the qualitative research component supports this finding. One of the seven demi-regularities identified in the interview data was the employees were encouraged to take advantage of training and development opportunities. The interview transcripts reference the importance of training to understand and properly utilize technology in the workplace, and highlighting the considerable amount of time training on new technology and the procedures necessary to operate that technology safely and effectively.

The respondents from Company X indicate that training on new equipment and processes is part of the job: manufacturers provide specific workshops and technical training on new equipment as it is implemented. This perspective underscores the purely pragmatic nature of the training. Training on specific equipment, processes, and procedures is determined by operational imperatives, rather than being determined by developmental goals. Training with an instrumental objective differs from training with an employee development objective. This sentiment was shared by respondents in both Company Y and Z. The complexity of the technology necessitates a thorough understanding of it, and its use in application. Responses from employees of both company Y and Z indicate that training on new systems, processes and procedures is ongoing, and seemingly continuous. However, an employee from Company Y indicated that much of the background research on new software programs is done on the employees' own time and is self-directed, and that management and operators receive differing degrees of instrumental training. An equipment operator in Company Z echoed this sentiment stating that while they receive significant amounts of training—nearly an overwhelming amount—it was not designed to support individual development, limiting the ability of the employee to consider different roles within the organization. This difference was noted by Santos et al. (2003) who point out that in cases where "line managers were highly involved in discussing training needs, setting development goals and reviewing progress and providing coaching and guidance, training was more likely to have a favourable impact on employees' motivation, job satisfaction and personal growth" (p. 41).

A review of the retroductive analysis reveals there is little evidence to suggest that any of the three companies training initiatives were employee-centric. Rather, they were primarily driven by instrumental necessity to leverage advanced technologies to achieve growth objectives. The exception was Company X, which did also focus on developing the skills of its employees. The agential impact of employee skill development served as a causal mechanism, transforming and shaping continuous innovation, and leading to a more highly regarded and meaningful experience of training.

The degree to which employees perceive that the training they receive is supported by management, is beneficial to them, and is accompanied by satisfactory pre- and post-training support constitutes effectiveness. The claim that Industry 4.0-enabled organizations' investments in training will allow workers to develop the skills needed for higher-level jobs, and help mitigate the perceived threats of automation is not supported by the analysis. A focus on instrumental necessity, rather than on employee development merely serves the needs of achieving organizational goals.

H3: Employee Productivity (EP) is a significant component of a composite index, Overall Employee Satisfaction (OES).

Employee Productivity (EP) refers to the degree to which employees feel as if their level of individual productivity has changed as a result of Industry 4.0 implementation. Employee Productivity (EP) consists of three dimensions: task performance, contextual performance, and counterproductive work behavior. Employees demonstrating a high level of job performance are highly productive. The first dimension, task performance, refers to the "behaviors that contribute to the production of a good or the provision of a service" (Ramos-Villagrasa et al., 2018, p. 196). It assesses completing job tasks, keeping knowledge up-to-date, working accurately and neatly, planning and organizing, and solving problems. The second dimension, contextual performance, is defined as "behavior that contributes to the goals of the organization by contributing to its social and psychological environment" (Rotundo et al., 2002, p. 67-68). It includes tasks beyond job duties, initiative, proactivity, cooperation, and enthusiasm. The third dimension, counterproductive work behavior, refers to "voluntary behavior that harms the well-being of the organization" (Rotundo et al., 2002, p. 69). Essentially, behaviors that are counter-productive, and detrimental at the personal and organizational levels. The adoption of Industry 4.0 technologies is claimed to lead to higher productivity by eliminating errors and risks, allow the production of a larger quantity of products in a shorter period of time, enable more efficient production, and lower costs through process optimization. Claims of higher productivity are made at the organizational as well as the individual level.

The quantitative analysis by confirmatory factor analysis (CFA) supports accepting the hypothesis that Employee Productivity (EP) is a significant component of the composite index measure, Overall Employee Satisfaction (OES). This is significant because the respondents in Industry 4.0 enabled organizations affirm that they either are, or believe they are more productive, and that increased productivity contributes positively to their subjective experience of work. An examination of the summary statistics of the survey responses (Figure 1) indicates a mean response of 0.707, indicating a high positive response rate. Based on the quantitative analysis, it can be concluded that within the context of the three organizations studied, the claim that Industry 4.0 enhances employee productivity, is supported.

An analysis of the qualitative data suggests that across all three companies, interviewees confirmed that the Industry 4.0 technologies adopted did increase output. That is true whether it refers to aerospace components, designs, CNC machines, or fertilizers and additives. The technology contributed to the automation of routine tasks, allowing employees to focus on core job functions. The increase in efficiency, and ultimately in productivity is achieved in a variety of ways, from decreasing the amount of time needed to run iterations for engineers to reducing tool change-over time for machine operators. Industry 4.0 technologies enhance organizational integration, knowledge sharing, the automation of routine tasks, and the increased speed of task completion. Only one of the respondents reported an increased workload as a result of Industry 4.0, while five others report theirs was unchanged.

H4: Job Control (JC) is a significant component of a composite index, Overall Employee Satisfaction (OES).

Job Control (JC) refers to the degree to which employees feel as if their organizations' investment in Industry 4.0 has increased task flexibility. Job control refers to control over job tasks, the pace of work, ways of completing work, and task order. While autonomy refers to the degree of freedom employees feel they have to adapt to changing circumstances and to solve problems in creative ways, job control refers to decision authority and skill discretion. Specifically, the worker's authority to make decisions on the job (formal decision authority) and the breadth of skills used by the worker on the job (job breadth). According to Smith et al. (1997) individuals have an intrinsic need to control their environment because it is often associated with positive outcomes: control is an important correlate of job-related stress and organizational and personal outcomes, including a decline in absenteeism and improved health (Smith et al., 1997). The adoption of Industry 4.0 technologies is claimed to make jobs more customizable, flexible, and innovative, including making flexible working arrangements more accessible. According to Cimini et al. (2020) a wider span of control has been advocated as part of an appropriate structure to complement Industry 4.0 technologies where "real-time information sharing, which increases awareness in employees, autonomous decision-making and work methods, are crucial" (p. 17).

The quantitative analysis by confirmatory factor analysis (CFA) supports accepting the hypothesis that Job Control (JC) is a significant component of the composite index measure, Overall Employee Satisfaction (OES). This is significant because the respondents in Industry 4.0 enabled organizations affirmed that they feel they have, and can exercise, decision authority in their roles. An examination of the summary statistics of the survey responses (Figure 1) indicates a mean response of 0.726, indicating a high positive response rate. Based on the quantitative analysis, it can be concluded that within the context of the three organizations studied, the claim that Industry 4.0 supports a wide span of control, contributes meaningfully to job flexibility, and informs a perception of control, is supported.

The qualitative analysis reveals that the adoption of Industry 4.0 technologies informs work that flexible, supports remote and flexible work options, improves accessibility, and contributes to the alignment of employee goals with those of the organization. One of the demi-regularities shared among the three companies studied was that Industry 4.0 facilitated a more accessible workplace. The growing organizational awareness of the benefits of ensuring workplaces are accessible informs a technological imperative to that end. Tools such as real-time equipment monitoring, remotely accessible ERP systems, and the ubiquity of collaborative software solutions (i.e., Slack, Zoom, Microsoft Teams, Dropbox, etc.) allow employees to engage with, and meaningfully contribute to their companies and execute their job duties in a variety of ways. This flexibility contributes to a higher degree of job control. Employees in Industry 4.0 organizations "have greater decision-making power…[because] the aim is to provide them with an informative content that allows them to choose which is the best thing to do at that moment: directing the autonomous management of their activities (empowering them) and relieving all activities with low value and motivation" (Cimini et al., 2020, p. 716). Automating repetitive and low-value tasks have helped develop employees' roles as decision-makers and coordinators (Hirsch-Kreinsen, 2016).

Companies X, Y and Z shared similar structural influence, and a common causal mechanism affording positive Job Control (JC) outcomes. Respondents from Company X both reported that technology frees up time for task focus, while also contributing to the speed of task completion and enhancing adaptability. All non-management employees across the companies indicated that the adoption of technologies increased job stress. All but one respondent indicated that they participated, in some capacity, in management decision-making related to their roles.

The reported alignment by all but one respondent—a production employee from Company Z—between personal goals and those of their organization has implications for job control. According to Biggs et al. (2013) strategic alignment "relates to employee's line of sight between their specific job tasks and the strategic priorities of the organization…specifically, it encompasses an employee's (i) awareness of the organization's strategic priorities, (ii) perceived importance of those priorities, and (iii) understanding of how their daily job tasks and roles directly contribute to the organization's capacity to achieve its priorities (Biggs et al., 2013, p. 301). This alignment is related to increased work engagement, the efficient deployment of resources for task completion, and both intrinsic and extrinsic motivation.

The degree to which employees feel that they have decision latitude over job tasks, the pace of work, ways of completing work, task order, and which skills to employ is informed by Industry 4.0, and contributes significantly to Overall Employee Satisfaction (OES) within Industry 4.0 environments.

H5: Safety Awareness (SA) is a significant component of a composite index, Overall Employee Satisfaction (OES).

Safety Awareness (SA) refers to the degree to which Industry 4.0 affects employee perceptions of organizational safety, and contributes to an increased focus on positive safety outcomes. Employee perceptions about safety level (policies, procedures and practices) within the organization has a significant impact on workers attitudes, behaviors, and ultimately, on work accidents and near misses (Brondino, 2011). An assessment of employees' perceptions about safety within advanced manufacturing settings is important because as production systems increase in complexity and there is increased interaction and collaboration between workers and machines, the risks to employee health and safety become amplified. One of the most widely documented problems concerns “the ergonomics of control interfaces and human-machine interactions” (Badri, 2018, p. 418), where interaction with technologies such as flexible and mobile ‘cobots’ represent a broad range of less predictable risks than exist in traditional manufacturing environments (Badri, 2018). The adoption of Industry 4.0 technologies is claimed to lead to superior safety outcomes, such as the limiting of manufacturing defects and errors, the protection of workforce safety through the use of sensors, providing immediate feedback and rapid reactions to unsafe conditions, and a host of ergonomic interventions to protect workers.

The quantitative analysis by confirmatory factor analysis (CFA) supports accepting the hypothesis that Safety Awareness (SA) is a significant component of the composite index measure, Overall Employee Satisfaction (OES). This is significant because the respondents in Industry 4.0 enabled organizations affirm that they perceive a safe work climate, and that perception contributes positively to their subjective experience of work. An examination of the summary statistics of the survey responses (Figure 1) indicates a mean response of 0.679. Based on the quantitative analysis, it can be concluded that within the context of the three organizations studied, the claim that Industry 4.0 contributes to a positive safety climate and informs a safe work environment, is supported.

An examination of the qualitative analysis suggests that all of the respondents in Companies X, Y, and Z attribute improved safety outcomes to the adoption of Industry 4.0 technologies. Employees of Company X indicate that technology reduces the amount of manual work technicians need to engage in when changing tools, or making changes to production. Processes are simpler, more adaptable, and the management-level employee reported that the company has an exemplary safety record with their new equipment. The sentiment was echoes by the respondents from Company Y, who noted that machines are significantly more efficient, capable, and far safer now than in in the past. Company Z indicated that improved monitoring has made maintenance on production equipment easier, more predictable, and large-scale repairs are less common, reducing the chances for injury.

Respondents in all three companies indicated that the adoption of advanced technologies has increased the level of communication between management and front-line staff, facilitated by improved monitoring and data sharing. Improved communication, coupled with less human intervention in the manufacturing process, improved ergonomics, and the consultation of employees in regard to safety issues has contributed to the positive perception of safety.

The degree to which employees feel that Industry 4.0 has informed a safe working environment contributes significantly to Overall Employee Satisfaction (OES) within Industry 4.0 organizations.

H6: The presence of a formal lean program will have a positive moderating effect on the relationship between the five dimensions and Overall Employee Satisfaction (OES).

Of the three companies studied, both Company X and Company Y had formally documented and operationalized lean manufacturing programs. Company Z did not. An examination of the moderating role of lean manufacturing on the relationship between Industry 4.0 technologies and operational performance improvement by Tortorella et al. (2018) concluded that without the systematic process improvements and design derived from lean manufacturing principles, Industry 4.0 technologies did not result in improved operational performance or outcomes. Whether the presence of a lean manufacturing program and adoption lean principles moderates the relationship between Industry 4.0 technologies and the experience of work was unclear in the literature.

The quantitative analysis confirms that the presence of a formal lean program does have a positive moderating effect on the relationship between the five tested dimensions and Overall Employee Satisfaction (OES). Provided all other variables remain constant, it can be concluded that those companies with formal lean manufacturing programs in place (i.e., Company X and Y) can expect to have employees report higher OES scores than in companies that do not.

The findings from the qualitative study help inform an understanding of this moderating relationship. The effect of lean manufacturing principles and methods as a moderating factor between Employee Autonomy (EA), Employee Productivity (EP), Job Control (JC) and Safety Awareness (SA) and Overall Employee Satisfaction (OES) supports a stronger positive relationship between the variables. Tortorella and Fettermann (2018) and Rossini et al. (2019) demonstrate in separate studies that companies which implement lean practices are more likely to adopt Industry 4.0 technologies. When processes are robustly designed and continuous improvement practices are established, companies' readiness for adopting novel technologies increases. The presence of these processes and methodologies in Companies X and Y help facilitate the successful integration of technologies into jobs and related tasks. Lean manufacturing practices help to install organizational habits and mindsets that favor systemic process improvements (Tortorella et al., 2019). The socio-technical organizational changes that coincide with lean manufacturing reinforce practices and behaviors which, when combined properly with contemporary technological advancements, enable companies to "compete successfully under the, at first sight, paradoxical scenario where high-tech applications and human-based simplicity exist concurrently" (Tortorella et al., 2019, p, 875). Following lean manufacturing principles, the application of technology is executed in such a way as to create value for people and processes.

Based on the quantitative and qualitative analyses, it can be concluded that within the context of the three organizations studied, the claim that the presence of a formal lean program will have a positive moderating effect on the relationship between the latent variables and the dependent variable, is supported.

b. Critical Analysis

Critical realism asserts that all explanations of reality are treated as fallible. Empirical explanations and subjective interpretations by research participants must be treated as potentially erroneous, as they are inextricably tied to imperfect observational methods, be they sensory, discursive, or experimental. Individual experience is conceived solely within the empirical domain, and observations of the empirical are limited as events in the real and actual domains can not be observed directly. While reality exists independently of individual perceptions where underlying entities may not be observable or directly measurable, it is experienced in a highly interpretive manner. Experiences are fluid and relative to human agents, and occur ‘out of phase’ (Bhaskar, 1975) with the actual events that occur, with the exception being pure inventions of the imagination. According to Bhaskar (1975) “knowledge is a social product, produced by means of antecedent social products” (p. 16). In this way, critical realism combines and reconciles ontological realism and epistemological interpretivism. Since individual subjective experiences of work in Industry 4.0-enabled organizations are informed by the interaction between various entities, structures, agency and empirical events, a critical analysis is necessary to better understand how structures created by organizations and technology inform employee perception. Importantly, structures of power need to be examined, and participant responses need to be problematized—interrogated and questioned—to understand how the entities identified in the case studies generate events and, ultimately, inform the subjective experience of work.

The quantitative exploration of the three case companies involved gathering survey responses from forty-seven individuals, interrogating subjective perspectives on the role of technology within manufacturing, relative to five commonly stated claims about the benefits of that technology. The qualitative exploration of the three case companies involved conducting interviews with nine individuals, three from each company—one manager and two non-management employees. Each individual’s experiences of a manufacturing environment in which Industry 4.0 technologies are used is unique, reflecting a different lived experience, albeit from a limited perspective. Critical analysis of these perspectives helps articulate a ‘discourse of suspicion’ (Mumby, 1997) where underlying structures of domination, resistance and interest-driven discursive strategies that underpin consensual meaning systems are explored (Hardy et al. 2000). In this way, organizations can be conceived as “political sites where various organizational actors and groups struggle to ‘fix’ meaning in ways that will serve their particular interests" (Mumby, 2004, p. 237). Critical analysis seeks to emancipate human beings from conditions of domination and oppression by providing a systematic critique of economic, political and cultural processes through which ideas are produced and reproduced.

According to Mumby (2004) research on organizational discourse reveals three central tenets of critical modernism, from which critical analysis stems: (1) communication and discourse constitute, and are constituted by, meaningful social practices; (2) a critical analysis of power relations is central to an understanding of these social practices; and (3) critical analysis suggests the possibility of social and organizational transformation by social actors. Critical analysis helps inform an understanding of how social practices, power relations, and the role of agency help shape empirical observation and ultimately, the subjective experience of the role of Industry 4.0 technologies in the three case companies. In this way, a critical perspective provides a richer, deeper understanding of the impact of technology than either a positivist or an interpretivist perspective can.

Critical realism suggests that within the real domain of organizations, social structures exist that enable or constrain individual actions within a social context. Within the actual domain, individuals, managers and non-managers alike perform actions, or refrain from performing actions, leading to events. The complex interaction of structures within the real domain of organizations governs the actions individuals perform in the actual domain. Individuals, however, can exercise agency, choosing to engage in activities that reproduce a system's structures or change them. Importantly, structures are reinforced by systems of power that undermine attempts to change them. Individual observations and experiences in the empirical domain are a consequence of actions and events in the actual domain. It is, therefore, important to interrogate those actions, events, and structures in order to fully understand the experience of Industry 4.0 within a manufacturing context. Critical analysis, therefore, is helpful in exploring the entities, structures, and mechanisms within the real and actual domains that give rise to the employee experiences captured in both the quantitative and qualitative components of the research study, specifically within the context of the dialectics of power and resistance.

While the three case companies studied (X, Y, and Z) share several characteristics, namely, that they are small, Canadian-based manufacturing companies that have embraced Industry 4.0 technologies to improve competitiveness, they are distinct organizations. It is worth exploring them individually to understand the unique entities, power structures and mechanisms at play within each.

A critical analysis of the demi-regularities, or emergent themes, identified in the retrodiction phase of the dissertation is warranted, within the context of the hypotheses posed.

According to McNeil (1978) organizations, as they mature, experience a 'paradox of domination' that develops when rational technique becomes embodied in organizational form. In order to gain predictability in inherently unstable markets, organizations develop strong power relationships over the people they served. Only through "impersonal coercion and discipline of subordinates and clients could organizations achieve the coordination necessary for rational, i.e., quantitatively or logically calculable, action" (p. 65). The concept of domination, a Weberian one, does not mean that organizational leaders or administrators have total control, but rather, organizational domination implies that an imbalance of power exists which structures social action in favor of desired organizational outcomes. Consider the implementation of Industry 4.0 technologies. The impetus for the implementation is driven by the prospect of improved organizational outcomes. These improved outcomes, or positive claims were tested in the quantitative analysis, where survey responses across the three case companies confirmed that of the six hypotheses, five were supported:

- Industry 4.0 provides not only the technological means, but the freedom to adapt and solve problems in creative ways.
- Industry 4.0 leads to increased employee productivity (elimination of errors and risks, production of larger quantities of products with fewer input hours), increased competitiveness, and improved profitability.
- Industry 4.0 informs improved safety awareness and enhanced safety outcomes.

- Industry 4.0 facilitates flexible working arrangements, improves organizational accessibility
- The presence of a formal lean program has a positive moderating effect between Industry 4.0 technology implementation and the outcomes resulting from it.

Within the context of power, seen as "a deep-structure phenomenon that is manifest (though in a distorted, ideological manner) in the daily, mundane enactment of discourse processes that constitute webs of meaning" (Mumby, 2004, p. 242), Industry 4.0 entrenches and reproduces inequitable relations through its use. Critical theory supports a dialectic approach in order to understand this asymmetric relationship, and why the employee responses support the claims made by proponents of Industry 4.0

A dialectical approach examines the inherent tensions and contradictions between agency and structure, and "between the multiple interpretive possibilities that exist in every discourse situation and institutional efforts to impose or fix meaning in particular ways" (Mumby, 2004, p. 243). There are no all-encompassing power structures, nor are there any pristine, authentic spaces of resistance that challenge dominant power relations. Rather, agents have the ability to 'act otherwise' or challenge established norms, processes, and relationships. A dialectical approach to power recognizes that resistance and domination are not simple binary oppositions, but exist in a mutually implicative relationship, where organizational discourse—stories, conversations, rituals, etc.—is taken up by competing organizational interests. A dialectical approach suggests possibilities for multiple and contradictory meanings and realities existing in the same discursive space. The integration of advanced technologies into daily activities alters the organizational discourse, changing the way meaning is created and recreated. It is important to recognize that employees, as social actors, are sensitive to the discursive and political conditions that shape their work and organizational life. A dialectical approach is taken to critically evaluate the hypotheses and the emergent themes from the data.

i. Employee Autonomy (H1)

The survey data supports the hypothesis that employee autonomy (EA) is a significant component of the composite index measure, overall employee satisfaction (OES). Within the context of the dissertation, the data suggests that Industry 4.0 provides not only the technological means, but the freedom for employees to adapt and solve problems in creative ways. Respondents affirmed that Industry 4.0 facilitated enhanced autonomy, and that it contributes positively to the subjective experience of work.

Employees of Company X reported that advanced technologies facilitated creative expression, use of creative skills in the workplace, intellectual stimulation, and ultimately, fulfillment as a result. Employees of Company X also reported improved work-life balance, enjoying a high degree of flexibility in scheduling tasks. There are two significant components worth examination: the provision of flexibility in task management, and intellectual engagement. At Company X, the officially stated organizational rhetoric brings together the concepts of autonomy and creativity. The company philosophy stresses the causal relationship between individual creativity, team participation, and high-quality outcomes. This relationship is espoused as crucial in the high quality, cutting-edge component design at Company X. The philosophy challenges engineers and designers to push their limits, to expand their knowledge of materials and systems integration, and to engage in imaginative work. This philosophy is complemented by the focus on flexible scheduling, and allowing non-manufacturing team members (i.e., engineers, designers, managers) to set their tasks and manage their in-office time. The two structural elements can contribute to ambiguity and to far-reaching organizational control. The ambiguity can result from high expectations of output, tight timelines, and a strong sales focus. Ensuring designs are not only cutting-edge but correct, limiting the costs associated with rework, and ensuring customers are satisfied is extremely demanding. Being creative within tight time parameters can be highly stressful, as can the ambiguity between create expression and strict design parameters. Similarly, organizational control over the creative output to drive sales growth and customer retention in a highly competitive global industry can be highly stressful. The discourse around remaining competitive, driving innovation, and offering unique components manufactured from cutting-edge materials mediates the relationship between the employees and the organization through social practice. The drive to be creative is enacted and embodied in everyday practices, including working overtime and working from home. Flexible working arrangements can serve the company's ends, as employees are now available at all hours, and are not bound by geography. The company is able to, paradoxically, exert power and control through flexible work arrangements. In this way, discourse, as a social practice, does ideological work that shapes actors' relationships with the company, and predisposes employees towards certain sense-making practices that ultimately benefit the company. Discourse as ideology by no means exhausts the interpretive possibilities in which individuals can engage in, but it certainly establishes a dominant narrative against which employees can enact forms of resistance.

Employees of Companies Y and Z reported that while the technologies they used (i.e., IoT, continuous monitoring, and associated software) tended to increase their autonomy, becoming proficient with the use of that technology was a very real challenge. It in this way, technology can be regarded as a potential gatekeeper to achieving autonomy. Technology, in this way, reinforces the power of the company, forcing conformity to established standards and norms. Mastering the technology functions as a rite, which serves as the material instantiation of discourse. Rites and rituals function to reproduce organizational relations of domination through social practice. Employees must engage in the rite of learning specific, and potentially esoteric technologies, practicing their use, and instantiating company processes. Only after sufficient investment and time and effort does an employee 'earn' flexibility, and ultimately, autonomy. The dialectic approach to rites suggests that while rites provide opportunities for entrenching organizational values and dogma, they provide an avenue of resistance, where employees can reject them, and attempt to constitute a new organizational reality. This resistance often comes at a cost, however. If employees are unwilling to engage in the deep learning required of advanced technologies, and wholly embrace its use in work processes, it is unlikely that they will be as efficient, or as effective as those that do, nor will they be able to utilize the technology fully, capitalizing on the flexibility it may offer.

ii. Training Effectiveness (H2)

Second, the survey data does not support the hypothesis that training effectiveness (TE) is a significant component of the composite index measure, overall employee satisfaction (OES). Within the context of the dissertation, the data does not support the notion that the training employees receive contributes meaningfully to a positive subjective experience of work. This is not to say that training was not provided to employees—quite the opposite in fact. It suggests that the training received did not contribute meaningfully to overall employee satisfaction.

Interview data from Companies X, Y and Z indicate that the training provided to employees was, mostly instrumental—concerned with specific equipment and processes—rather than developmental. A critical approach suggests that training in this way is not a feature of organization, but a medium and outcome of organizing itself. A narrow focus on the pragmatic serves a specific outcome, advancing the goals of the company, and not those of individual employees. This too can be regarded as a means of domination. Specific training, designed by the company to learn and reinforce policy, process, and/or a specific technology imposes a dominant system of meaning upon employees that represents efforts to fix meanings in particular ways over other possible alternatives. Not only does training in this way reinforce a structured process for knowledge creation and transmission, but it also limits access to on-the-job developmental learning opportunities for employees. One possible reason that the quantitative data did not support a positive relationship between training and overall satisfaction is that pragmatic training, especially to the extent required for Industry 4.0 applications, is extensive and must be sustained over time. Employees are asked to invest significant time, effort and energy in learning new technologies and systems, but do not necessarily develop marketable skills. Organizations are able to impose control over employee attention and effort. In addition to the effort required to learn and understand new technologies, the unsettling effect of constant upgrades and changes to technology can be overwhelming. The dialectic supposes two alternatives for employees: (1) resist in the form of limited participation; or (2) find alternative employment. Modes of resistance are limited, as employees will ultimately be required to understand the processes and technologies in the workplace, or face job loss.

iii. Employee Productivity (H3)

Third, the survey data supports the hypothesis that employee productivity (EP) is a significant component of the composite index measure, overall employee satisfaction (OES). Industry 4.0 technologies help eliminate errors and risks, help manufacture higher quantities of products with fewer input hours, and help improve quality, resulting in increased competitiveness and improved profitability for companies. Interview responses across all three companies, X, Y, and Z suggest that the use of advanced technologies, whether it is IoT, digital twins, big data analytics, or cyber-physical systems, or another technology, contribute to enhanced output in a variety of ways, including the automation of routine tasks, enhanced rates of iteration, and reduced change-over time. The enhanced output potential often involves a high work pace driven by technology (Sellberg et al., 2014), high pressure, and unpredictable demands. This machine pace reflects an asymmetric power structure in which output targets are set by the company. The dialectic creates a space for resistance and emancipation, however. Many organizational processes and ultimately, targets, require employee input. Whether these are sales deadlines, manufacturing capacity recommendations, or logistics parameters, employees have an opportunity to provide feedback on targets and pace, at least to an extent. The reality of work is that there has always been, for most professions, some impetus for task completion. Defining and achieving productivity targets is an expression of power, a dialectical phenomenon characterized by interdependent processes of struggle, resistance, and control. The power to define objectives, to marshal and align resources to those objectives, and to set the pace of objective completion reflect a dominance within an organizational structure. For employees, there may be some opportunities to inform targets or pace, but otherwise, they are at the mercy of an inequitable structure. From this perspective, the implementation of technology in order to set the pace of work is both a medium (a space where actors interact with the technology) and a product of the ideological production and reproduction of deep-structure power relations.

The fact that within the context of the dissertation, employees indicated that increased productivity was related to increased satisfaction speaks to two possibilities: (1) there is an inherent satisfaction gained from achieving targets and contributing positively to organizational outcomes; and/or (2) employees are incentivized in such a way that it aligns with increased output. In either case, employees in all three case companies indicate that technology helps improve productivity, and that is intrinsically related to their subjective level of satisfaction.

iv. Job Control (H4)

Fourth, the survey data support the hypothesis that employee productivity (EP) is a significant component of the composite index measure, overall employee satisfaction (OES). Job control refers to an employee's control over tasks, pace of work, ways of completing work, and control over task order. Job control refers to decision authority and skill discretion. Industry 4.0 technologies facilitate flexible working arrangements and improve organizational accessibility. This allows employees more control over their working environment, leading to reduced stress and improved health outcomes (Smith et al., 1997). Employees in all three case companies, X, Y and Z indicated that Industry 4.0 technologies facilitated a more accessible workplace, meaning that employees are able to execute their job duties, and meaningfully contribute to their companies in a variety of ways. Importantly, in a way that is best suited to their particular situation.

Critical analysis suggests that an increased level of accessibility reflect a mutually implicative relationship between resistance and domination with the organizations studied. Advanced technologies, particularly communication technologies (i.e., remote equipment monitoring, cloud-based computing, ERP systems, Slack, etc.) are difficult to wield either as a form of domination, or as a tool of resistance because they are so ubiquitous, complex, and because there are so many alternatives to any single tool or platform. Neither companies nor individuals can rely on accessibility to further their particular goals. On one hand, companies are able to increase the availability of labor hours, reduce absenteeism, and increase output. On the other, individuals are able to resist working in a single, defined physical space, are better able to make decisions about how to complete their tasks that align with their personal schedules, energy levels, etc., and are able to reclaim their schedules to better accommodate responsibilities such as child care, or attending appointments. Improved accessibility and job control improve labor force participation, benefitting both companies and individuals.

v. Safety Awareness (H5)

Fifth, the survey data support the hypothesis that employee productivity (EP) is a significant component of the composite index measure, overall employee satisfaction (OES). The data suggest that, in the context of this dissertation, Industry 4.0 technologies inform improved safety awareness, and enhance safety outcomes. Whether it is through real engineered controls of hazards, or the perception that advanced technologies contribute to safe working conditions, employees indicated that Industry 4.0 technologies contribute meaningfully to overall satisfaction.

Interview responses across all three case companies indicated that the adoption of advanced technologies has increased the level of communication between management and employees, facilitated by improved equipment monitoring and data sharing. Improved communication around hazards, risks, and efforts at mitigation contributed to a positive perception of technology. Moreover, the reduced need for human intervention in automated manufacturing processes, improved ergonomics, and consultation with employees regarding safety issues helped contribute to a positive perception of technology as it relates to safety.

A critical perspective suggests that companies may rely on storytelling to improve perception, while including safety as part of a control system to achieve organizational aims.

According to Mumby (2004) storytelling is a constitutive feature of organization members' sense-making processes. Due to its discursive power and embeddedness in organizational life, narrative "functions ideologically to privilege certain interests and social realities over others" (p. 243). Consistent with a discourse of suspicion, critical analysis suggests that organizational storytelling is a powerful means of “simultaneously reifying and obscuring deep-structure power relations beneath taken-for-grantedness of everyday discourse” (Mumby, 2014, p. 243). The very structure of storytelling—emphasizing the role technology plays in creating safe and healthy workplaces—predisposes organizational members towards a culture of obedience, and the acceptance of the status quo. The interactive, dialectical model of the storytelling process, where the organization ‘tells’ and employees ‘listen’ reduces the likelihood that the audience will challenge the veracity of the truth claims made (Witten, 1993). Repeatedly emphasizing the safety benefits of new equipment or machinery and related processes helps organizations assert concertive control, providing an interpretive frame for employees. Different groups and agents within organizations interpret narrative differently, usually in a way that furthers their goals. For instance, technologies that contribute significantly to increased output will likely be favored by company management. Whether they are safer than existing technologies is immaterial, they may make the claim that they are. Operators who interact with equipment may enjoy different features the equipment offers, rather than improved safety features, but buy into the narrative anyway. This is not to suggest that new equipment is not safer than older equipment—contemporary regulations regarding design and testing in application likely ensure that it is—but it is not a given and should not be assumed to be true in every situation. The use of storytelling to influence perception and exert control can be applied to the context of safety awareness, just as it can to many other areas. Storytelling and narrative are both a discursive mechanism of control and an interpretive frame for strategies of resistance and emancipation. How it is applied, and by whom, reflects structural processes and power dynamics within an organization.

A focus on safety, and the benefits accrued to employees, can also be viewed as a component of a broad system of control. According to Weber (1968) those in power seek to justify their use of power: managers must justify their exercise of power to owners and to subordinates. In order to do so, managers must “rigidly adhere to the rationalities of profit maximization, abstract legal logic through which they tap the coercive power of the state, and scientific knowledge which enhances calculability in organizational procedures” (McNeil, 1978,

p. 73). Those in positions of power within organizations, such as managers, have an inherent interest in ensuring workers are safe, and follow safety regulations. Exerting power to compel employees to follow safe work practices, adhere to reporting guidelines, and utilize safe machines and technology can be regarded as a rational and pragmatic use of that power. Manufacturing organizations must decide what specific criteria define safe work, then develop strategies to control to ensure success in meeting those criteria. This process gives companies important discretionary power, and a justifiable rationale to maintain it.

The dialectic approach to critical analysis suggests that employees too can exert power, in the form of resistance, through safety. As safety requirements are legislated and codified by law, employees can be assured that minimum safety standards are adhered to. Companies can face steep fines, and individual managers and executives can face incarceration if found guilt of safety violations. Organizations then have a vested interest in ensuring that employees are kept safe, and that employee participation in safety programs, the formulation of policies and procedures, participation in reporting, training, and risk mitigation is encouraged. Since employees are aware of the importance of their participation in safety, it can be an outlet, or a means by which to subvert organizational control.

vi. Presence of a Formal Lean Program (H6)

Finally, the survey data support the hypothesis that the presence of a formal lean program will have a positive moderating effect on the relationship between the five dimensions proposed in the study, and the composite index measure, OES. The case narratives identify that Companies X and Y have formal lean manufacturing programs, which support their organizational strategies. Company Z does not. The quantitative data suggest that, provided all other variables remain constant, companies with a formal lean program can expect employees to report higher satisfaction scores than those companies that do not.

While current research suggests that companies with established lean programs share organizational habits and mindsets that favor systemic process improvement and ease the integration of new technologies, a critical perspective of lean offers a more nuanced understanding. In practice, lean can be conceptualized, in part, as a complex interplay between resistance, control, and identity, where ideological processes operate in social practice, rather than ideationally. Employees at all levels of an organization engage in organizational events which provide possibilities for the instantiation and entrenchment of dominant organizational values—namely continuous improvement and the elimination of waste. The adoption of Industry 4.0 technologies further entrenches these values in practice where IoT, cyber-physical systems, digital twins, and real-time analytics shape physical practices and organizational processes. Employees are physically engaged with technologies and embedded in processes, enacting the desired behaviors and ideological processes. Meaning is constructed in the relationship between ritual behavior (i.e., Kaizen events, MUDA walks, or continuous improvement) and structures of power. In this way, lean practices and the use of technology within a lean system function to "crystallize extant relations of power, cementing hierarchy and reproducing social order" (Mumby, 2014, p. 248).

However, a critical-dialectical approach suggests that organizational rites and rituals, such as those found in a lean program, are a rich site of interpretive struggle. While they can be regarded as a means of instantiating and re-instantiating organizational values, they always harbour "transgressive possibilities, providing opportunities for ironic and parodic interpretations of dominant meanings" (Mumby, 2014, p. 248). Employees often engage in behavior that appropriates and transforms aspects of official culture, subverting it. This sort of subversion is not easy, however. Companies that have established formal lean programs will typically have employees that see the value, or benefit from it, making subversive tactics less common, and less disruptive than they could potentially be.

With respect to the different hypotheses, a critical approach explores the power structures that exist, and the different experiences that individual employees have. All explanations of organizational reality are treated as fallible, and all experiences need to be problematized to fully understand the role Industry 4.0 technologies have on the subjective experience of work.

c. Answering the Research Question

The research question posed in the study inquires about how employees in organizations with a formal lean manufacturing program experience work in relation to the stated claims about the implementation of Industry 4.0 technologies. Assessing how the various claims made by theorists and practitioners relate to the everyday lived experiences of employees, and how they influence work was explored both quantitatively through an employee survey, as well as qualitatively through semi-structured interviews. The analysis of subjective experience along five dimensions supports the hypotheses that the implementation of Industry 4.0 technologies in three different organizations contributes to increased Employee Autonomy (EA), Employee Productivity (EP), Job Control (JC) and Safety Awareness (SA), and those four dimensions are significant components of the composite index measure, Overall Employee Satisfaction (OES). The degree to which employees feel as if their organizations' investment in training has allowed them to upgrade their skills, enabling them to manage automated processes and take on 'creative' jobs, or Training Effectiveness (TE), is not a significant component of the composite index. The study also revealed that, based on the three organizations studied, the presence of a formal lean manufacturing program has a positive moderating effect on the relationship between the four contributory dimensions (Employee Autonomy, Employee Productivity, Job Control, and Safety Awareness) and the composite index, Overall Employee Satisfaction (OES).

Overall Employee Satisfaction (OES) serves as a composite measure of an employee's reported experience of work in an Industry 4.0-enabled workplace, where a higher OES score reflects a higher level of subjective satisfaction with the employees' workplace. The dimensions contributing to OES are a function of Industry 4.0 adoption, reflecting the claims made regarding the benefits of the adoption. The results support the notion that the adoption of advanced Industry 4.0 technologies in a systematic way contribute to enhancing Employee Autonomy (EA), Employee Productivity (EP), Job Control (JC) and Safety Awareness (SA), and they are significantly, and positively, related to the composite index.

An examination of the qualitative data identified several key themes, or demi-regularities:

- Industry 4.0 technologies enhance output potential
- Work was reported to be fulfilling, either personally, or professionally
- Employees are encouraged to take advantage of training and development opportunities; There is an increasing need for continuous learning, and an increasing quantity of material to be learned
- The outlook for the organization implementing Industry 4.0 is positive
- Industry 4.0 technologies facilitate a more accessible workplace
- There is a shared perception that Industry 4.0 contributes meaningfully to a safe workplace
- Industry 4.0 facilitates a positive and constructive relationship between coworkers

In addition, the qualitative data emphasized that respondents in the three organizations studied shared common characteristics of experience in Industry 4.0 environments:

- Job tasks have changed;
- There is a need for continuous learning; and
- Industry 4.0 adoption has led to significant organizational change.

The subjective experiences of employees involved in the three Industry 4.0-enabled manufacturing companies suggest that, based on the hypotheses made in the study:

1. Industry 4.0 provides not only the technological means, but the freedom to adapt and solve problems in creative ways.
2. Industry 4.0 leads to increased employee productivity (elimination of errors and risks, production of larger quantities of products with fewer input hours), increased competitiveness, and improved profitability.
3. Industry 4.0 informs improved safety awareness and enhanced safety outcomes.

4. Industry 4.0 facilitates flexible working arrangements, improves organizational accessibility
5. The presence of a formal lean program has a positive moderating effect on the relationship between Industry 4.0 implementation and the aforementioned outcomes.

The supported claims, represented by the independent constructs, contribute positively to the composite index measure of Overall Employee Satisfaction (OES).

The choice of a case study approach allowed for the development of case-specific knowledge that can be generalized analytically (concerned with explanation of how empirical phenomena occur, or not), rather than generalized statistically, which is, in positivist tradition, concerned with prediction.

The exploration of the relationship between technological intervention and the subjective experience of work in different organizations, specifically through retroduction, identified that four demi-regularities share common mechanisms. The analytical generalization that can be drawn is that the implementation of Industry 4.0 technologies: (1) facilitate more accessible workplaces; (2) contribute to a positive future outlook; (3) contribute meaningfully to safe workplaces; and (4) facilitate a positive and constructive relationship between coworkers in the same way across the three companies. The implementation of Industry 4.0 technologies enhance output, contribute to employee fulfilment, and encourage participation in training and development opportunities in all three companies, albeit in different ways, and through different mechanisms.

The application of Industry 4.0 technologies, within the context of this dissertation, results in a preponderance of positive outcomes for both the companies and employees. While some negative subjective experiences were reported, they were predominantly associated with the difficulties of managing change and the challenges associated with the breadth and complexity of training. Changes in workflow, job tasks, task assignment, training and job design are significant in Industry 4.0 environments, and were associated with positive subjective experiences in the cases studied.

d. Emancipatory Perspective

Critical realism has a predilection to connect the particular with the general: this entails an examination of social structures and mechanisms in order to understand how events unfold in the empirical domain of reality. Since social interaction, or agency, produces and reproduces social structures, critical realism is useful in questioning the assumed status quo. In questioning the assumed status quo in social interaction, critical realism assumes that everyday life has superficial and often conflicting aspects. In relation to work, these aspects manifest themselves in the labor process, or the lived experience of work. Engaging in social behavior in the workplace, engaging in organizational cultural practices, rites of passage, organizational traditions etc. inform the reproduction of social structure. The *critical* aspect of critical realism implies a link to critical social theory, which draws from numerous critical traditions. For instance, Marxist theory, according to Hassard et al. (2001), inaugurated a radical critique of the use of technology in organizations because of the potential of increased exploitation of workers. This implies an examination of the construction and use of technology used to further increase the process of exploitation of employees by managers, to help achieve desirable organizational outcomes. A critical realist approach challenges accounts of the status quo in organizations, and aims to deconstruct dominant ideology (Wilson & Greenhill, 2004). In the case of Industry 4.0 technologies in manufacturing, two notions to be criticized are: (1) managerialism, for seeking to increase productivity and curtailing worker resistance; and (2) technological determinism, which excludes human agency, and discourages the examination of social and organizational contexts (Lopez & Potter, 2001).

Critical approaches, in addressing managerialism and technological determinism focus on issues of equality. According to Bhaskar (1998) critical researchers have recourse to the dialectic of equity, since “the principle of sufficient practical reason states that there must be ground for difference. If there is no such reason then we are rationally impelled to remove them” (p. 676). In seeking reasons that inform inequality, critical realism examines patterns and conditions of employment and in the process of work that highlight areas of inequity. The process of work is both a reflection of inequalities in broader society, and plays a part in the generation and perpetuation of those inequalities (Wilson & Greenhill, 2004). This commitment to issues of equality implies a commitment to changing the world for the better, and for the creation of structures that are wanted, needed, or generally emancipatory (Hollis, 1994). Exploring the way organizations are, and the way they are structured highlights the role of humans in the reproduction of social structures and social interactions that stand in the way of emancipation. Critical realism is useful in that it helps seek ways of transforming asymmetric relations, and identifies alternative structures that may help employee emancipation and potentially, flourishing. To achieve this, critical realism provides a means of questioning the status quo, deconstructing the dominant organizational ideology, and identifying instances of inequality.

An examination of the qualitative data revealed seven demi-regularities, or key themes that emerged from the coding process. These themes span across the three case companies, and reveal, broadly, critical learnings and insights. There are, however, several masked threads of analysis that need to be explored, not only to provide a better understanding of the subjective experience of work, but to inform a meaningful emancipatory perspective. This is significant in the context of the dissertation, as it assesses detrimental conditions and circumstances, and provides insights into how employees can address them. These detrimental conditions can be explored broadly within the context of managerialism and technological determinism.

Critical inquiry is antithetical to mainstream functionalist management thinking—scholarship with a broad generic focus on improving the efficiency and effectiveness of management practice. In manufacturing, managerialism is concerned with increasing productivity, improving quality (decreasing defects), and increasing efficiency. While critical theory represents a well-established perspective in management scholarship, this does not imply a rejection of management, or managerialist perspective per se, but rather, critical perspectives actively and pragmatically intervene in specific debates about management to drive improvement in practice. Within the context of this dissertation, a critical inquiry is not a rejection, or denigration of a managerial perspective, but an attempt to improve management practice in advanced manufacturing. With the goal of exploring the subjective analysis deeply in order to improve management practice, four threads of analysis uncovered in the retroductive analysis are: (1) change is inherently difficult; (2) stress is often high; (3) training is limited and often difficult; and (4) improved flexibility comes with encroachment, blurring the line between work and home.

First, change is inherently difficult. Within the context of the case studies, this manifests as difficulties in writing new procedures, developing new processes, monitoring and improving morale, getting team buy-in, and constantly needing to 'sell' the value of new technologies to change-fatigued employees. A manager with company X describes the situation: "trying to stay on top of the latest technologies and remain on the cutting edge is very expensive, and very difficult to manage. Getting an entire team on the same page, and fully supportive on constant change is harder to do than you would think." Organizational change is notoriously difficult, for both managers and employees. An operator in company Y indicated that "the challenging part is keeping up with all the new developments and technology." This is echoed by an equipment operator in company Z, who points out that "because there is so much I need to know, and the new equipment is so sophisticated, it feels like I am constantly learning and being challenged to ensure the new line can keep up, and that we're doing the best that we can." The implementation of technology to strategically drive organizational performance improvements inherently involves users (i.e., people and processes), and as a result, change efforts need to focus on the people affected by the change (Markus, 2004). These can include assessing people's readiness for change, training them and initiating cultural changes, redesigning jobs or organizational structures, devising new ways to manage and reward people, or involving them in planning the implementation of change. Without addressing the human-centered component of technological adoption, it is impossible to emancipate people from the adoption of technology itself. Of course, addressing the human-centered component of technological adoption is difficult, in part, because technologies are expected to produce significant improvements in organizational outcomes, and as such, do not necessarily focus on people, organizational structures, or human resource management policies. Rather, the focus tends to be on investment in the technology itself (Markus, 2004). Ideally, technological solutions are complemented with related organizational changes to achieve an appropriate fit between technology and the organization. Critical theory recognizes employees as subjects who have higher order needs and appreciate the value of managing people in a caring, responsible manner, and require the investment of sufficient time and effort to meet those needs. This contrast between a managerialist imperative of "safeguarding the interests of shareholders by controlling the productive capacity of workers" (Alvesson & Willmott, 1992, p. 433) with freeing those workers from alienating conditions of work contributes to the difficulty associated with change. Often, this is the result of constrained resource allocation, insufficient investment in pre- and post-implementation support, and ineffective communication.

Change management can be defined as "the process of continually renewing an organization's direction, structure, and capabilities to serve the ever-changing needs of external and internal customers' (Moran & Brightman, 2001, p. 111). Due to the reported velocity and scope of change associated with the implementation of Industry 4.0 technologies in the three case companies, the importance for organizations to identify their future needs, and how to manage the changes required to get there seems self-evident. However, the interviews suggest otherwise. It tends to be reactive, discontinuous, ad hoc, and often triggered by a situation of organizational crisis (By, 2005). According to Balogun et al. (2004) a failure rate of close to 70 percent characterize all organizational change programmes initiated. The reasons for this vary, as the literature suggests. However, from a critical realist perspective, the concept of inscription is worth exploring further. Inscription, in the context of organizational change, refers to the idea that social structure and culture are inscribed within the material components of technology (hardware, software, etc.) in a way that sustains structural and cultural relations through organizational change. For instance, a company may, through a structural and/or cultural imperative of performance management, inscribe those imperatives within a data storage system in such a way to concentrate information in the hands of management, affecting the power relations in an advantageous way. In the context of the case companies, the implementation of a technology like a 5-axis CNC machine equipped with IoT for company X could inscribe structural and/or cultural imperatives in much the same way, recording cycle times, uptime (OEE), logging errors, etc. to privilege managerial imperatives. This use of inscription helps understand how power and dominance are often reproduced through the use of technology, rather than facilitating meaningful change.

Technological determinism suggests that social changes can be determined by technology, independent of human will, contradicting the doctrine of free will. As emancipation describes the process through which individuals and groups become freed from repressive social and ideological conditions, human need and the expansion of autonomy in personal, social and work life assumes that humans have, and can exercise, free will. Technological determinism, according to Drew (2016) is characterized by a rejection of the notion that social structures and technologies co-evolve in unpredictable, emergent ways. This characterization is problematic as it suggests that social structures and technologies interact in predictable, prescribed ways. If that were the case, organizations would be better able to predict outcomes, and would, ideally, mitigate the impact of the known changes for employees. The qualitative evidence suggests that the former is evident. Change is hard to predict, hard to cope with, and mitigating it conflicts with the managerialist imperative. Seeking emancipation is thus difficult in environments characterized by a high degree of change.

Second, it became apparent that stress was reported to be moderate or high among many of the interview subjects. This stress was rooted in numerous causes, including uncertainty about the outcome of the technology, as described by an employee of company Z: “some days are still stressful, especially if things go wrong. We’re not as familiar with the technology in the same way that we knew the olds ways. But, we’re learning.” Stress can be understood in terms of different theoretical perspectives, including from an idiographic or individual appraisal perspective, an environmental perspective, or from a conservation of resources perspective, among others. The latter suggests that individuals are seen as motivated to obtain, retain, foster, and protect the things they value (Westman et al., 2004).

From a resource perspective, organizational stress occurs under one of three situations: when resources are threatened, actually lost, or when there is a lack of resource gain following significant resource investment. The adoption of new technologies is inherently disruptive to established systems and norms, affecting distribution of, and access to, organizational resources. Regardless of the specific cause, the propensity for employees in advanced manufacturing environments to report being moderately or highly stressed is problematic, and undermines an emancipatory perspective.

Whether due to the challenges of adapting to change, the difficulties associated with learning and becoming proficient with new technology, or uncertainty of outcome, employee stress may best be thought of as an outcome of the dialectic of control and resistance. Within the context of critical realism, this dialectic can be conceptualized as a succession of conflicts between major, integrated managerial control strategies, and small-scale reactions to these control forms (Alvesson & Willmott, 1992). These partial, temporary movements away from forms of oppression can be stress-relieving as employees face tight timelines and high workloads, as companies seek to maximize productive capacity of their technology investments. According to one employee from company Z "most days are hectic, with a lot of work to do and tight timelines to meet customer demands. It can be stressful at times, especially if something goes wrong, or we have to invest in rework." A movement towards emancipation may involve successive moves toward a state of liberation as employees seek to cope with the daily stresses of technological adoption. Emancipation, in this way, can be considered as a precarious, endless enterprise where employees "fight continuously in order to create more space for critical reflection and to counteract the effects of traditions, prejudices, the ego administration of mass media, and so forth, which reduce the ways in which the social world can be understood and enacted" (Alvesson & Willmott, 1992, p. 447). The emancipatory idea is not one large, singular movement, but a series of smaller movements, each limited in terms of time, space, and success.

Third, training is limited and often difficult for employees to successfully complete and apply. According to an employee from company Y: "we receive some training from manufacturers when integrating new equipment into our own manufacturing processes. It's ironic, however, that as an organization that puts together training for other companies on the use of their technology and Industry 4.0, we don't have a lot of training ourselves. Most of our training, at least as far as my role is concerned, is self-directed." This sentiment was shared by an employee from company X, who indicated that "we never learned how to design components on these systems in school, so we're kind of on our own." Making training available, but leaving it to employees to access and complete on their own time, or in an unstructured way, reduces the effectiveness of the training. This reflects the quantitative finding in the study that Training Effectiveness (TE) was not a significant component of employee satisfaction. This approach reflect the struggle between the exercise of power and reactions to power in organizations. Power involves subordination, as well as the expansion of productive capacities. Companies may choose to make training available, but be unwilling to invest significantly in freeing up employee time to engage meaningfully with the material, as labor hours can be extremely expensive given the lost productivity associated with them. An employee from company X reiterates this point: "training our designers, working with our operators, and ensuring that everyone is trained properly on the equipment is a massive undertaking. It takes months for operators to not only learn, but be comfortable with a new machine." By limiting organizational time available for training and development, companies engage in an exercise of power, signaling organizational priorities. This overt exercise of power over employees is interesting, given that with the complexity of the technologies involved and the high costs involved, organizations benefit directly from highly trained, and highly competent employees. Given the complexity around designing effective organizational training, including adapting suitable pedagogies, conducting effective needs assessments, and engaging in meaningful feedback discussions, it may be simplistic to limit the discussion to one of organizational power, but it is effective for framing an emancipatory analysis. Addressing the complexities of training and ensuring it is purpose-suited and effective, not only from an organizational perspective, but from an employee perspective, is a function of company engagement and investment.

According to the subjective descriptions by employees of all three case companies, the training that was provided was highly esoteric, pragmatic, and technology-specific. An employee from company Z points out that "I haven't received as much support for development, in that, if I wanted to take on a different role in the company, there is no real pathway to do so." This focus on the esoteric is designed to build practical skills in order to maximize the effectiveness of the technology investment. There is limited focus on developmental training to build employee capacity, and cross-functional skills. This narrow training focus, while appreciated by employees, limits the ability to select specific areas of interest to pursue. As a result, employees may not value the training as much as they otherwise would, if they received a broader personal benefit from it. The instrumentality of training can be regarded as an exercise of organizational power in the same way as availability of training is. By limiting training to support a managerial imperative, companies effectively limit the acquisition of transferable skills, limiting options for employees. This serves to direct employee attention to managerial-prioritized tasks. From an emancipatory perspective, resistance to, or subversion of an idea or intended practice manifests as limited participation in training, or devaluing the process. Employees may be less willing to engage fully in the process, blunting the effectiveness of intended training, and ultimately, of the effectiveness of the underlying technology.

Fourth, the improved flexibility (a component of job control) afforded to employees through the widespread adoption of communication technologies and inter-connected machinery resulted in the blurring of the lines between work and home for employees. The managerial imperative of increased productivity drives a desire for connectivity, and increasing the availability of employees to monitor and respond to organizational needs support that. Increased connectivity risks extending employee workdays, and interferes with employee time away from work. This extension of the workplace beyond the physical barriers of the office or plant has a wide variety of potentially detrimental effects, and is itself a vast subject of scholarly inquiry. It is pertinent, however, to examine the implications of this extension in the context of emancipatory action. The broad implementation of a variety of communications technologies in all three case companies effectively expanded the sites for emancipation, as the possibilities for organizational oppression have become so vast. Communication technology expands the means by which organizations can exert influence and control, and emancipatory actions that address means "challenge the necessity and value of established methods of organization, such as the hierarchical and fragmented division of labor, certain leadership styles, or technocratic modes of control" (Alvesson & Willmott, 1992, p. 450), need to match. Forms of emancipatory action include using flexible work arrangements to accommodate personal commitments and priorities, and shifting work to when it is most convenient for the employee. Communication technology offers equal opportunity for the imposition of managerial imperatives, while also serving as an opportunity for emancipation and resistance.

An emancipatory perspective is well situated within a critical realist analysis. Critical realism recognizes that all forms of knowledge are power-laden, and can become a source of oppression. The interaction of social structures at work with the agency of employees informs a robust space for emancipatory action, leading, ultimately, to more positive and satisfying employee outcomes.

e. Theoretical Implications

This dissertation has demonstrated applied empirical research using critical realism as a philosophical and methodological framework. The aim of critical realist research is to obtain a deep knowledge of phenomena without generalizing the universality of the findings. The implementation of Industry 4.0 practices and technologies in manufacturing companies, notably the impact on employees, and the integration with lean manufacturing methodology, had not been widely explored, and has not been well understood within a critical realist framework. The positive benefits purportedly associated with the implementation were examined from the employee perspective, rather than from an organizational perspective. Characterized by ontological realism and epistemological subjectivism, critical realism represents an approach that is concerned with providing descriptions of human subjective experience, and explanations of the various forms of those interpretations. Through the application of a stratified otology in which reality, actuality and experience are differentiated, critical realism allowed for an engagement in a reflexive and dialogical interrogation of the subjective experience of work. Specifically, how Industry 4.0 and associated technologies affected employee autonomy, training, job control, productivity, and safety awareness. How Industry 4.0 interacted with these constructs and the consequences for employees were explored in a novel way.

Critical realism asserts that all explanations of reality are treated as fallible (Bhaskar, 1979) including explanations provided by research participants, theorists, and researchers. The ontological departure from interpretivism—critical realism holds that there is an objective reality that is theory-laden, but not theory-determined—helps contextualize research in which participants offer competing explanations of a phenomenon, often challenging existing knowledge and theory. The various perspectives gathered through the semi-structured interview process were examined through various theoretical perspectives, offering a rich and compelling understanding of the experience of Industry 4.0 across organizations. Specifically, the interaction between entities, structures, agency and empirical events were examined through competing theoretical perspectives to fully understand how they manifested within different organizations. The philosophy of critical realism employs retroductive analysis to search for mechanisms underpinning empirically observed events, and an examination of mechanisms allows for a meaningful comparison between organizations when seeking commonality or analytical generalizability.

Critical realism is often proposed as a third way in business research, occupying a middle ground between positivism and interpretivism. As one of the key approaches favored by critical management scholars, it facilitates the critique of management ideology, aiming to empower and emancipate individuals within organizations. The study of companies X, Y and Z from an emancipatory-critical perspective allowed for a distinction between agency and structure, permitting a thorough analysis of organizational structures, social conditions, and the relationships between agents in those companies. In providing a critique of contemporary manufacturing, critical realism allowed for the emphasis on the social construction of work, and the role organizations, people, relationships, attitudes and ideas (such as the ideas associated with lean manufacturing) as foundations of explanation when considering the lived experience of work. A critical realist perspective allowed for a deep exploration of the fundamental nature of experience, rather than simply the measurable properties of that experience by focusing on entities and their interactions.

The use of mixed-methods research, specifically the use of surveys and semi-structured interviews allowed for the integration of information obtained from extensive and intensive sources. Abductive theorizing allowed for the identification of patterns and associations in the quantitative data, which was useful in identifying causal mechanisms and understanding outcomes for employees when coding and examining the qualitative data. This integration of mixed-methods was well supported by a critical realist framework. McEvoy et al. (2006) suggest that the integration of qualitative and quantitative methods in critical-realist informed research serves three purposes: completeness, abductive inspiration, and confirmation. While extensive approaches, such as the survey data help establish latent variables and characteristics of the agents (Eastwood et al., 2014), intensive approaches provide the tools for producing in-depth knowledge of the contingent conditions under which generative mechanisms are activated. This dissertation illustrates how critical realism underpins the essential methodological characteristics of both quantitative and qualitative research methods, and facilitates the integration of the two to enhance retroductive theorizing. It illustrates how applied critical realist methodology offers explanatory value through the interplay of multiple empirical aspects to better understand how Industry 4.0 technologies shape the subjective experience of work. The pluralistic retroductive theorizing approach used in the analysis of demi-regularities illustrates the interaction between data obtained from the integration of mixed methods in order to identify contextual conditions and mechanisms in different cases. The highly discursive and iterative process of retroductive theorizing, while challenging, offers a unique means of examining organizational phenomena such as the introduction of novel technologies in manufacturing companies.

f. Interpretive Role of the Researcher

The application of a critical realist framework to management research presupposes that in addition to positing the existence of a world independent of researchers' knowledge of it, it "holds to a fallibilist epistemology in which researchers' knowledge of the world is socially produced" (Miller et al., 2010, p. 144). Hence, claims of knowledge can be challenged and assessed empirically. The role of the researcher in a critical realist study involves identifying structures, agency, material artifacts and understanding the rules and practices that define the relationships and organization among them. In the three case companies studied, understanding the causal effects of technological interventions (generative mechanisms) and linking them to subjective, lived experiences and observed events requires exercising judgmental rationality. Recognizing how technological and methodological interventions inherent in Industry 4.0 change organizations and influence individual experience involves applying the dialectical-relational component of critical realist ontology to the separate cases to understand not just *what* employees experience, but *how* their experiences are created and reproduced. The researcher serves an interpretive role, analyzing both quantitative and qualitative data and interpreting the results through an iterative and dynamic process, carefully avoiding the epistemic fallacy.

g. Contributions of the Research to the Literature

This dissertation contributes significantly to the literature in lean manufacturing, Industry 4.0, critical realism and organizational behavior in three ways:

1. It provides an example of a mixed-methods study in which critical realism offers a useful theorizing framework and a robust platform for integrating qualitative and quantitative methods. It provides an example of a critical realist approach to management research.
2. It explores the subjective experience of work in Industry 4.0-enabled companies with respect to the claims made by proponents of technological integration, focusing on

employee experience and perception, rather than organizational outcomes. The dissertation concludes that within the context of the study, four of five claims about the benefits of technology are supported.

3. It examines the relationship between lean manufacturing and Industry 4.0, indicating that, in the context of the study, the presence of a formal lean program plays a significant role in how employees subjectively experience Industry 4.0 implementation.

The dissertation addresses the issue of the changing nature of work, a timely and important topic considering social trends and technological advancements. As technological interventions become more widespread in a wide range of organizations, increasing numbers of workers find themselves interacting with Industry 4.0 technologies. By exploring the subjective experience of work in relation to the stated claims about the implementation of technology, this dissertation contributes to better understanding the relationship between changes at the organizational level, and how they are experienced at the individual level. The adoption of Industry 4.0 technologies can, as the case studies demonstrates, support increased autonomy, productivity, job control and safety awareness, contributing significantly to an increase in employee satisfaction with their work.

h. Implications for the Practice of Management

The Doctor of Business Administration (DBA) degree combines advanced management theory and practice with practical research that makes a difference for business practitioners. The pursuit of this dissertation work sought not only a greater understanding of the impact of Industry 4.0 on employees in manufacturing companies, but to provide practitioners with pragmatic tactics with which to improve business. This dissertation provides several key insights for managers and organizational leaders in the manufacturing sector, based on the analytic generalizability of the findings:

- The positive impact of Industry 4.0 technologies is moderated by the presence of a formal lean manufacturing program. The results support the claim that companies with formal lean programs are better able to integrate new technology, and employees report higher levels of satisfaction.

- The integration of Industry 4.0 technologies contributes to enhancing employee autonomy, productivity, job control and safety awareness, contributing significantly to enhanced employee satisfaction.
- Training and employee development are critical to facilitating Industry 4.0 integration and sustainability. The results of the study indicate that all interviewees recognize that training is necessary, is encouraged, and that continuous learning is vital to fully understand and leverage Industry 4.0 technologies.
- The retroductive analysis suggests that Industry 4.0 technologies necessitate significant organizational change, disrupt tasks, workflows and jobs, and requires systematic and thoughtful adoption while considering employee outcomes.

Chapter 6: Conclusion

a. Summary

The purpose of this dissertation was to understand whether the subjective experience of work supported or disputed the stated claims about the benefits of Industry 4.0 technologies in manufacturing organizations. Situating the exploration of the role of technology within a critical realist framework facilitated the study of the structures, agencies, events, actions and context in order to identify and explicate the causal mechanisms that informed empirical outcomes. The study found that, through multiple case studies, the adoption of Industry 4.0 technologies contributes to increased Employee Autonomy (EA), Employee Productivity (EP), Job Control (JC) and Safety Awareness (SA), and those four dimensions contributed significantly to a composite index measure of Overall Employee Satisfaction (OES). An examination of semi-structured interviews revealed several common themes:

- Industry 4.0 technologies enhance output, and output potential
- Work in advanced manufacturing environments is fulfilling, either personally or professionally
- Employees are encouraged to take advantage of training and development opportunities
- Industry 4.0 technologies facilitate a more accessible workplace
- The outlook for organizations that have implemented Industry 4.0 is positive
- There is a shared perception that Industry 4.0 contributes meaningfully to a safe workplace
- Industry 4.0 facilitates a positive and constructive relationship between coworkers

Employees generally benefit from newly adopted and integrated technologies and enjoy a commensurate benefit with respect to an increased level of satisfaction with their work. Those employees in organizations that had a formal lean manufacturing program in place tended to experience higher levels of satisfaction, due to its moderating role. Ultimately, the exploration of the relationship between Industry 4.0 technologies in manufacturing organizations and work determined that the subjective experiences of employees support four of five of the positivist claims made by proponents of advanced technological solutions in manufacturing.

b. Limitations of the Research Findings

This study was limited in scope, focused on three case studies of manufacturing organizations in a Canadian context. The study assessed the stated claims of Industry 4.0 proponents and practitioners, and explored whether those claims could be supported with a limited context. The results of the study are not generalizable statistically, based on the sample size (47) and multiple case approach (three cases and nine interviews). Rather, the results reflect findings for three manufacturing companies at a single point in time, and can only be generalized analytically.

Regarding the quantitative model, Overall employee satisfaction, or OES, was operationalized as a composite of the five dimensions (EA, TE, SA, EP, and JC). The five dimensions are theorized to contribute to a measure of satisfaction—that is, they are causally related. The confirmatory factor analysis (CFA) allows for an exploration of variation, and the relative contribution of each variable for explanatory value.

The five dimensions were tested for statistical significance, and all but one—Training Effectiveness, or TE—contributed significantly to the composite index measure of OES.

Satisfaction was operationalized as being composed of a summative scale of the five dimensions of satisfaction. The alternative would be a wholly independent measure of satisfaction, but it would be unanchored to the dimensions specifically informed by the presence of advanced technology. A wholly independent measure of satisfaction would have to be very carefully crafted, as satisfaction could be derived from any number of factors unrelated to technology use (i.e., high-quality coffee in the staff lunchroom, an advantageous shift structure, a supportive network of friends at work, etc.). Since the composite index measure explores satisfaction as informed by the antecedents of technology implementation, it was anchored to dimensions.

A confirmatory factor analysis tested the degree to which the data fit the hypothesized measurement model of satisfaction. The way the measure of satisfaction was crafted was limited within the context of the study, in that, the measure of satisfaction as a construct of the five dimensions, provided an understanding of not only which dimensions contributed significantly to the measure of satisfaction, but in what way. The factor analysis helped inform an understanding of a very specific, and limited, measure of employee satisfaction as it relates specifically to technology. It allowed for a better understanding of how the dimensions interact, in order to assess the assumptions that underpin them.

The limitations of the model present challenges if it were to be applied more broadly. Satisfaction, if it were clearly separated from the constructs it was hypothesized to be influenced by, could be examined in the context of a variety of different dimensions, allowing the researcher to determine if any extraneous variables were significant. The researcher would have to clearly define and create a distinct scale to measure satisfaction, and would have to address the challenges and opportunities of doing so. Future work in this area could examine the antecedents of employee satisfaction using a wholly independent measure of employee satisfaction, which could provide further insights into the relationship between claims about working conditions, and whether they are realized. An exploration of demographic factors (i.e., age, education level, tenure, etc.) could provide an interesting comparative element to a future study, helping understand how different groups could have different experiences with technology in the workplace.

The relatively small quantitative sample size is a significant limitation of the study, even though the findings are supplemented by the qualitative exploration. A more substantial study with a larger sample size will allow for a more definitive exploration of the research question, and inform statistically generalizable findings. This represents a possibility for future study. Despite the limitations of the study, however, key findings may provide insights into similar organizations, and may serve as a framework for assessing the role of technology in manufacturing, and how Industry 4.0 interacts with lean manufacturing methodology.

c. Future Directions

At the time of completion of this dissertation, artificial intelligence (AI) is increasingly contributing to the evolution of Industry 4.0. As companies and diverse industries focus on improving product consistency, productivity and controlling operating costs, hyper-connected manufacturing processes that depend on smart machines will undoubtedly leverage AI automation to improve manufacturing outcomes (Javaid et al., 2022). Using AI to process data from IoT devices and connected machines, to iterate and design, and enhance predictive analytics will likely intensify Industry 4.0 adoption. The analysis of the qualitative data reveals that four of the interviewees referenced AI, anticipating its introduction, and all indicating that AI will likely be beneficial for their role. Future research in this area will have to consider the impact AI will have on Industry 4.0, and how it will continue to shape and inform the subjective experience of work. Industry 4.0 and associated technologies are likely to undergo significant change in the near future as artificial intelligence and similar technologies such as Machine Learning become more ubiquitous. This trend will undoubtedly have significant implications for workforce interactions, the ways work and organizations are structured, and how individuals engage in the process of work, how they interact, and how they engage with the technologies.

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Appendix A: Interview Guide

Q: How do employees within lean manufacturing organizations experience work in relation to the stated claims about the implementation of Industry 4.0 technologies for organizations?

Exploring the subjective experience of work requires the interviewer to overcome several challenges associated with the recollection of that experience, including unstable attention, absorption of the objective, escape into representation, lack of awareness of the level of detail required by the interviewer, and the impossibility of immediate access (Petitmengin, 2006).

The context and the conditions of the interview are important to help subjects maintain attention, and to reflect fully on their experience. The interview will take place over an online meeting (i.e., Zoom, Teams, Skype, etc.), and the subject should be in a physical space in which they are comfortable and can focus. Borrowing from the Focusing Method, (Lyons et al., 2021), subjects will be encouraged at the start of the interview to leave aside any issues of concerns unrelated to the interview at hand, so they can focus clearly and intensely on the experience to be explored.

As the interview progresses the interviewer will actively attempt to stabilize the attention of the subject through the regular reformulation of what the subject has said. Each time there is a digression, the interviewer should repeatedly and unceasingly reformulate all the descriptive elements concerning the experience itself, refocusing the attention on the experience itself. The goal, according to Petitmengin (2006) is to ensure that the subject doesn't drift away from a description of their experience in order to make comments or judgments about it. The focus should be on the experience itself. The use of direct reference (Gendlin, 1962), which consists of encouraging the individual interviewed that, when a feeling that is difficult to articulate emerges to identify it and to designate it with a generic term, so it can be isolated and referenced.

Since the goal of the semi-structured interview of to gain an understanding of the subjective experience of work in organizations that employ advanced lean systems, it is important that the attention of the interview subjects is focused less of the objects which appear to the consciousness, but rather towards the subjective modes of appearance of these objects (Husserl, 1962), or the phenomenological conversion. Attention is directed from the perceived object to the act of perceiving, or from the object of the memory toward the act of remembering. In order to help the subject executive this conversion of attention, that is, to describe what they experienced, and not what they imagined they experienced, the interviewer should help them focus on singular experiences, rather than general descriptions. The focus on singular experience allows the interviewee to become aware of the pre-reflective dimension of their experience, and describe it in detail. According to Vermersch et al. (1997) the more the interviewee is in contact with a specific and genuinely lived experience, the less likely it is that they make generalizations. This can be accomplished through the re-enactment of past experience, which involved facilitating a recollection of the spatio-temporal context of the experience (where, when, with whom, etc.) focusing on the visual, auditive, tactile, olfactory and kinesthetic sensations associated with the experience.

The interview experience requires that there is a relationship of trust between the two people involved. According to Petitmengin (2006) this is for two reasons: (1) it is important for the interviewee to understand the objective of the interview, and be able to accept direction from the interviewer; and (2) the interviewee must be comfortable dropping their guard, and allowing themselves to be vulnerable with the interviewer, which is characterized by an inherent intimacy.

With these preconditions in place, the interview will proceed in a semi-structured manner, and is estimated to last 45-75 minutes, depending on the flow of the conversation, the follow-up questions required, and the level of detail provided.

1. Please provide your name, your job title, and how long you have been with the organization.
2. Can you please describe your role.
3. Please take me through your daily tasks, as they exist currently.
4. How have your tasks changed with the adoption of new methods, and/or new technologies?
5. How do you feel about how those changes will impact you?
6. Do you feel like your job will become easier, or will it be more difficult? Why?
7. Do you have any anxiety about the changing nature of your role?
8. How has the new technologies changed your workload?
9. Would you characterize the technology you use on a daily basis as either as constricting, or do you find it freeing? Please explain.
10. Has your work-life balance been affected by the changes at work?

11. Describe the level of autonomy in your role. What role has the changes and new technology had on your level of autonomy?
12. Have you been offered any opportunities for training or development?
13. How do you feel about your work?
14. Do you find your work to be fulfilling, both personally and professionally?
15. Do you ever think about finding a different role, or looking for work elsewhere? Why?
16. How would you describe your level of stress?
17. Do you feel like your personal and professional goals are aligned with those of the organization?
18. Do you feel like if the company benefits from these programs and investments, you will too? In what way?
19. Were you involved in the changes made to your role, or your tasks? If so, please describe the process. How did you feel about it? If not, would you like to be?
20. Describe your relationship with your manager. Do you feel as if these changes will impact that relationship? How?
21. Describe your relationship with your coworkers. Have the changes made affected any workplace relationships?
22. How would you describe the morale of your unit/area? Does that differ from the organization, insofar as you can tell?
23. How do you feel about the company's future? Do you believe these changes are positive?
24. How do you feel about the prospect of more changes to come?
25. How long do you see yourself in this role?

Each of the questions will inform an individual narrative regarding the experience of Industry 4.0 adoption in organizations that have a robust lean program in place. The objective is to understand the subjective experience of employees in these organizations, and to see if their experiences are aligned with stated organizational goals.

Appendix B: Questionnaire

H1 - Autonomy

1. Employees here are allowed to make work decisions without consulting anyone else.
2. How things are done here is left pretty much up to the person doing the work.
3. I feel certain about how much authority I have.
4. I am required to learn new things for my job.
5. I feel like I can be creative at work.
6. My job requires a high level of skill.
7. I control the pace of my work.
8. I am able to determine the order in which I complete tasks.

Scale: Strongly Disagree; Disagree; Neither Agree or Disagree; Agree; Strongly Agree

H2 - Training Effectiveness

1. My manager encourages and supports me to take advantage of training and development opportunities.
2. My manager regularly discusses my training and development with me.
3. My manager jointly sets tasks and development goals with me.
4. My manager jointly reviews progress on tasks and development goals at timely intervals.
5. My manager coaches and guides me effectively.

Scale: To a great extent; To a moderate extent; To a limited extent

H3 - Productivity

1. I manage to plan my work so that I finish it on time.
2. I keep in mind the work result that I need to achieve.
3. I am able to set priorities.
4. I am able to carry out my work efficiently.
5. I manage my time well.
6. On my own initiative, I start new tasks when my old tasks are completed.

7. I take on challenging tasks when they were available.
8. I work on keeping my job-related knowledge up-to-date.
9. I work on keeping my work skills up-to-date.
10. I take on extra responsibilities in the workplace.
11. I come up with creative solutions for new problems.
12. I continually seek new challenges in my work.
13. I actively participate in meetings and/or consultations.

14. I complain about minor work-related issues at work.
15. I make problems at work bigger than they are.
16. I focus on the negative aspects of situations at work instead of the positive aspects.
17. I talk to colleagues about the negative aspects of my work.
18. I talk to people outside the organization about the negative aspects of my work.

Scale: Never; Seldom; Sometimes; Often; Always

H4 - Job Control

1. How much control do you have over the variety of methods you use in completing your work?
2. How much can you choose among a variety of tasks or projects to do?
3. How much control do you have, personally, over the quality of your work?
4. How much control do you have over how quickly or slowly you work?
5. How much control do you have over the scheduling and duration of your rest breaks?
6. How much control do you have over when you come to work, and when you leave?
7. How much control do you have over when you take vacation or days off?
8. How much are you able to predict what the results of decisions you make on the job will be?
9. How much are you able to decorate, rearrange, or personalize your work area?
10. How much can you control the physical conditions of your work station (lighting, temperature, etc.)?
11. How much control do you have over how you do your work?
12. How much can you control when and how much you interact with others at work?

13. How much influence do you have over the policies and procedures in your work unit?
14. How much control do you have over the sources of information (data sets, experiments, knowledge, etc.) you need to do your job?
15. How much are things that affect you at work predictable, even if you can't directly control them?
16. How much control do you have over the resources (i.e., tools, materials, etc.) you get?
17. How much can you control the number of times you are interrupted while you work?
18. How much can you control the number of times you are interrupted while you work?
19. How much control do you have over the amount you earn at your job?
20. How much control do you have over how your work is evaluated?
21. In general, how much overall control do you have over work and work-related matters?

Scale: Very Little; Little; A Moderate Amount; Much; Very Much

H5 - Safety Awareness

1. There is an opportunity to discuss safety in meetings.
2. Management pays attention to workers ideas to improve safety.
3. Workers are consulted on safety issues.
4. Information is provided on current safety issues.
5. Investments are made in safety training for workers.
6. Safety training provided is of high quality.
7. Management care about safety when setting production schedules.
8. Management considers safety when moving or promoting people.
9. Management cares about safety more than delays in production.
10. Management clearly demonstrates a desire to improve safety in the workplace.
11. Management reacts quickly to solve safety hazards.
12. Company safety officers have power to make decisions and take action to address issues.

13. Supervisors care about safety rules when a delay in production occurs.
14. Supervisors show care to provide workers with safety equipment when needed.
15. Supervisors care about the use of safety equipment.
16. Supervisors show concern about safety rules when workers are tired.
17. Supervisors provide coaching about safety.
18. Supervisors offer praise for safety behaviors.
19. Team members speak about speak about safety.
20. Team members actively discuss safety incidents, and discuss prevention measures.

21. Team members discuss safety hazards.
22. Team members emphasize safety, even when under pressure.
23. Team members care about the level of safety awareness.
24. Team members mentor each other about working safely.
25. Team members care about safety at the end of the shift.
26. Team members care about safety, even when tired.
27. Team members care about safety, even when a delay in production occurs.
28. Team members care about worker's safety equipment, and its availability.
29. Team members remind one another about using safety equipment properly.
30. Team members care about one another’s compliance with safety rules.

Scale: Never; Seldom; Sometimes; Often; Always

Appendix C: NVivo Codebook

DBA 899 – Dissertation – Code Book

Name	Description
(EA) Employee Autonomy	Do you feel that, because of the technological environment, you have more freedom to adapt and solve problems?
(-) Change is difficult	Change is taxing, and is quite difficult to implement and sustain. Expensive, stressful and hard.
(-) Declining work-life balance	Industry 4.0 has negatively affected employee work-life balance.
(-) Difficulty of training	Training is difficult to manage, difficult to plan, and difficult to grasp for individuals that are not as comfortable with technology.
(-) Limited autonomy	Industry 4.0 has resulted in limited, or restricted autonomy, or led to a decline in autonomy.
(+) Enhanced Decision-Making	Technology improves decision-making process, and leads to better decisions being made.
(+) Enhances autonomy	Industry 4.0 technology informs a feeling, or self-declaration of autonomy.
(+) Enjoy technology	Enjoy working with new technologies (a positive challenge)

Name	Description
(+) Formal leadership	Formal leadership is part of role
(+) Fulfilling	Work is fulfilling, personally &/or professionally.
(+) Improved work-life balance	Technology has facilitated an improvement in work-life balance.
(+) Skills used	Working with technology requires a high level of skill, and allows individuals to use their skills
(+) Tech informs creativity	The tech enhances creative efforts, and allows employees to experience and enjoy a higher level of creativity at work
Need to learn	An increase in the amount that one needs to learn to complete on-the-job tasks.
Static Autonomy	The technology has not significantly changed the level of autonomy; employee autonomy is derived from some other area (i.e., existing organizational structure or hierarchy)
Tasks have changed	The technology has driven a change in role, and a change in job tasks. Neither positive or negative
Tasks have not changed	Tasks have NOT changed significantly as a result of Industry 4.0 technological adoption.
Unchanged work-life balance	Work-life balance unchanged as a result of the implementation of Industry 4.0.

Name	Description
(EP) Employee Productivity	Do you feel you are more productive because of the technology you are using?
(-) Increased Workload	The implementation of Industry 4.0 has led to an increased workload.
(+) AI will be beneficial	AI will be beneficial as it's integrated into emerging Industry 4.0 systems.
(+) Automate routine tasks	The routinization of mundane and administrative tasks will allow for more focus on value-added and skilled work.
(+) Good communication	Good communication; provision of coaching and the provision of guidance
(+) Increased output	Technology has enhanced the ability to increase manufacturing output
(+) Increased team collaboration	Technology necessitates increased collaboration between organizational units, teams, and individuals who may otherwise not.
(+) Increased Transparency	Technology has increased transparency about the organization's internal activities.
(+) Pride in work	Employees are proud of the work that they do, and generally feel positively about their work and workplace.
(+) Tech eliminates errors	The technology helps reduce errors and risks in the manufacturing process.

Name	Description
Static Workload	Workload has neither increased nor decreased. Shifted perhaps, but no absolute increase.
(JC) Job Control	Do you have access to more flexible work arrangements, and is your workplace more accessible? Is there more transparency in your organization?
(-) Constricted Focus	The technology leads to a constricted focus, as employees are inherently bound to a single technological setup.
(-) Flexibility	Reduced flexibility in role.
(-) Goals not aligned	Personal and professional goals are not aligned with the organization.
(-) Stress is High	Technology and its use contribute to high stress, negatively impacting the employee.
(-) Tasks set by mgmt (no Involvement)	Employees are not consulted or involved in the changes made to their roles. Changes are ultimately decided by management.
(-) Workload increased	Workload has increased as a result of the technology
(+) Accessibility	Technology facilitates a more accessible workplace (i.e., employees with mobility issues are engaged, and are able to contribute without facing barriers).

Name	Description
(+) Flexibility	Technology increases the perception and feeling of flexibility.
(+) Goals aligned with organization	Personal and professional goals are positively aligned with the organization.
(+) Influence over policies and procedures	Influence over the policies and procedures at work
(+) Office location	Primary location is in an office
(+) Participation in management	Being a member of, or acting in the capacity of, management within the organization.
(+) Staying in role	Employee is interested in remaining in their role, and not seeking to leave.
(+) Stress is low, or well-managed	Stress is low, or well managed. There are programs in place to ensure employees monitor and maintain a healthy level of stress, and are able to cope well with it.
(+) Technology frees up time	Technology is ultimately freeing, in that it provides more flexibility, free time, and more options for employees.
(+) Technology increases speed & adaptability	Technology increases the speed at which employees are able to respond/react to problems, and adapt quickly

Name	Description
Stress is moderate	Neither an increase nor a decrease in the stress of any employee
Workload unchanged	Workload neither increased nor decreased as a result of the technology.
(SA) Safety Awareness	Do you feel that the technology that you are using is making your job and jobsite safer?
(-) Creates complacency	Organizations rely too heavily on technology to drive safety, creating complacency.
(+) Communication emphasized in training	Training provides information on the safe use of technology.
(+) Employees are consulted	Employees are consulted on safety issues, and are engaged in a meaningful way.
(+) Improved Ergonomics	Technology has helped improve ergonomics of employees, reducing potential for strains and related injuries.
(+) Improves Safety	Employee perception is that Industry 4.0 contributes meaningfully to, and helps inform, a generally safe workplace. The workplace is safer than it otherwise would be.
(+) Less human intervention in process	Less human intervention in the manufacturing process (i.e., involvement in changeovers, tool changes, etc.). Less physical intervention is inherently safer.

Name	Description
(+) Management Attention	Management pays attention to issues and addresses them
(TE) Training Effectiveness	Do you receive training to keep your skills up-to-date with the technology?
(-) Limited Training	Organizational-directed training has been limited. Engagement in self-directed learning to understand the technology.
(+) Training is encouraged	Manager encourages employee to take advantage of training and development opportunities.
Continuous Learning	Continuous learning will need to be implemented and supported by organizations, and available to employees.
Technology Integration	
(-) Anxious about change	Anxiety about changes, and worry about the level of investment in Industry 4.0.
(-) Longevity in role	Limited longevity in role
(-) Looking for new employment	Identified that employee is seeking alternative employment, and/or looking to make a change.
(-) Relationship with manager	A negative relationship with manager.

Name	Description
(+) Customer Value	Improves ability to provide quality and timely information to customers.
(+) Future Outlook	Outlook for the organization is generally positive; Industry 4.0 is positively received, and contributes meaningfully to this perspective.
(+) Good Morale	Organizational morale is good, or generally positive.
(+) Longevity in role	Employee expects, or is interested in, remaining in role for a relatively long duration.
(+) Optimistic about change	Generally optimistic about future changes and developments.
(+) Relationship with coworkers	Employee reports a positive and constructive relationship with coworkers in an Industry 4.0 environment.
(+) Relationship with manager	Employee reports a positive relationship with manager.
(+) Successfully integrated	Industry 4.0 has been implemented successfully, and integrated well into the organization's systems.
Significant organizational change	There is a significant organizational change as a result of Industry 4.0 technological implementation. Neither positive or negative.

Name	Description
Technology Interconnectedness	Technology enables interconnectedness; Employees work in an interconnected and interdependent workplace.

Appendix D: Structure/Agency Codebook

Cluster 1: Structure		Cluster 2: Agency	
Name	Description	Name	Description
(+) Increased output	Technology has enhanced the ability to increase manufacturing output	(+) Fulfilling	Work is fulfilling, personally &/or professionally.
(+) Training is encouraged	Manager encourages employee to take advantage of training and development opportunities.	(+) Future Outlook	Outlook for the organization is generally positive; Industry 4.0 is positively received, and contributes meaningfully to this perspective.
(+) Skills used	Working with technology requires a high level of skill, and allows individuals to use their skills	Need to learn	An increase in the amount that one needs to learn to complete on-the-job tasks.
(-) Difficult to manage change	Change is difficult to manage and expensive.	(+) Goals aligned with organization	Personal and professional goals are positively aligned with the organization.
(+) Accessibility	Technology facilitates a more accessible workplace (i.e., employees with mobility issues are engaged, and are able to contribute without facing barriers).	(+) AI will be beneficial	AI will be beneficial as it's integrated into emerging Industry 4.0 systems.
(+) Automate routine tasks	The routinization of mundane and administrative tasks will allow for more focus on value-added and skilled work.	(+) Longevity in role	Employee expects, or is interested in, remaining in role for a relatively long duration.

(+) Flexibility	Technology increases the perception and feeling of flexibility.	(+) Optimistic about change	Generally optimistic about future changes and developments.
(+) Improves Safety	Employee perception is that Industry 4.0 contributes meaningfully to, and helps inform, a generally safe workplace. The workplace is safer than it otherwise would be.	(+) Enhances autonomy	Industry 4.0 technology informs a feeling, or self-declaration of autonomy.
Tasks have changed	The technology has driven a change in role, and a change in job tasks. Neither positive or negative	(-) Stress is High	Technology and its use contributes to high stress, negatively impacting the employee.
(+) Good communication	Good communication; provision of coaching and the provision of guidance	(+) Relationship with coworkers	Employee reports a positive and constructive relationship with coworkers in an Industry 4.0 environment.
(+) Office location	Primary location is in an office	(+) Good Morale	Organizational morale is good, or generally positive.
(+) Participation in management	Being a member of, or acting in the capacity of, management within the organization.	(+) Relationship with manager	Employee reports a positive relationship with manager.
Continuous Learning	Continuous learning will need to be implemented and supported by organizations, and available to employees.	(+) Enjoy technology	Enjoy working with new technologies (a positive challenge)
Significant organizational change	There is a significant organizational change as a result of Industry 4.0 technological implementation. Neither positive or negative.	Stress is moderate	Neither an increase nor a decrease in the stress of any employee

(+) Increased team collaboration	Technology necessitates increased collaboration between organizational units, teams, and individuals who may otherwise not.	(+) Management Attention	Management pays attention to issues and addresses them
(+) Increased Transparency	Technology has increased transparency about the organization's internal activities.	(-) Limited autonomy	Industry 4.0 has resulted in limited, or restricted autonomy, or led to a decline in autonomy.
(+) Technology frees up time	Technology is ultimately freeing, in that it provides more flexibility, free time, and more options for employees.	(+) Improved work-life balance	Technology has facilitated an improvement in work-life balance.
(+) Technology increases speed & adaptability	Technology increases the speed at which employees are able to respond/react to problems, and adapt quickly	Unchanged work-life balance	Work-life balance unchanged as a result of the implementation of Industry 4.0.
(-) Limited Training	Organizational-directed training has been limited. Engagement in self-directed learning to understand the technology.	(-) Constricted Focus	The technology leads to a constricted focus, as employees are inherently bound to a single technological setup.
(+) Successfully integrated	Industry 4.0 has been implemented successfully, and integrated well into the organization's systems.	(-) Flexibility	Reduced flexibility in role.
(-) Change is difficult	Change is taxing, and is quite difficult to implement and sustain. Expensive, stressful and hard.	(-) Anxious about change	Anxiety about changes, and worry about the level of investment in Industry 4.0.
(-) Difficulty of training	Training is difficult to manage, difficult to plan, and difficult to	(-) Longevity in role	Limited longevity in role

	grasp for individuals that are not as comfortable with technology.		
(+) Formal leadership	Formal leadership is part of role	(-) Declining work-life balance	Industry 4.0 has negatively affected employee work-life balance.
(+) Less human intervention in process	Less human intervention in the manufacturing process (i.e., involvement in changeovers, tool changes, etc.). Less physical intervention is inherently safer.	Static Autonomy	The technology has not significantly changed the level of autonomy; employee autonomy is derived from some other area (i.e., existing organizational structure or hierarchy)
(+) Customer Value	Improves ability to provide quality and timely information to customers.	(+) Pride in work	Employees are proud of the work that they do, and generally feel positively about their work and workplace.
Tasks have not changed	Tasks have NOT changed significantly as a result of Industry 4.0 technological adoption.	(-) Goals not aligned	Personal and professional goals are not aligned with the organization.
Static Workload	Workload has neither increased nor decreased. Shifted perhaps, but no absolute increase.	(+) Staying in role	Employee is interested in remaining in their role, and not seeking to leave.
(+) Influence over policies and procedures	Influence over the policies and procedures at work	(+) Stress is low, or well-managed	Stress is low, or well managed. There are programs in place to ensure employees monitor and maintain a healthy level of stress, and are able to cope well with it.

(+) Communication emphasized in training	Training provides information on the safe use of technology.
(+) Employees are consulted	Employees are consulted on safety issues, and are engaged in a meaningful way.
(+) Enhanced Decision-Making	Technology improves decision-making process, and leads to better decisions being made.
(+) Tech informs creativity	The tech enhances creative efforts, and allows employees to experience and enjoy a higher level of creativity at work
(+) Tech eliminates errors	The technology helps reduce errors and risks in the manufacturing process.
(-) Workload increased	Workload has increased as a result of the technology
(+) Improved Ergonomics	Technology has helped improve ergonomics of employees, reducing potential for strains and related injuries.
Technology Interconnectedness	Technology enables interconnectedness; Employees work in an interconnected and interdependent workplace.
(-) Increased Workload	The implementation of Industry 4.0 has led to an increased workload.

(-) Creates complacency	Organizations rely too heavily on technology to drive safety, creating complacency.
(-) Looking for new employment	Identified that employee is seeking alternative employment, and/or looking to make a change.
(-) Relationship with manager	A negative relationship with manager.

(-) Tasks set by mgmt (no Involvement)	Employees are not consulted or involved in the changes made to their roles. Changes are ultimately decided by management.
Workload unchanged	Workload neither increased nor decreased as a result of the technology.

Appendix E: Manual Code Clusters

Q: How do employees in organizations with a formal lean manufacturing program experience work in relation to the stated claims about the implementation of Industry 4.0 technologies for organizations?

Coding: First Round

1. **[Employee Autonomy – EA]** Industry 4.0 will enable connected workflows in intelligent technological environments to give workers not just the tools, but the freedom to adapt and solve problems in creative ways (Hoey, 2018);

Cluster 1: Work is fulfilling (satisfies curiosity, stimulates interest, and is engaging)	Cluster 2: Enables use of skills (challenging, utilizes skills to address problems and solve)	Cluster 3: Requires learning (upgrading of skills and changing work)	Cluster 4: Tasks have changed	Cluster 5: Increased autonomy (freedom to adapt)

(+) Fulfilling (+) Tech informs creativity (+) Enjoy technology	(+) Skills used (+) Formal leadership (+) Enhanced Decision-Making	Need to learn (-) Difficulty of training	Tasks have changed (-) Change is difficult Tasks have not changed	(+) Enhances autonomy (+) Improved work-life balance (-) Limited autonomy (-) Declining work-life balance Unchanged work-life balance Static Autonomy

2. **[Job Control – JC]** Industry 4.0 will require organizations to actively invest in their workforce through retraining efforts and upgrading employees' current skill sets so they can manage automated processes or take on "creative" jobs that are less likely to be replaced by automation. As automated tasks are phased in, simultaneously training existing workers with the incremental skills needed for higher-level jobs (e.g., data analysis, process improvements) can help mitigate the perceived threat of automation (Navales, 2018);

Cluster 1: Industry 4.0 leads to increased output; increased pride in outcome	Cluster 2: Change is difficult to manage and adapt to	Cluster 3: The growing role of AI; speculation about the future	Cluster 4: Automation	Cluster 5: Improved communication

(+) Increased output (+) Pride in work	(-) Difficult to manage change (-) Increased Workload Static Workload	(+) AI will be beneficial	(+) Automate routine tasks (+) Tech eliminates errors	(+) Good communication (+) Increased team collaboration (+) Increased Transparency

3. **[Employee Productivity – EP]** Industry 4.0 leads to higher productivity (elimination of errors and risks, production of larger quantities of products, reduction of working hours); higher flexibility (individualized products, more efficient production, wide variability in control processes); higher competitiveness (lower production costs, implementation of innovations and innovative solutions, flexible responses to fluctuations in demand); higher profitability (mass production, process optimization, lower stocks, more economical production);

Cluster 1: Alignment	Cluster 2: Accessibility of work	Cluster 3: Flexibility	Cluster 4: Employee control over job/tasks
(+) Goals aligned with organization (+) Staying in role (-) Goals not aligned	(+) Accessibility (+) Office location	(+) Flexibility (+) Technology increases speed & adaptability (+) Technology frees up time (-) Flexibility	(+) Participation in management (+) Influence over policies and procedures (-) Workload increased

		(-) Constricted Focus	(-) Stress is High (-) Tasks set by mgmt (no Involvement) (+) Stress is low, or well-managed Stress is moderate Workload unchanged

4. **[Safety Awareness – SA]** Industry 4.0 leads to superior safety outcomes (limiting defects and errors—software, protection of workforce safety by sensors, immediate reactions and interventions) (Grenčiková et al., 2020); and

Cluster 1: Industry 4.0 leads to improved safety outcomes, and a higher degree of safety awareness and engagement	Cluster 2: Industry 4.0 has reduced the need for humans to intervene in manufacturing processes, and improved ergonomics (reducing the chances of injury)
(+) Improves Safety (+) Management Attention (+) Employees are consulted (+) Communication emphasized in training	(+) Less human intervention in process (+) Improved Ergonomics (-) Creates complacency

5. **[Training Effectiveness – TE]** The emerging technologies of Industry 4.0 have made flexible working arrangements more accessible and transparent, which are becoming more important to staff attraction and retention (O'Brien, 2018).

Cluster 1: Training and development is encouraged	Cluster 2: Continuous learning needs to be implemented, supported, and available to employees
(+) Training is encouraged (-) Limited Training	Continuous Learning

Broad statements concerning the investment in, and integration of Industry 4.0 technologies in manufacturing operations:

Cluster 1: Optimistic about the future of the company	Cluster 2: Overall positive experience informing employee commitment	Cluster 3: Optimistic about the role of the technology	Cluster 4: Organizational change (neither positive or negative)
(+) Future Outlook (-) Anxious about change	(+) Longevity in role (+) Relationship with coworkers (+) Relationship with manager (+) Good Morale (-) Longevity in role	(+) Optimistic about change (+) Successfully integrated (+) Customer Value	Significant organizational change Technology Interconnectedness

	(-) Looking for new employment (-) Relationship with manager		

Coding: Third Round

Demi-Regularities

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
(+) Increased output	(+) Fulfilling	(+) Training is encouraged	(+) Future Outlook	(+) Accessibility	(+) Improves Safety	(+) Relationship with coworkers
(+) Automate routine tasks (+) Technology increases speed & adaptability (+) Technology frees up time	(+) Skills used (+) Enhances autonomy (+) Participation in management (+) Enjoy technology	Need to learn Tasks have changed (-) Stress is High Continuous Learning (-) Difficulty of training	(+) Goals aligned with organization (+) Longevity in role (+) Optimistic about change (+) Good Morale	(+) Flexibility	(+) Less human intervention in process Static Workload (+) Employees are consulted	(+) Good communication (+) Relationship with manager (+) Increased team collaboration

	(+) Formal leadership Stress is moderate		(+) AI will be beneficial Significant organizational change (-) Change is difficult			(+) Increased Transparency (+) Management Attention (+) Office location

Appendix F: Retroductive Analysis

Summary

Demi-Regularity (Event)		Mechanism(s) - ACTUAL	Structure(s) - REAL	Theoretical Foundation
Industry 4.0 technologies enhance output, and output potential (+ Increased Output)	X	(1) Focus on process optimization; (2) investment in advanced engineering software	(1) Highly regulated industry; (2) Cost-competitive nature of the industry	Theory of Constraints
	Y	(1) Investment in software; (2) Strategic focus on output	Strong customer demand	Lean Manufacturing
	Z	(1) Application of CI methodology; Investment in production technology	(1) Strong customer demand; (2) shared cultural beliefs	Resource Dependence Theory
Work was reported to be fulfilling, either personally, or professionally (+ Fulfilling)	X	(1) Alignment of personal values and organizational values; (2) Provision of autonomy and decision-making power	Integration of humans into production systems	Self-determination Theory
	Y			
	Z			

Employees are encouraged to take advantage of training and development opportunities (+ Training is Encouraged)	X	(1) Extensive training provided to employees; (2) Improved employee skill	(1) Focus on growth; (2) Highly regulated industry	Constructivist Learning Theory
	Y	Extensive employee training	(1) Rapid changes in customer design requirements; (2) Strong customer demand	Organizational Learning Theory
	Z	Extensive employee training	Focus on growth	Organizational Learning Theory
Industry 4.0 technologies facilitate a more accessible workplace (+ Accessibility)	X Y Z	Advanced technologies and organizational systems	Social awareness of accommodation and flexible workplaces	Social Model of Disability
The outlook for the organization implementing Industry 4.0 is positive	X Y Z	(1) Implementation of technology; (2) Organizational alignment to growth objective	Market opportunity for sales growth	Expectancy Theory
There is a shared perception that Industry 4.0 contributes meaningfully	X Y	Implementation of technology		Safety Culture Theory

to a safe workplace (+ Improves Safety)	Z		Recognition of the importance of safety and employee well-being	
Industry 4.0 facilitates a positive and constructive relationship between coworkers	X	Implementation of technology	Recognition of the value of collaboration	Social Learning Theory
	Y			
	Z			

Detail

Demi-Regularity (Event)	Participant	References	Event(s)	Interacting Entities	Mechanism(s)	Structure(s)	Theoretical Foundation	Context (Circumstances)/ Social Conditions
Industry 4.0 technologies enhance output, and output potential (+ Increased Output)	P1	The additive manufacturing technology has greatly expanded our ability to deliver high quality parts and service to our customers, as quickly as possible.	1. Delivery of high quality parts 2. Increased delivery speed (parts and service)	Regulators (Transport Canada; ISO); 3D Printers; QA Operators and SOPs; Sales and Operations Communications; Industry Norms	Technology (3D Printing); Safety culture in aerospace; Six-Sigma adoption and low tolerance for failures; High costs of liabilities and insurance rates; Highly regulated environment; High up-front costs for quality to reduce long-term costs	Growth strategy (Company X) focused on domestic and international expansion; Highly regulated manufacturing environment; Institutional norms (no room for failure) in aerospace	Systems Theory (Regulations in aerospace stem from systems thinking to ensure aircraft operate harmoniously and safely); Reliability Engineering Theory (Rigorous testing and QA; FMEA and RCM); Stakeholder Theory (Regulations need to balance competing interests to ensure sustainability and social benefit)	High growth organizational strategy; leverage LEAN manufacturing program to maximize efficiencies and reduce cost

	P1	In a commercial manufacturing environment the use of sensors and smart tech will provide real-time diagnostics and help identify issues and failures.	Real-time diagnostics	Sensors and related hardware; Institutional Norms	Emphasis on reducing the risk of failures; focus on the reduction of equipment downtime; Proactive maintenance	Technological infrastructure; management systems (LEAN and Six Sigma); workplace culture; incentive systems (performance-based bonuses and incentives); safety regulations; QC and assurance (industry driven)	Information Theory; Network Theory & Distributed Systems; Embedded Systems Theory; Ubiquitous Computing Theory	Management engaged in monitoring and sharing data across job functions; high degree of collaboration between managers and non-managers
	P2	Monitoring the production process and monitoring machine status allows us to optimize our processes, limit downtime, and schedule maintenance and changeovers.	1. Real-time diagnostics 2. Reduced Downtime 3. Improved maintenance scheduling	Sensors and related hardware; continuous improvement/optimization methodology; cultural norm (reduced downtime); economic factor (cost control and profitability)	Focus on process optimization; Proactive maintenance	Technological infrastructure; management systems (LEAN and Six Sigma); workplace culture (focus on efficiency); Organizational structure (latitude in improving maintenance scheduling, non-unionized)	Information Theory; Network Theory & Distributed Systems; Embedded Systems Theory; Ubiquitous Computing Theory	Significant investment of time in process optimization

	P2	As computers become more sophisticated and software more advanced, we can run better simulations much faster than even a few years ago, allowing us to simulate a broad range of operating conditions, loads, and stressors that our parts and aircraft may face.	Improved computer models (more iterations, more quickly)	Software; Computer Hardware; Individuals (engineers); Industry best practices	Power to iterate more quickly; Emphasis on scenario analysis & broad range of scenarios	Cultural beliefs (focus on efficiency); economic systems (improve profitability); regulatory environment	Lean Thinking; FMEA; Total Productive Maintenance (TPM); Six Sigma; Reliability Theory	Investment in the engineering component of the manufacturing process, namely in design
	P2	I feel that I am able to spend more time working on design issues, and less time having to work with machines. I think that the integration of our machines and our systems has made everyone more productive. We're producing more now than we ever have, and we're doing it at a competitive price point.	1. Less time spent on machines 2. Increased output of components/parts	Individuals (operators and engineers); production machines; manufacturing process; organizations (customers)	Focus on competitive pricing; technology integration into existing systems	Cultural beliefs (focus on efficiency); economic systems (improve profitability); regulatory environment	Theory of Constraints (TOC); Lean; Total Quality Management (TQM); Continuous Flow	Integration is not an easy, nor is it a fast process. New equipment takes months to integrate, and takes considerable investment, planning, and engineering capability.

	P7	Without a doubt, yes. I can accomplish far more in terms of design and prototype development and testing than I ever could have before. The technology we use is unbelievable in its productive potential.	Improved computer models (more iterations, more quickly)	Software; Computer Hardware; Individuals (engineers); Industry best practices	Power to iterate more quickly; Emphasis on scenario analysis & broad range of scenarios	Cultural beliefs (focus on efficiency); economic systems (improve profitability); regulatory environment	Lean Thinking; FMEA; Total Productive Maintenance (TPM); Six Sigma; Reliability Theory	Investment in the engineering component of the manufacturing process, namely in design
	P3	From my perspective, yes. Collaborative software and advanced software used in design and testing have made us more productive. The technology that we use in manufacturing has made us far more efficient, safer, and more productive.	Increased productivity	Software; Computer Hardware; individuals; economic factors; communication between groups	Investment in advanced software	Economic systems (focus on ROI); Technological infrastructure; organizational norms	Theory of Constraints (TOC); Lean; Total Quality Management (TQM); Continuous Flow	Company manufactures machining equipment, often integrating their own designs and equipment into the processes, giving it a unique ability to test integration.

	P4	Absolutely, one hundred percent. The amount that we can do in a day is dramatic. The technology is great at driving productivity.	Increased output and task productivity (faster and more effective task execution)	Individuals; technology	Focus on outputs	Economic systems (focus on ROI); Technological infrastructure; organizational norms	Economies of scale; Lean; TOC	Productivity is measured objectively by output (designs, iterations, tests, etc. completed; as well as parts machines and final assemblies completed)
	P8	We have tablets that connect wirelessly to each machine, and we can pull all sorts of useful data out. The days of pulling wires and testing with a voltmeter are not gone, but it's a much faster, and much less frustrating process now.	Increased output and task productivity (faster and more effective task execution)	Individuals; technology	Focus on outputs	Economic systems (focus on ROI); Technological infrastructure; organizational norms	Economies of scale; Lean; TOC	Productivity is measured objectively by output (designs, iterations, tests, etc. completed; as well as parts machines and final assemblies completed)
	P8	Yes, definitely. Troubleshooting is so much easier now. Commissioning is easier. I'm definitely more productive.	Increased productivity	Software; Computer Hardware; individuals; economic factors; communication between groups	Investment in advanced software	Economic systems (focus on ROI); Technological infrastructure; organizational norms	Theory of Constraints (TOC); Lean; Total Quality Management (TQM); Continuous Flow	Company manufactures machining equipment, often integrating their own designs and equipment into the processes, giving it a unique ability to test integration.

	P5	Absolutely. Without a doubt we are more productive. We can track our uptime, our maintenance downtime, and our output. We are far more productive, both in absolute terms, and in production per person. Our labor hours are stable, and our production is dramatically increased over what we were doing before.	1. Improved tracking and monitoring 2. Improved productivity per capita 3. Stable labor hours (higher automation)	Individuals; ideas and beliefs (monitoring is beneficial); economic factors (reduced cost & reduced labor)	Emphasis on tracking; focus on reducing downtime; maximizing efficiency of labor hours; sharing results with team	Organizational norms (efficiency); technological infrastructure; cultural beliefs (automation is inherently good)	Technology adoption; Resource Dependence Theory	Company Z has identified metrics (KPIs) as a critical component to monitoring
	P5	Absolutely. We've seen dramatic increases in our manufacturing productivity	Increased manufacturing output	Individuals; ideas (productivity is beneficial)	Focus on physical output for customers	Economic systems (focus on maximizing output)	Capacity planning theory	Productivity is measured objectively by output
	P6	The equipment is surprisingly smart, and adapts to changes. I have to monitor, look for ways to improve, and ensure that I am there if anything goes wrong.	1. Enhanced monitoring capability 2. Continuous improvement mindset/methodology	Software; Computer hardware; Continuous improvement methodology; individual operators; training	Adaptability of technology; use of continuous improvement methodology	Technological infrastructure	Lean Thinking; FMEA; Total Productive Maintenance (TPM); Six Sigma; Reliability Theory	Monitoring linked to smartphones

	P6	We are much busier now. The new automated lines and integrated systems have us filling more orders, creating custom batches and custom blends, and stocking more product for sale.	1. Increased physical output 2. Mass customization 3. Increased inventory to support sales	Automated manufacturing lines; customers orders, ERP system; individual operators; customer orders; warehouse	Focus on increasing overall output; mass customization	Market structures; organizational norms	Customer-Centric approach; Service Quality Model (SERVQUAL); Customer satisfaction and loyalty; relationship marketing	Customizing products and blends is very easy from a manufacturing perspective; intuitive
	P6	Yes, definitely. We are very productive. We could even double our current output by adding a shift, and we wouldn't even have to hire more people. Of course, there's no need to be that productive. Not yet, anyway.	1. Increased output 2. Increased manufacturing capacity	Automated manufacturing lines; individual operators; economic factors (reduced cost); customer expectations	Focus on automation (as opposed to hiring); capacity to expand sales	Cultural beliefs (focus on efficiency); economic systems (improve profitability)	Capacity planning theory; Resource Dependence Theory	Company invested in excess capacity; high growth strategy
	P6	Yes, definitely. Very productive. We're run off our feet some days trying to keep up. As long as the orders continue to go out the door, we'll continue to produce.	Output increased at machine pace	Automated manufacturing lines; individual operators; ERP; customer demand	Demand-driven production (machine pace)	Cultural beliefs (focus on efficiency); economic systems (improve profitability)	Capacity planning theory; Resource Dependence Theory	High growth organizational strategy; leverage LEAN manufacturing program to maximize efficiencies and reduce cost

	P9	Yes, I am definitely more productive. Once person can do the work of three people on the old system.	Increased output capacity; increased speed	Automated manufacturing lines; individual operators; economic factors (reduced cost); customer expectations	Focus on automation (as opposed to hiring); capacity to expand sales	Cultural beliefs (focus on efficiency); economic systems (improve profitability)	Capacity planning theory; Resource Dependence Theory	Company invested in excess capacity; high growth strategy
	P9	Without a doubt. We are far more productive now. We are able to build large orders quickly, and can easily respond to changes if needed.	Familiarity with technology	Automated manufacturing lines; individual operators; economic factors (reduced cost); customer expectations	Focus on automation (as opposed to hiring); capacity to expand sales	Cultural beliefs (focus on efficiency); economic systems (improve profitability)	Capacity planning theory; Resource Dependence Theory	Company invested in excess capacity; high growth strategy
Work was reported to be fulfilling, either personally, or professionally (+ Fulfilling)	P1	I would say that yes, I find my work to be fulfilling. Working with new technologies and software solutions allows our company to meet and exceed customer expectations, and provides a rewarding challenge.	Working with new technologies	Individual; technology; idea (continuous improvement)	Investment in advanced software; Communication with customers	Organizational structure; technological infrastructure	Self-determination theory; job characteristics model; positive psychology; social exchange theory; organizational support theory	Customer consulted frequently; more options for customization and refinement

	P1	Our capability to provide manufacturing engineering, inspection, material testing, additive manufacturing and precision machining offers significant fulfillment and interesting work.	Provision of a variety of services and parts to customers	Individual; technology	Investment in advanced technology (engineering software, testing, 3D printing, machining); Compelling field of work	Organizational structure; technological infrastructure	Self-determination theory; job characteristics model; positive psychology; social exchange theory; organizational support theory	Company is vertically integrated with its capabilities
	P2	I love this work. I think I'm decent at it. It's a challenging industry. The exact standards and the engineering challenges we face are very interesting to work on	Solving engineering challenges (new designs and/or processes)	Individual; technology; organizations (customers)	Compelling field of work; investment in advanced technology	Organizational structure; technological infrastructure	Self-determination theory; job characteristics model; positive psychology; social exchange theory; organizational support theory	Significant investment made in software for design and testing
	P2	Being able to work in such a dynamic industry is very rewarding.	New components, new materials, and constant innovation	Individual; technology	Compelling field of work; investment in advanced technology	Organizational structure; technological infrastructure	Self-determination theory; job characteristics model; positive psychology; social exchange theory; organizational support theory	Rapidly changing customer demands and expectations as companies seek flexibility

	P7	I really like what I do. I enjoy the challenge of design. It's an interesting industry, and certainly one that is far more cutting-edge than others that I have worked in.	Solving engineering challenges (new designs and/or processes)	Individual; technology; organizations (customers)	Compelling field of work; investment in advanced technology	Organizational structure; technological infrastructure	Self-determination theory; job characteristics model; positive psychology; social exchange theory; organizational support theory	Significant investment made in software for design and testing
	P3	That being said, it's exciting to understand the challenges and demands of our customers, and what they want to see out of their equipment.	Customer requests for designs and RFPs	Individual; technology; organizations (customers)	Investment in advanced software; Communication with customers	Organizational structure; technological infrastructure	Self-determination theory; job characteristics model; positive psychology; social exchange theory; organizational support theory	Custom design allows for greater specialization and customized options for customers; reduced cost of equipment relative to older models

	P3	I like my work. It's a challenging and interesting space. I think that the future of manufacturing is very exciting, and being a part of it, by designing the CNC machines that manufacturers use, and helping them install, service, and troubleshoot them in very rewarding.	Equipment design and testing	Individual; technology; organizations (customers)	Investment in advanced software; Communication with customers	Organizational structure; technological infrastructure	Self-determination theory; job characteristics model; positive psychology; social exchange theory; organizational support theory	Increasingly, time is spent troubleshooting and training customers on how to use equipment within their unique operations
	P4	It's challenging. I enjoy that. Overall, it's a good job. It's a lot of fun being on the cutting edge.	Use of new and innovative software and equipment	Individual; technology	Investment in advanced technology (engineering software, testing, 3D printing, machining); Compelling field of work	Organizational structure; technological infrastructure	Self-determination theory; job characteristics model; positive psychology; social exchange theory; organizational support theory	Continuous improvement, a part of the LEAN program, is engrained strongly in operating philosophy

	P5	I love my work. I feel that I do important work.	Feeling of fulfilment or satisfaction	Individual; technology	Compelling field of work; investment in advanced technology	Organizational structure; technological infrastructure	Self-determination theory; job characteristics model; positive psychology; social exchange theory; organizational support theory	Customers across Canada are in the agricultural and horticultural industries
	P6	I am happy with my work. I enjoy seeing our gains, and seeing our orders being completed. The growth has been hard, but rewarding.	1. Successfully implemented organizational change 2. Feeling of satisfaction	Individual; technology; organizations (customers)	Compelling field of work; investment in advanced technology	Organizational structure; technological infrastructure	Self-determination theory; job characteristics model; positive psychology; social exchange theory; organizational support theory	Company has a high-growth strategy, and has been modernizing rapidly
	P6	Sort of. I find fulfilment in doing a good work, and in improving. However, it's just a job.	Pride in accomplishment	Individual; technology; organizations; ideas and beliefs	Investment in advanced technology	Organizational structure; technological infrastructure	Self-determination theory; job characteristics model; positive psychology; social exchange theory; organizational support theory	Operator role with several years of experience

Employees are encouraged to take advantage of training and development opportunities (+ Training is Encouraged)	P1	It takes a considerable amount of time and training to optimize.	Time required for training; training process (self-paced, classroom, seminar)	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in technology; investment in training; emphasis on the value of continuous learning and skills development	Organizational structure; technological infrastructure	Transfer of learning theory	Training is extensive; software is complex
	P1	Definitely, yes. Learning new technologies and being able to configure and optimize that technology requires significant training and learning, especially from the OEM, or manufacturer. There are always new things to learn with design.	Time required for training; training process (self-paced, classroom, seminar); Experimentation with technology	Individuals; technology (software, hardware, and equipment); training materials; trainers	Participating in OEM training; investment in technology, investment in training	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Engagement with OEMs is an important part of getting training and reference materials

	P1	I think that as long as we keep up with our training and ensure that our operators understand the equipment, risks, and we continue to emphasize the importance of safe processes and ergonomics, the technology will allow us to maintain our tremendous safety record.	Time required for training; training process (self-paced, classroom, seminar); Experimentation with technology; Safety-specific training	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in training with an emphasis on safe operation	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Training is explicitly stated as part of the organization's LEAN strategy
	P2	With the new machines being integrated into our process, we're constantly receiving training on new capabilities.	Time required for training; training process (self-paced, classroom, seminar)	Individuals; technology (software, hardware, and equipment); training materials; trainers	Integrating technology into processes; investment in training and skills development	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Integration is not an easy, nor is it a fast process. New equipment takes months to integrate, and takes considerable investment, planning, and engineering capability.

	P2	All of our machines involve manufacturer training. Part of my role is to understand the process and to help put together training for our operators.	Time required for training; training process (self-paced, classroom, seminar, hands-on)	Individuals; technology (software, hardware, and equipment); training materials; trainers	Integrating OEM training; Developing training materials and process	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Training is developed and delivered by engineering
	P7	The training we get from our software providers and machine manufacturers is extensive.	Time required for training; training process (self-paced, classroom, seminar, hands-on)	Individuals; technology (software, hardware, and equipment); training materials; trainers	Integrating OEM training; Developing training materials and process	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Training is developed and delivered by OEMs
	P7	Yes. We receive training from the equipment manufacturers and the software developer. Our team has also created in-house training for staff, mostly focused on processes.	Time required for training; training process (self-paced, classroom, seminar); Experimentation with technology; Safety-specific training	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in training with an emphasis on safe operation	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Training is explicitly stated as part of the organization's LEAN strategy
	P3	If we change a process or procedure, we train the operators, machinists and supervisors.	Time required for training; training process (self-paced, classroom, seminar, hands-on)	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in technology; investment in training	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Updating processes and procedures takes considerable time (may be a target for AI)

	P4	Yes. We get training all the time on new systems, new equipment, and new procedures.	Time required for training; training process (self-paced, classroom, seminar, hands-on)	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in technology; investment in training	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	LEAN principle of continuous improvement is well understood; continuous learning philosophy is shared
	P4	Yes, internally. I provide training on processes and procedures to our customers. A big part of my role is assisting in the development of training programs and workshops.	Development of external training programs and materials; training process	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in technology; investment in training; emphasis on the value of continuous learning and skills development	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Different companies use different equipment, software, ERPs, making training very specific and esoteric

	P8	In my role, the technology itself is really useful in training us. It's very useful. We can also run diagnostics easily on the machines that we build, and we offer connected services to our customers. I am involved in assisting with PLC programming issues and any electrical hardware problems the customer may have. I used to work as a service technician in the field, but have since moved back into manufacturing. Assembly, more specifically.	Development of external training programs and materials; training process	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in technology; investment in training; emphasis on the value of continuous learning and skills development	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Different companies use different equipment, software, ERPs, making training very specific and esoteric

	P8	Yes, definitely. I received extensive training on new components, on PLC programming. The new machines are very complex, and we get a lot of support from engineering. The manufacturer of the panels and components provide training several times a year.	Development of external training programs and materials; training process	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in technology; investment in training; emphasis on the value of continuous learning and skills development	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Different companies use different equipment, software, ERPs, making training very specific and esoteric

	P9	Yes, all the time. We get training on the system and new processes all the time. This past year I received training in quality management, for instance. I am new to quality control and testing, but it's something I'm interested in learning, and something management has been willing to help me with.	Development of external training programs and materials; training process	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in technology; investment in training; emphasis on the value of continuous learning and skills development	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Different companies use different equipment, software, ERPs, making training very specific and esoteric
	P9	If we change any process, we train all the operators on it. We don't change recipes much for the products, but we've had changes in labelling, bottle sizes, and case quantities.	Development of external training programs and materials; training process	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in technology; investment in training; emphasis on the value of continuous learning and skills development	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Different companies use different equipment, software, ERPs, making training very specific and esoteric

	P5	Absolutely. Some days, I feel that's all we do. There's so much to learn with this new technology, and it's always being updated.	Continuous learning; training process (self-paced, classroom, seminar, hands-on)	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in technology; investment in training; emphasis on the value of continuous learning and skills development	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Training seems ad-hoc, as opposed to LEAN companies that apply it more systematically
	P6	Yes, absolutely. We receive training on new systems and new technologies when we introduce them. There is always a lot to learn. It takes a long time to learn the machines, to troubleshoot, and become comfortable with them.	Continuous learning; training process (self-paced, classroom, seminar, hands-on)	Individuals; technology (software, hardware, and equipment); training materials; trainers	Investment in technology; investment in training; emphasis on the value of continuous learning and skills development	Organizational structure; technological infrastructure	Social learning theory; experiential learning theory; motivation theories	Training is not a one-time activity; reference manuals and the opportunity for operators to be able to consult when they have to complete rare or new tasks is important

The outlook for the organization implementing Industry 4.0 is positive	P1	I feel confident about the company's future. We're leading the way in [our industry], and the only company of our kind in [The Maritimes]. Our dedication to innovation and the use of new technologies to support our organizations give me optimism and hope for a profitable future.	Feeling of confidence and optimism; Implementation of technology	Individuals; Technologies; Ideas (Investment is positive; dedication to positive outcomes)	Investment in technology; Dedication to innovation	Technological infrastructure; organizational structures	Attribution theory; self-efficacy theory; cognitive dissonance theory	Company has a formal LEAN program, and has a history of exploring new equipment and new solutions

	P2	The digitalization that we are working towards comes in two phases: the first requires developing a completely integrated development process that goes from product to process to production. This is where we are now, as a company. The second phase, which is coming fast, involves connecting that workflow to artificial intelligence, smart manufacturing systems, and new product development technologies. We're working hard on integration, and as we invest in the newest machines, we get closer and closer	Implementation of technology and integrated processes; integration of AI; Investment in equipment	Individuals; Technologies; Ideas (Investment is positive; dedication to positive outcomes)	Integrating technology into processes; investment in training and skills development	Technological infrastructure; organizational structures; cultural beliefs	Attribution theory; self-efficacy theory; cognitive dissonance theory	There was a strong emphasis on what changes will be coming with AI integration

		to full integration.						
	P2	I think the future is bright. There's a lot of exciting innovations in the field, for instance, in new materials.	Feeling of confidence and optimism; Implementation of technology	Individuals; Technologies; Ideas (Investment is positive; dedication to positive outcomes)	Organizational commitment to support innovation	Technological infrastructure; organizational structures; cultural beliefs	Attribution theory; self-efficacy theory; cognitive dissonance theory	The cost of new materials in 3D printing is an important consideration for customers
	P7	I'm fairly optimistic about the changes we're seeing. I think that it helps is one is open to new experiences and new challenges.	Feeling of confidence and optimism; Implementation of technology	Individuals; Technologies; Ideas (Investment is positive; dedication to positive outcomes)	Organizational commitment to support innovation	Technological infrastructure; organizational structures; cultural beliefs	Attribution theory; self-efficacy theory; cognitive dissonance theory	The cost of new materials in 3D printing is an important consideration for customers

	P3	First, the investment allows us to improve our capabilities to manufacture equipment. This offers hands-on experience with these technologies. Second, since our equipment is used in the manufacturing processes of other companies that integrate into their advanced manufacturing systems, I have the opportunity to work with advanced software and advanced hardware.	Implementation of technology and integrated processes	Individuals; Technologies; Ideas (Investment is positive; dedication to positive outcomes)	Supporting hands-on (experiential) training; investment in technology	Technological infrastructure; organizational structures; cultural beliefs	Attribution theory; self-efficacy theory; cognitive dissonance theory	Company has an existing LEAN program, and is considered a pioneer in new and innovative techniques and technology

	P3	I think that the future is very good for us. Our machines are in high demand, and we're having trouble keeping up. Manufacturing is booming in Canada, and we're fortunate to be a domestic supplier of quality equipment. We've invested heavily into advanced technologies to support our own manufacturing, and leverage that knowledge to consult other manufacturers on their systems.	Increased orders increased demand; investment in technology	Individuals; Technologies; Ideas (Investment is positive; dedication to positive outcomes)	Investment in technology; leveraging knowledge; consulting with customers	Technological infrastructure; organizational structures; cultural beliefs	Attribution theory; self-efficacy theory; cognitive dissonance theory	Significant investment in new technologies
	P4	The future of manufacturing is Industry 4.0. We're only going to see ever-greater automation.	Feeling of confidence and optimism; Implementation of technology	Individuals; Technologies; Ideas (Investment is positive; dedication to positive outcomes)	Investment in technology and automation	Technological infrastructure; organizational structures	Attribution theory; self-efficacy theory; cognitive dissonance theory	Automation and robotics are employed widely in manufacturing operations

	P4	I think that the future is bright. The company continues to grow, and the manufacturing space is strong. Canada is well positioned for smart manufacturing.	Feeling of confidence and optimism	Individuals; Technologies; Ideas (Investment is positive; dedication to positive outcomes)	Investment in technology	Technological infrastructure; organizational structures	Attribution theory; self-efficacy theory; cognitive dissonance theory	Growing emphasis on domestic manufacturing and shorter supply chains
	P8	I think the future looks good. We're busy, and seem to be doing well. That's good enough for me.	Feeling of confidence and optimism	Individuals; Technologies; Ideas (Investment is positive; dedication to positive outcomes)	Investment in technology	Technological infrastructure; organizational structures	Attribution theory; self-efficacy theory; cognitive dissonance theory	Growing emphasis on domestic manufacturing and shorter supply chains

	P5	As long as the ROI is there for additional changes, I'm confident that we'll continue to invest in new technologies. We're light years ahead of where we were, and it's been an exciting journey. I don't know if we can afford to always be on the cutting edge, but we've seen a big improvement. We've been around for quite a few years, I can't see that changing.	Investment in technology; Working with 'cutting edge' technology and uses	Individuals; Technologies; Ideas (Investment is positive; dedication to positive outcomes)	Investment in technology; Supporting innovation	Technological infrastructure; organizational structures; cultural beliefs	Attribution theory; self-efficacy theory; cognitive dissonance theory	Company remained relatively small and unchanged for years before seeking higher growth and new opportunities
	P6	I think so. The investment in technology gives us all new opportunities to learn, grow, and build our skills. We get a lot of good training.	Investment in technology; participation in training	Individuals; Technologies; Ideas (Investment is positive; dedication to positive outcomes)	Investment in skills development and training	Technological infrastructure; organizational structures; cultural beliefs	Attribution theory; self-efficacy theory; cognitive dissonance theory	Operator training tends to be hands-on

Industry 4.0 technologies facilitate a more accessible workplace (+ Accessibility)	P1	Yes, absolutely. The technology has made it easier for me personally to stay connected with work, and it has made many tasks, notably the changing of tools, far easier for our operators.	Remote connectivity with work (meetings, ERP)	Individuals; technologies (communications and collaborative); groups (in-person and remote workers)	Communications and collaborative technologies; remote monitoring; safe and accessible equipment; optimized manufacturing	Technological infrastructure; organizational structures; cultural beliefs	Social contract theory; capability approach; participatory action research; employment equity; social model of disability	Increasing focus on work-life balance; preference for flexible options expressed
	P2	Our interconnected technologies allow us to work remotely if needed. We have a great culture here at the office, and being such a small team, it's nice to work in-person.	Remote connectivity with work (meetings, Slack, ERP)	Individuals; technologies (communications and collaborative); groups (in-person and remote workers)	Communications and collaborative technologies; integrated teams	Technological infrastructure; organizational structures; cultural beliefs	Social contract theory; capability approach; participatory action research; employment equity; social model of disability	
	P2	We have several members of our team that benefit from remote work options, and a couple of members with some mobility issues.	Remote connectivity with work (meetings, Slack, ERP)	Individuals; technologies (communications and collaborative); groups (in-person and remote workers)	Communications and collaborative technologies; integrated teams	Technological infrastructure; organizational structures; cultural beliefs	Social contract theory; capability approach; participatory action research; employment equity; social model of disability	

	P3	The fact that we can offer remote support has been a big win for us, and cut down on travel.	Remote connectivity with work (meetings, Slack, ERP)	Individuals; technologies (communications and collaborative); groups (in-person and remote workers)	Communications and collaborative technologies	Technological infrastructure; organizational structures; cultural beliefs	Social contract theory; capability approach; participatory action research; employment equity; social model of disability	
	P3	For myself, I can be out of town at a conference, or away for a couple of days, and be able to access our systems and work seamlessly with the team.	Remote connectivity with work (meetings, Slack, ERP)	Individuals; technologies (communications and collaborative); groups (in-person and remote workers)	Communications and collaborative technologies, integrated ERP; organizational structure	Technological infrastructure; organizational structures; cultural beliefs	Social contract theory; capability approach; participatory action research; employment equity; social model of disability	
	P3	A lot of the technology we use, particularly collaboration software and our online ERP system, have certainly made work more accessible, yes.	Remote connectivity with work (meetings, Slack, ERP)	Individuals; technologies (communications and collaborative); groups (in-person and remote workers)	Communications and collaborative technologies, integrated ERP; organizational structure	Technological infrastructure; organizational structures; cultural beliefs	Social contract theory; capability approach; participatory action research; employment equity; social model of disability	

	P4	Definitely. A lot of the office-related tasks we do can be done remotely, and collaborative software has come a long way, helping our team work together.	Remote connectivity with work (meetings, Slack, ERP)	Individuals; technologies (communications and collaborative); groups (in-person and remote workers)	Communications and collaborative technologies, integrated ERP; organizational structure	Technological infrastructure; organizational structures; cultural beliefs	Social contract theory; capability approach; participatory action research; employment equity; social model of disability	
	P5	Yes, without a doubt. It has allowed our team to work and contribute meaningfully from off-site and remotely. Our systems allow us to work from home, to work if we have mobility issues, or if there is inclement weather.	Hybrid work environment	Individuals; technologies (communications and collaborative); groups (in-person and remote workers)	Communications and collaborative technologies, integrated ERP; organizational structure, work-from-home policy; safety culture	Technological infrastructure; organizational structures; cultural beliefs	Social contract theory; capability approach; participatory action research; employment equity; social model of disability	

	P9	I have a few health issues, and sometimes it's hard to do the physical work. The technology makes it much easier to monitor the production line, and easier to schedule. Less downtime, and fewer changes. This sort of thing is wonderful for people like me that can't always get around easily.	Improved scheduling and manufacturing predictive capability; standardization of training; ability to manufacture in less time	Individuals; technologies (communications and collaborative); groups (in-person and remote workers)	Communications and collaborative technologies, integrated ERP; organizational structure, work-from-home policy; safety culture	Technological infrastructure; organizational structures; cultural beliefs	Social contract theory; capability approach; participatory action research; employment equity; social model of disability	
	P6	Yes, absolutely. I was on modified duties not long ago and the technology helped me remain in my role, and remain productive. I could monitor and plan, and I didn't have to engage in the process in the way I would have had to before.	Hybrid work environment; engaged modified work	Individuals; technologies (communications and collaborative); groups (in-person and remote workers)	Communications and collaborative technologies, integrated ERP; organizational structure	Technological infrastructure; organizational structures; cultural beliefs	Social contract theory; capability approach; participatory action research; employment equity; social model of disability	

There is a shared perception that Industry 4.0 contributes meaningfully to a safe workplace (+ Improves Safety)	P1	The technology we use reduces the amount of manual work our technicians have to do when we have to make changes, or change tools. Our processes are simpler, more adaptable, and we've had a stellar safety record with our new equipment.	Improved safety record; reduced hours spent manually intervening in manufacturing process	Individuals; ideas and beliefs (teamwork; effective cooperation, safety culture); technologies (Zoom; ERP; Slack, etc.); safety regulations	Monitoring technology; equipment design (ergonomics); process integration	Technological infrastructure; organizational structures; cultural beliefs	Risk management theory; systems theory; human factors theory; hierarchy of controls, behavior-based safety theory	Safety is an explicit component of strategy
	P2	Yes, definitely. The newer machines are far safer, and far more ergonomic. There is less of a need for human intervention in the manufacturing process, reducing the risk of injury.	Improved safety record; fewer injuries; reduced hours spent manually intervening in manufacturing process	Individuals; ideas and beliefs (teamwork; effective cooperation, safety culture); technologies (Zoom; ERP; Slack, etc.); safety regulations	Monitoring technology; equipment design (ergonomics); process integration	Technological infrastructure; organizational structures; cultural beliefs	Risk management theory; systems theory; human factors theory; hierarchy of controls, behavior-based safety theory	

	P7	Everything in aerospace needs to be light, strong, and 100% reliable. With our new machines we're able to use 3D printing with some new alloys and innovative materials to build components. The design side is very challenging trying to keep up to the technology and the materials.	Improved safety record; fewer injuries; reduced hours spent manually intervening in manufacturing process	Individuals; ideas and beliefs (teamwork; effective cooperation, safety culture); technologies (Zoom; ERP; Slack, etc.); safety regulations	Monitoring technology; equipment design (ergonomics); process integration	Technological infrastructure; organizational structures; cultural beliefs	Risk management theory; systems theory; human factors theory; hierarchy of controls, behavior-based safety theory	

	P7	Safer? Yes, I think so. The machines require far less maintenance than the old ones, meaning less interaction between machines and people. We have fewer physical changeovers, and we don't change tools nearly as much. I think that yes, we are more safe as a company than we were even a few years ago.	Improved safety record; fewer injuries; reduced hours spent manually intervening in manufacturing process	Individuals; ideas and beliefs (teamwork; effective cooperation, safety culture); technologies (Zoom; ERP; Slack, etc.); safety regulations	Monitoring technology; equipment design (ergonomics); process integration	Technological infrastructure; organizational structures; cultural beliefs	Risk management theory; systems theory; human factors theory; hierarchy of controls, behavior-based safety theory	
	P3	Machines are significantly more efficient, capable, and far safer now than they ever have been.	Improved safety outcomes	Individuals; ideas and beliefs (teamwork; effective cooperation, safety culture); technologies (Zoom; ERP; Slack, etc.); safety regulations	Equipment design (ergonomics); process integration	Technological infrastructure; organizational structures; cultural beliefs	Risk management theory; systems theory; human factors theory; hierarchy of controls, behavior-based safety theory	Company has a formal LEAN program, operators, customers, and owners all share a concern about improving safety outcomes

	P3	The technology that we use in manufacturing has made us far more efficient, safer, and more productive.	Improved safety outcomes; increased efficiency; increased productivity	Individuals; ideas and beliefs (teamwork; effective cooperation, safety culture); technologies (Zoom; ERP; Slack, etc.); safety regulations	Equipment design (ergonomics); process integration	Technological infrastructure; organizational structures; cultural beliefs	Risk management theory; systems theory; human factors theory; hierarchy of controls, behavior-based safety theory	
	P3	Yes, absolutely. Not only does the technology itself make our manufacturing process safer by reducing the number of moving parts, it helps us reduce downtime and the need for large maintenance work. In terms of capability, the use of powerful new software allows us to run better simulations and test our designs, ensuring that we offer the safest, most advanced equipment on the market.	Reduced equipment downtime (OEE); reduced maintenance costs; improved simulations; improved safety record	Individuals; ideas and beliefs (teamwork; effective cooperation, safety culture); technologies (Zoom; ERP; Slack, etc.); safety regulations	Equipment design (ergonomics); process integration; integrated maintenance scheduling; technology (design software)	Technological infrastructure; organizational structures; cultural beliefs	Risk management theory; systems theory; human factors theory; hierarchy of controls, behavior-based safety theory	

	P4	Yes. Monitoring is improved. Maintenance is easier and more predictable	Reduced equipment downtime (OEE); reduced maintenance cost; improved monitoring capability	Individuals; ideas and beliefs (teamwork; effective cooperation, safety culture); technologies (Zoom; ERP; Slack, etc.); safety regulations	Investment in technology; integrated maintenance scheduling	Technological infrastructure; organizational structures; cultural beliefs	Risk management theory; systems theory; human factors theory; hierarchy of controls, behavior-based safety theory	
	P8	Yes, definitely. For electricians, any time we don't have to go near energized equipment or live wires, the better. The new tools we have make our work much safer.	Reduced equipment downtime (OEE); reduced maintenance cost; improved monitoring capability	Individuals; ideas and beliefs (teamwork; effective cooperation, safety culture); technologies (Zoom; ERP; Slack, etc.); safety regulations	Investment in technology; integrated maintenance scheduling	Technological infrastructure; organizational structures; cultural beliefs	Risk management theory; systems theory; human factors theory; hierarchy of controls, behavior-based safety theory	
	P9	Definitely! Fewer changeovers, less issues. The whole system is much safer	Improved safety outcomes	Individuals; ideas and beliefs (teamwork; effective cooperation, safety culture); technologies (Zoom; ERP; Slack, etc.); safety regulations	Investment in technology	Technological infrastructure; organizational structures; cultural beliefs	Risk management theory; systems theory; human factors theory; hierarchy of controls, behavior-based safety theory	Company emphasizes safety and reports safety metrics

	P5	I think that the technology does make the jobsite safer	Improved safety outcomes	Individuals; ideas and beliefs (teamwork; effective cooperation, safety culture); technologies (Zoom; ERP; Slack, etc.); safety regulations	Investment in technology	Technological infrastructure; organizational structures; cultural beliefs	Risk management theory; systems theory; human factors theory; hierarchy of controls, behavior-based safety theory	
Industry 4.0 facilitates a positive and constructive relationship between coworkers	P1	My relationship with my coworkers is great. I work closely with our engineers and technicians in the design and manufacture of components, explore new capabilities, and consider new offerings. I work well with our senior leadership team.	Effective co-operation	Individuals; ideas and beliefs (teamwork; effective cooperation); technologies (Zoom; ERP; Slack, etc.)	Organizational culture (emphasis on cross-collaboration, teamwork); investment in technology	Technological infrastructure; cultural beliefs (social acceptance of remote work); gender dynamics; organizational structure	Social exchange theory; social identity theory; group dynamics theory	Teamwork and collaboration are common

	P7	I have a very good relationship with my colleagues. We're a small group, and the company is small as well. Everyone knows everyone. We work closely together, and that's nice. I personally know everyone in the process, and I can talk to anyone at any time. This helps when we're troubleshooting an issue, or exploring an engineering change.	Effective co-operation	Individuals; ideas and beliefs (teamwork; effective cooperation); technologies (Zoom; ERP; Slack, etc.)	Organizational culture (emphasis on cross-collaboration, teamwork); investment in technology	Technological infrastructure; cultural beliefs (social acceptance of remote work); gender dynamics; organizational structure	Social exchange theory; social identity theory; group dynamics theory	

	P3	It's positive and cordial. Technology has improved the level of collaboration that we have. I do find that we can do more with less, and so we manage with a team that is smaller than it otherwise would be in a more traditional manufacturing environment.	Use of collaborative software; effective co-operation; smaller teams	Individuals; ideas and beliefs (teamwork; effective cooperation); technologies (Zoom; ERP; Slack, etc.)	Organizational culture (emphasis on cross-collaboration, teamwork); investment in technology	Technological infrastructure; cultural beliefs (social acceptance of remote work); gender dynamics; organizational structure	Social exchange theory; social identity theory; group dynamics theory	
	P4	It's great. I work closely with a number of different disciplines.	Effective cross-collaboration	Individuals; ideas and beliefs (teamwork; effective cooperation)	Organizational culture (emphasis on cross-collaboration, teamwork); investment in technology	Technological infrastructure; cultural beliefs (social acceptance of remote work); gender dynamics; organizational structure	Social exchange theory; social identity theory; group dynamics theory	

	P8	It's also pretty good. There's a good crew here, and we all get along. None of the changes we've made to the equipment or the assembly process changed the relationships much.	Use of collaborative software; effective co-operation; smaller teams	Individuals; ideas and beliefs (teamwork; effective cooperation); technologies (Zoom; ERP; Slack, etc.)	Organizational culture (emphasis on cross-collaboration, teamwork); investment in technology	Technological infrastructure; cultural beliefs (social acceptance of remote work); gender dynamics; organizational structure	Social exchange theory; social identity theory; group dynamics theory	
	P9	We all have a good relationship. We're a small team (there are five of us). I think we all like the production system now, and it makes it easy to work together.	Effective co-operation	Individuals; ideas and beliefs (teamwork; effective cooperation)	Organizational culture (emphasis on cross-collaboration, teamwork); investment in technology	Technological infrastructure; cultural beliefs (social acceptance of remote work); gender dynamics; organizational structure	Social exchange theory; social identity theory; group dynamics theory	
	P5	I have a positive relationship with my coworkers. Everyone that works in production gets along. No issues.	Effective co-operation	Individuals; ideas and beliefs (teamwork; effective cooperation)	Organizational culture (emphasis on cross-collaboration, teamwork); investment in technology	Technological infrastructure; cultural beliefs (social acceptance of remote work); gender dynamics; organizational structure	Social exchange theory; social identity theory; group dynamics theory	

	P6	The team has a really good relationship. We've been together for quite a while, and went through a lot over the past couple of years. The technology hasn't changed that.	Effective co-operation	Individuals; ideas and beliefs (teamwork; effective cooperation)	Organizational culture (emphasis on cross-collaboration, teamwork); investment in technology	Technological infrastructure; cultural beliefs (social acceptance of remote work); gender dynamics; organizational structure	Social exchange theory; social identity theory; group dynamics theory	

Appendix G: Ethics Approval

Athabasca University
RESEARCH CENTRE

CERTIFICATION OF ETHICAL APPROVAL

The Athabasca University Research Ethics Board (REB) has reviewed and approved the research project noted below. The REB is constituted and operates in accordance with the current version of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2) and Athabasca University Policy and Procedures.

Ethics File No.: **24859**

Principal Investigator:

Mr. Ian Chitwood, Doctoral Student
Faculty of Business\Doctor of Business Administration (DBA)

Supervisor/Project Team:
Dr. Hussein Al-Zyoud (Supervisor)

Project Title:
UNDERSTANDING THE EXPERIENCE OF WORK: A CRITICAL EXPLORATION OF INDUSTRY 4.0 TECHNOLOGIES IN ADVANCED LEAN MANUFACTURING

Effective Date: July 27, 2022 **Expiry Date**: July 26, 2023

Restrictions:
Any modification/amendment to the approved research must be submitted to the AUREB for approval prior to proceeding.

Any adverse event or incidental findings must be reported to the AUREB as soon as possible, for review.

Ethical approval is valid *for a period of one year*. An annual request for renewal must be submitted and approved by the above expiry date if a project is ongoing beyond one year.

An Ethics Final Report must be submitted when the research is complete *(i.e., all participant contact and data collection is concluded, no follow-up with participants is anticipated and findings have been made available/provided to participants (if applicable))* or the research is terminated.

Approved by: **Date: July 27, 2022**

Weiming Liu, Chair
Faculty of Business, Departmental Ethics Review Committee

Athabasca University Research Ethics
Board University Research Services
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Telephone: 780.213.2033

Athabasca University
RESEARCH CENTRE

CERTIFICATION OF ETHICAL APPROVAL - RENEWAL

The Athabasca University Research Ethics Board (REB) has reviewed and approved the research project noted below. The REB is constituted and operates in accordance with the current version of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2) and Athabasca University Policy and Procedures.

Ethics File No.: 24859

Principal Investigator:
Mr. Ian Chitwood, Doctoral Student
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Dr. Hussein Al-Zyoud (Supervisor)

Project Title:
UNDERSTANDING THE EXPERIENCE OF WORK: A CRITICAL EXPLORATION OF INDUSTRY 4.0 TECHNOLOGIES IN ADVANCED LEAN MANUFACTURING

Effective Date: July 26, 2023 **Expiry Date**: July 23, 2024

Restrictions:

Any modification/amendment to the approved research must be submitted to the AUREB for approval prior to proceeding.

Any adverse event or incidental findings must be reported to the AUREB as soon as possible, for review.

Ethical approval is valid *for a period of one year*. An annual request for renewal must be submitted and approved by the above expiry date if a project is ongoing beyond one year.

An Ethics Final Report must be submitted when the research is complete *(i.e., all participant contact and data collection is concluded, no follow-up with participants is anticipated and findings have been made available/provided to participants (if applicable))* or the research is terminated.

Approved by: **Date: June 15, 2023**

Paul Jerry, Chair
Athabasca University Research Ethics Board

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Appendix H: Information Sheet

Principal Investigator (Researcher): Supervisors:

Ian Chitwood Dr. Hussein Al-Zyoud; Dr. Patricia McLaren

ichitwood1@learn.athabascau.ca husseina@athabascau.ca; pmclaren@wlu.ca

I am seeking organizations that are willing to participate in a doctoral thesis project entitled 'Understanding the experience of work: A critical exploration of Industry 4.0 technologies in advanced manufacturing.'

Introduction

My name is Ian Chitwood and I am a Doctorate of Business Administration (DBA) candidate at Athabasca University. As a program requirement for my doctorate, I am conducting research into whether the claims made by organizations regarding the implementation of technology are realized by employees within those organizations. I am conducting this project under the supervision of Dr. Hussein Al-Zyoud and Dr. Patricia McLaren.

Why are you being asked to take part in this research project?

I am seeking to work with organizations that have first-hand knowledge and experience with Industry 4.0 technologies. This will provide unique insight into how they impact the employee experience of work.

What is the purpose of this research project?

The purpose of the study is to understand whether the subjective experience of work supports or disputes the stated claims about the benefits of Industry 4.0 technologies in organizations. It will offer new insights into the evolving role of technology in lean workplaces, and how it shapes employees' experience of work in that context.

What will be required?

I am seeking to both survey and interview individuals within the organization. Interviews will ask questions related to the experience of work, and how employees are impacted by the implementation of new technologies. Interviews will be conducted virtually and will last between 20-60 minutes.

Survey participants will be asked to complete a short online questionnaire about their personal experiences of work, and how technology has affected their job. Participation will take approximately 15 minutes.

What are the benefits and risks?

The research should be beneficial in a variety of ways. The study addresses the issue of the changing nature of work, which is both a timely and important topic given the pace of change in work, precipitated by recent social trends and technological advancements. As technological intervention becomes more widespread in organizations—whether they are involved in manufacturing or the provision of services—they are becoming increasingly defined by the ubiquitous nature of that technology.

While the dissertation work will further scholarship in several different areas of academic inquiry including lean manufacturing, Industry 4.0, critical realism and organizational behavior, business practitioners will benefit from the research. Notably, it will help organizations understand how Industry 4.0 adoption will affect employees in organizations, and how organizational initiatives can best be executed to ensure that employees' experiences are both positive and aligned with desired organizational outcomes.

The research question being posed is:

Q: How do employees experience work in relation to the stated claims about the implementation of Industry 4.0 technologies for organizations?

The risks of participating in this research are seen as exceptionally low. A requirement to conduct research is to identify all relevant possible risks and how the researcher will eliminate or mitigate these risks. The only potential risks that were identified, and that could concern interviewees with participation in this research, are 1) the interview and sharing of personal and organizational information could be compromised or 2) that their anonymity could be compromised.

To eliminate these risks, the following safeguards are in place: All interview information and financial information will be reported in aggregate (personal information would never be revealed and only known to the researcher). Electronic copies of the interviews and information will be password protected and kept on a password protected computer that only the researcher has access. Hard copy financial information, if given, will be kept in a locked filing cabinet that only the researcher has access. After the write-up of the Doctoral Thesis, all personal and organizational information will be deleted or destroyed.

Additionally, all organizational names, interviewee names or other potentially identifiable information will be eliminated or given pseudonyms, such as Company "A", Company "B" etc. As mentioned above, these risks are seen as low. Candid and honest answers to the interview questions is paramount to the success of this research. As such, the confidentiality of answers and information is taken very seriously and will not be shared, identified or identifiable.

Who will receive the results of the research project?

A copy of the final thesis is available to you via the Athabasca University library. The existence of the research will be listed in an abstract posted online at the Athabasca University Library's Digital Thesis and Project Room and the final research paper will be publicly available

As stated above, one goal of the research is to increase our academic understanding of the role of technology in advanced manufacturing companies, and whether the claims made by those organizations are realized by employees. As such, a goal of the research is to have it published in accounting academic journals. Research articles using the data will be submitted for publication ensuring the confidentiality and anonymity of the data and interviews.

Additionally, a summary of the findings will be e-mailed to each organization after the research has been completed. This will provide a high-level summary of the research and the findings.

Who can you contact for more information or to indicate your interest in participating in the research project?

Thank you for considering this request. If you have any questions or would like more information, please contact me, Ian Chitwood by e-mail at ichitwood1@learn.athabascau.ca or by phone at 403-470-7857. My supervisors may be contracted by e-mail at husseina@athabascau.ca or pmclaren@wlu.ca. If you are ready to participate in this project, I will set up an initial meeting to review, and seek a signed consent.

Thank you.

This project has been reviewed by the Athabasca University Research Ethics Board. Should you have any comments or concerns regarding your treatment as a participant in this project, please contact the Research Ethics Officer by e-mail at rebsec@athabascau.ca or by telephone at 1-800-788-9041, ext. 671.