Doctoral School of Business and Management

Summary of Thesis

of doctoral dissertation:

The Effect of the Fourth Industrial Revolution on Entrepreneurial Leadership Attributes

Avny Ronnen

Supervisor: Deutsch Nikolett, dr. Habil

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1. Research background and justification of the topic

Throughout the history of humankind, innovation has contributed vastly to the achievement of significant goals. Using human creativity to overcome technological restraints is one of the important shaping forces of history. Innovation appears to be one of the significant forces supporting economic development. One of the first innovation theorists was Schumpeter (1911/1934), who promoted the concept that innovation is the ultimate source of economic growth and hence worthy of study (Fagerberg et al., 2013). Innovation is widely considered to be the primary catalyst for companies to thrive, expand, and maintain high profitability by securing and preserving their competitive advantage over rivals (Drucker, 1988a; Christensen, 1997; Teece, 2015).

In the current era, as the world faces the Fourth Industrial Revolution (FIR), technological progress has significantly accelerated. Kurzweil (2004, p.1) notes, "we won't experience 100 years of progress in the 21st century—it will be more like 20,000 years of progress [at today's rate]." As barriers to introducing innovative technology diminish, these phenomena are associated with the FIR (Schwab, 2016). The adoption rate of emerging technologies by the public has become rapid (Ritchie & Roser, 2017). Moreover, independent learning has surged owing to the vast Internet knowledge base, enabling unconventional innovations by individuals and groups previously uninvolved in innovation. This allows for more efficient development and deployment of new products and technologies (Roser et al., 2015). Additionally, recent years have seen significant global changes, some due to the FIR and others due to events such as the COVID-19 pandemic and the Russia-Ukraine War.

The FIR holds significant promise, including enhanced decision-making capabilities, advanced workshop floor monitoring and control, optimized resource utilization, and improved demand forecasting just mention a few. It is imperative for industry players to maintain pace by ensuring a high level of preparedness for the FIR in order to realize these benefits (Schwab, 2016; Hernandez-de-Menendez et al.,2020; Saleh & Ijab, 2022). The focus of this research lies at the heart of the characteristics associated with the FIR.

As illustrated in Figure 1, the literature review adopted a multifaceted approach to trace the historical progression of academic knowledge, economic landscapes, and technological

advances in three key areas: innovation management, leadership and entrepreneurship, and technological shifts from industrial revolutions. It identified the Fourth Industrial Revolution as the temporal context ("when?") and innovation as the primary change driver ("what?"). To meet the research objectives, the review established a foundational understanding of entrepreneurial leadership as the assessment tool, focusing on the attributes used for analysis ("how?").

Figure 1 - *Cross Intersection between FIR, Innovation and Leadership Analysis Framework*

Years	1760-1900	1900-1960	1960-2000	2010-ongoing
Industrial Revolution – "when?" (Chapter 2)	**First**	**Second**	**Third**	**Fourth**
Technology & Industrial Paradigm – "what?" (Chapter 2)	(1) How the technology changed? (2) What are the effects of the industrial revolution?			
Innovation Paradigm – "what?" (Chapter 3)	(1) What are the leading innovation paradigms? (2) How to manage innovation? (3) Changes in the innovation systems during time			
Leadership Paradigm- "how?" (Chapter 4)	(1) What is role of innovation? (2) How leadership affect innovation? (3) Interrelations between Entrepreneurship and Leadership?			
Analysis	↓	↓	↓	↓
Entrepreneur Paradigm – "how?"	(1) How the entrepreneur changes along the history? (2) How the entrepreneur cope with the changes in the technology?			

Source: Own edition.

Industrial Revolution

Industrial revolutions over the past three centuries represent periods of rapid development, markedly increasing productivity and reducing costs while fostering significant innovations (Schumpeter, 1911; Schumpeter, 1934; Daemmrich, 2017). These periods transform work and consumption by altering production methods. For instance, the First Industrial Revolution prompted urbanization, as people migrated to cities seeking factory jobs (Mantoux, 1955; Allen, 2009). Similarly, the Third Industrial Revolution has led to globalization through the spread of computing power and the Internet, facilitating swift global communication (Daemmrich, 2017). Contrary to the belief that changes stem from human adaptation to new technologies, these shifts result from a dynamic interplay among inventors, entrepreneurs, and consumers (Daemmrich, 2017). Industrial revolutions correlate with economic cycles,

observed in the 18th and 19th centuries, characterized by recurring phases of expansion, peak, contraction, and trough (Burns & Mitchell, 1946). The severity and duration of these cycles are influenced by several factors. The relationship between industrial revolutions and economic cycles remains ambiguous, particularly concerning the role of technological changes in driving investment growth and economic restructuring (Kondratieff, 1926; Schumpeter, 1934; Perez, 2002). Investigating a revolution necessitates examining several factors, including external triggers, internal dynamics, and societal transformations (Stearns, 2020). This research explores the impact of the First Industrial Revolution on innovation, particularly on entrepreneurial leadership attributes.

Understanding the implications of the FIR and its consequences necessitates a clear definition within the dissertation's context. The FIR is interpreted through two distinct perspectives, the first, Industry 4.0, is commonly referenced in Europe, particularly Germany, originating from the German government's "Industrie 4.0" initiative aimed at ensuring the manufacturing industry's long-term sustainability (Kagermann et al., 2013). Sanders et al. (2016, p. 816) highlighted Industry 4.0's significant impact on production dynamics, noting, "Industry 4.0 significantly influences the production environment with radical changes in the execution of operations." This is supported by initiatives such as the "Industrial Internet of Things" in the United States and South Korea's "Smart Manufacturing Innovation Strategy" (Müller & Voigt, 2018). The second perspective pertains to the FIR's global impact on societal functions, as characterized by Schwab (2016), and is more appropriate for this research. This broader perspective encompasses technological and societal transformations, with primary technological drivers being Cyber-Physical Systems and the convergence of digital, physical, and biological technologies. Illustrative examples include Virtual Reality glasses augmenting physical vision and brain-computer interfaces enabling cognitive control of devices. Another significant technological impact is enhanced connectivity among agents, facilitated by advancements in information and communications technologies, including the Internet of Things (IoT) and cloud computing, which enable remote computation and Big Data analytics (Nascimento et al., 2019). These advancements, in conjunction with the high computing power from the Third Industrial Revolution, underpin Artificial Intelligence (AI) and Machine Learning (ML) capabilities, enabling computers to perform tasks that traditionally required human intelligence (Li et al., 2017).

The FIR has driven numerous social impacts through technology, notably in productivity and efficiency, via automation and AI for optimized processes, enhanced production, and resource management. Its significant influence includes advancements in communication and collaboration, such as teleconferencing and virtual reality, which dissolve geographical and physical barriers, facilitating seamless cross-border and cross-sector interaction. This has led to economic growth and improved living standards. These effects, fundamental to the FIR's broader definition, possess the potential to transform industries, generate new jobs, and boost productivity (Drath & Horch, 2014; Mosterman & Zander, 2017). A summary of this comparison can be seen in Table 1, while this research focuses on the marked concept of FIR.

Table 1 - *FIR and Industry 4.0 – comparison between the concepts*

Parameter	FIR	Industry 4.0
Period Of History	2000-	
Geographical Source Origin	Worldwide, mainly USA	Germany
Main Focus	Broad market and society	Industry, production line, efficiency of manufacturing
Core Component	Merging domains – digital, physical, biological	Creation of "smart factories" and improving efficiency, flexibility, and responsiveness.
Technological Driver	AI, IOT, cloud computing, AR/VR, biotechnology	IOT for industry and production lines, AI, simulation, digital twin, 3D printing
Main Impact	Human life as whole, quality of life, work-life balance	Industries, and cost of production
Outcome And Examples	AI impact of life, Transformation of work, disruption of transportation industry, tailormade medical treatment	Increased productivity, flexible production line, agility and ability to rapid change in the production

Source: Own edition.

Innovation models and their evolution

The current body of knowledge and academic literature emphasizes the importance of innovation for economic growth and socio-economic development (Chen et al., 2018; Fagerberg et al., 2013; Lundvall, 2016). However, despite the vast body of literature available, it is not easy to provide a comprehensive definition of the term innovation and a clear description of its source and nature. Innovation is considered a multidimensional concept that includes varied meanings and definitions from the perspective of different disciplines, with some being constantly developed in emergent fields such as innovation studies (van der Kooij, 2013; van der Kooij, 2018; Fagerberg & Verspagen, 2009; Chen et al., 2018; Cunningham, 2013; Edwards-Schachter & Wallace, 2017; Edwards-Schachter, 2018).

The comparison of innovation models reveals a progression from linear, firm-centric frameworks to open, collaborative paradigms that reflect the evolving complexities of economic, technological, and societal domains. Understanding this evolution is crucial for contextualizing entrepreneurial leadership and identifying attributes that foster innovation in an era of rapid change and interconnectedness, thus establishing the foundation for the subsequent empirical investigation. The literature review elucidates the evolving innovation paradigm's interplay with economic and societal contexts. This summary, featuring Figure 2 and Table 2, delineates this historical evolution. Innovation is not a static concept but one that continually evolves. Initial models emphasized linear, closed systems within national innovation systems or individual firms, focusing on internal research and limited external collaboration. The advent of open innovation and the Helix model highlights the dynamic nature of innovation ecosystems. Diverse actors such as startups, venture capitalists, and social media platforms underscore the significance of cross-boundary collaboration and knowledge sharing. This ongoing evolution reflects an interconnected world in which innovation thrives through global idea exchange. Table 2 details historical changes, while Figure 6 maps the evolution chronologically.

Figure 2 - *Innovation Paradigm Evolution Historical Illustration*

Source: Own edition

Table 2 - *Evolvement and Evolution of Innovation Concept along History*

Year	Phase	Main promoters of innovation	Connection to the surrounding
1930-1970	Linear-Closed Model	Prosperity, post WW2 Technology Push – technology promote innovation. Demand-pull approach – the market demand promote innovation. Necessity to invest in basic research and focus on individual innovation. Mass production line.	The model aims to be closed in the firm. Customer increasing demand at low price. Need to invent new production.
1970-2000	Interactive Closed Model	Digitalization, third industrial revolution. Effective management of R&D activities. Methodology of innovation management Different actors from different fields	Initiate the metrics of measurement the economics of R&D. Establishment of national institute for knowledge development.
1990	National Innovation Systems	Governmental led initiatives.	Clusters – geographical hubs on interconnected firms. Nation-based cooperation.
1995	National Innovative Capacity	Government establishment of specialized technology domains hubs.	Local clusters of mutual technology inter-connection.
2000	Enterprise Innovation Systems	In-firm innovation promotion initiatives.	Innovation as leading term in economy.
2000-today	Open Interactive Model	Outside firm's actors interacting with internal innovation leader inside the firms.	Knowledge transfer with eco-system.
2005 – today	Helix Model of Innovation	Collaboration and cross-functional communication in the innovation process. Triple helix - university-industry-government. N helix – new participators such as venture capitalists and banks, social media, individual innovators.	The interrelation between all actors within the helix impacts each other. The innovation paradigm penetrates different domains within society.
2005-today	Disruptive Innovation	New entrants to the market and start-up companies utilize existing technologies in order to compete with incumbent firms.	Dual influencing vectors – the changing environment promotes disruptive innovation, disruptive technologies which can alter and change the environment.
2010 - today	Open Innovation Ecosystems	Fourth industrial revolution implications, such as the pace of technological advancement. Working along eco-system – sharing knowledge, problems, insights.	Firms work with close connections and collaborate. Rely on service models (SaaS and similar). Outsourcing core components.

Source: Own edition

Leadership And Entrepreneurship

Leadership is a broad and multifaceted subject of academic inquiry, encompassing a vast array of information and theories (Avolio & Bass, 1991; Bennis & Townsend, 1995; Burns, 1978; Kotter, 1988). Furthermore, it is interconnected with other domains that fall within the purview of this research, such as innovation management, strategic management, and entrepreneurship. Innovation management is a complex and intriguing research topic; however, the underlying causes often remain elusive (Demircioglu & Audretsch, 2017; Heraud, 2019), as there are numerous obstacles to achieving success in innovation (MacVaugh & Schiavone, 2010; Rajapathirana & Hui, 2018).

Exploring the intricate relationship between leaders and entrepreneurs is crucial, as they possess overlapping and distinct features. Although often used interchangeably, these roles differ yet remain interconnected in business and innovation. Entrepreneurs, as visionaries and innovators, create new ideas and ventures, taking risks and challenging norms. Leaders, on the other hand, inspire, motivate, promote collaboration, and steer teams towards common goals, navigating uncertainty and complexity as strategists and decision-makers. Despite their differences, leadership and entrepreneurship are closely linked, with leaders supporting and nurturing entrepreneurial ventures in a multifaceted dynamic. Recognizing shared skills and perspectives between these roles is key to building successful ventures and leading change, with leadership attributes associated with entrepreneurship also applicable to firm leaders.

Leadership attributes refer to the collection of traits, characteristics, skills, and competencies that are deemed essential for effective leadership (Bryman et al., 2011). Similarly, entrepreneurial attributes refer to the personal characteristics, behaviors, and skills necessary for an individual to achieve innovation and gain a competitive advantage over their competitors (Ensley et al., 2006; Fernald et al., 2005). Before proceeding, it is important to define the term of 'attributes' as they relate to leadership attributes. Leadership attributes are defined as the personal qualities, characteristics, and skills that distinguish leaders from non-leaders and cause others to perceive a person as a leader, thereby enhancing their leadership performance (Northouse, 2010; Antonakis & Day, 2018). The term "attributes" is also known as "competencies," which are often viewed as a "fuzzy concept" that can vary depending on the context in which they are applied (Le Deist & Winterton, 2005). In the entrepreneurial context, these attributes can be categorized into cognitive, functional, and social competencies (Cheetham & Chivers, 1996; Le Deist & Winterton, 2005).

Research gap

This research aims to investigate the changes in innovation phenomena, and more precisely, the leadership phenomena related to innovation, due to the transformations in the world as part of the Fourth Industrial Revolution (FIR). The aforementioned intersections were previously delineated as a framework for the literature review (Figure 2), whereas in this context, they will be examined as a foundation for subsequent stages. The first inter-relation to examine is between leadership theory and the Fourth Industrial Revolution, as seen in Table 3.

Table 3 – *Integrative summary of historical view toward leadership and technology advancement*

Years	**1860-1900**	**1900-1960**	**1960-2000**	**2000-Present**
Industrial Revolution	1st -> 2nd transition	2nd revolution	3rd revolution	4th revolution
Leading theories	Trait theory "Great man"	Situational - Contingency theory	Transformational theory	Full range leadership theory
Main Paradigm	Focus on the personality of the leader. The leader should have certain leadership attributes.	No single leadership style is universally effective	leaders inspire and motivate followers to not only achieve their goals, but also to achieve their full potential and become more effective leaders themselves.	leaders use a variety of different leadership styles depending on the specific situation and needs of their followers.
Link to the Technology and Innovation world	Mixed view on technology – understanding the potential and fear	Technology considered as key-factor to achieve success and prosperity	The pace of technology change grows, and leaders adapted method to promote innovation and advance the technology	E-leadership as a framework of leaders in the digital eco-system
What is the role of the leader to promote innovation	Drive changes, convince the need to foster innovation, embrace the creativity and changes	Implementing innovation ideas, structured method for mange innovation, adapt structured process	Collaboration with innovation systems, implementing firm's internal and external innovation initiatives,	Close working with the eco-systems, leading the share of ideas, challenges, and solutions.

Source: Own edition.

A second inter-relation exists between the innovation theories developed during the industrial revolution and the evolution of these theories over time in response to the changing global technological landscape. Innovation is the process of introducing new elements or changing existing ones. In the workplace, leaders play a crucial role in promoting innovation, especially in reacting to competitive markets, developing new products, adapting to technological advancements, and encouraging employees to enhance their skills and commitment to the organization (Daemmrich, 2017; Cohendet et al., 2017). Simply put, leaders must stay ahead of the curve by either introducing new processes or revitalizing existing ones to ensure their organizations remain at the forefront of their industries. In a highly dynamic and competitive business environment, leaders play a critical role in the survival, success, and growth of their business by directing the innovation process. An entrepreneurial leader can effectively facilitate members in generating and realizing new ideas, thereby improving the impact of other leadership styles on the innovation process of their business (Renko et al., 2015; Arshi & Viswanath, 2013). Research on 350 workers in technology firms confirms the direct influence and relationship between entrepreneurial leadership and innovative work behavior (Makhdoom & Asim, 2020).

Another inter-link is between leadership and innovation, as studies suggest that strength, openness, and supportiveness between different levels of employees are necessary for a creative environment. Numerous studies have shown that effective leadership is essential for fostering innovation. To encourage creativity, leaders must create an environment where employees feel comfortable taking risks and challenging conventional thinking. Studies by Avolio et al. (1999) and Drucker (1998a) have found that transformational leadership and the creation of an entrepreneurial organization, respectively, are positively correlated with innovation in both the public and private sectors. Additionally, Chesbrough (2003) emphasized the importance of leaders adopting an open innovation approach, which involves collaboration with external partners to access new ideas and technologies.

The existing body of research on innovation primarily focuses on knowledge and findings that are up to a decade old, overlooking significant shifts in the innovation landscape that have occurred since then. These changes encompass the accelerated pace of innovation, its profound impact on companies, the diverse target audiences engaged in innovation, improved global communication capabilities, and more. While innovation has been studied extensively in the past, the dramatic changes in technological advancement, particularly due to the FIR, necessitate a fresh examination of the dimensions and attributes of innovation (Daemmrich, 2017).

One key research gap lies in the insufficient exploration of the connection between the FIR and innovation. Specifically, there is a lack of research and empirical knowledge on how the FIR influences the pace and speed of innovation development. This gap is particularly significant given the profound impact of the FIR on our daily lives, as evidenced by the proliferation of technologies such as smartphones and semi-automatic vehicles.

Additionally, existing innovation frameworks may not adequately address the challenges and opportunities presented by the current high-paced technological world. Further research is needed to determine which innovation attributes remain relevant in this era and how entrepreneurs' leadership attributes can be adapted to foster innovation in the face of rapid technological change. This could involve a re-evaluation of traditional innovation management frameworks and the development of new approaches that align better with the realities of the FIR. Ultimately, there is need for a comprehensive study is required to understand how entrepreneurs, as innovation leaders within firms, should adapt and evolve to successfully navigate the complexities of the current innovation landscape.

2. Methodology

This study utilizes a comprehensive strategy, primarily examining how the FIR influences entrepreneurial leadership qualities, as business leaders and innovators seek to embrace new technologies to establish and sustain their companies' market edge (Teece, 2017). The research addresses this central question by examining and differentiating these qualities across various industrial revolution periods. This investigation can be conceptualized through three fundamental questions: "when?," "what?," and "how?". The question "when?" focuses on the timing of the change, specifically the Fourth Industrial Revolution. The question "what?" examines the main force driving these changes and shaping the revolution, namely innovation. Finally, the question "how?" addresses the research craft, which involves analyzing the changes in entrepreneurial leadership attributes across different eras of industrial revolutions.

The investigation employed a qualitative methodology, utilizing Grounded Theory Method and automated content analysis on interviews and biographies of 147 entrepreneurs across various periods from the First Industrial Revolution to the present Fourth Industrial Revolution. The primary analytical tool was Natural Language Processing (NLP) to automatically identify leadership attributes in extensive written texts. While NLP facilitated document analysis, data collection remained labor-intensive. Sources comprised electronic public documents from internet databases, libraries, and repositories, encompassing books, biographies of firm leaders, chapters on specific firms, newspapers, journals, and related publications. The diverse and extensive nature of these sources necessitated significant effort to gather and curate, underscoring the commitment to constructing a comprehensive and reliable dataset.

The research problem is how the current industrial revolution affects the innovation paradigm, or more precisely, how it influences the entrepreneur of today?

Three research questions (RQ), which are the core of the research and based on the research problem, will be investigated to focus the research on specific areas of interest:

- **RQ1. What have been the effects of the Fourth Industrial Revolution on entrepreneur leadership attributes?**
- **RQ2. Which leadership attributes are more common in technology firms nowadays?**
- **RQ3. How have these leadership attributes influenced the innovation paradigm of technological firms?**

This research employs three distinct pathways to investigate the research problem comprehensively. Each pathway represents a different methodological approach, providing a unique perspective on the research question. The first pathway involves quantitative analysis, using descriptive statistics to analyze the data collected through Natural Language Processing (NLP) techniques. The second pathway utilizes the Grounded Theory Method, a qualitative approach, to develop a theoretical framework based on the data. The third pathway consists of a use-case analysis, examining specific examples to provide in-depth insights and validate the findings from the other pathways. This multifaceted approach ensures a robust and comprehensive investigation of the research problem, combining quantitative and qualitative analysis to provide a holistic understanding of the phenomenon under study. Figute 3 and Table 4 summarizes the overall research design and framework.

Figure 3 - *Overall Research Design and Research Method*

Table 4 - *Research Framework Summary*

Subject	**Which type will be use in this research?**	**What are the characteristics of this type?**	**Why used in this research?**
Research Paradigm	Constructivism	Seek to understand the world. The researcher looks for interpretation of social interaction.	This research aims to develop a new theory or update existing one.
Research Approach	Qualitative (mainly)	Inductive method. Enables the generation of theory. Suitable for text analysis, looking for theme and patterns interpretation.	Pre-defined methods do not exist (questionnaire, numerical data)
	Mixed method – explanatory	**Investigate the underlying reasons behind quantitative results by examining the deeper**	

Subject	Which type will be use in this research?	What are the characteristics of this type?	Why used in this research?
		aspects, such as motivations, experiences, and contexts.	
Research Design – RQ1 What have been the effects of the Fourth Industrial Revolution on entrepreneur leadership attributes?	Grounded Theory Method (GTM) – constructive method	Based on the constructivist paradigm. Develop new theory based on prior knowledge. RQ can be evolved during the process.	This research aims to develop a new theory or update existing one.
Research Design – RQ2 – Which leadership attribute are most common in present day technology firms?	Mixed method – Descriptive Statistics	**Investigate the underlying reasons behind quantitative results by examining the deeper aspects, such as motivations, experiences, and contexts.**	To be used for analyzing and reporting the results of the first stage of the research.
Research Design – RQ3 – How have these leadership attributes influenced the innovation paradigm of technological firms?	Mixed method – Quantitative and Qualitative –	**Investigate the underlying reasons behind quantitative results by examining the deeper aspects, such as motivations, experiences, and contexts.**	To be used for analyzing and reporting the results of the first stage of research.
Research design – data	Documents	Public written data texts, books, biographies, interview etc. The sample will be based on technology firms which affected by the industrial revolution	To be used for the coding process. Enables research into different time periods.
Research design – data analysis	Utilize NLP Tools	Locate leadership attributes, which pre-defined based on knowledge review.	Fast, affordable, and efficient processing.

Source: Own edition.

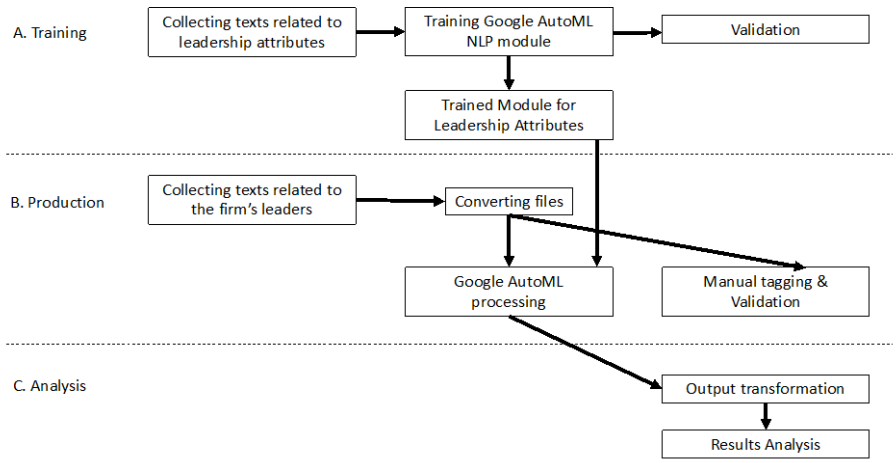
Data Processing based on Natural Language Processing (NLP)

The data collection process has been divided to three steps: first, choosing the firms that were affected by the industrial revolution and introducing product innovation initiatives; second, identifying the firms' leaders; and third, gathering written material about the firms' leaders. The data were derived from written texts, books, newspaper articles, biographies, and other similar materials, which were subsequently analyzed utilizing Natural Language Processing (NLP) tools. The range of this dataset ensured that each industrial revolution was represented and that the changes over time could be traced.

Google Vertex AI, a leading machine learning platform, was utilized in this project for item identification in photos and video streams, sentiment analysis of text, and NLP (Google Vertex, n.d.). Content analysis and NLP were crucial due to the historical context requiring data from unreachable participants. Initially, a training phase was conducted to ensure the NLP tool accurately identified entrepreneurial attributes in text. The current phase analyzes leadership

traits of 147 executives, assessing their entrepreneurial characteristics across over 900 textual sources. Post-training, an evaluation phase tested the accuracy and reliability of tagging, comparing newly tagged texts with pre-tagged ones to record errors. The trained NLP model then identified entrepreneurial attributes in the texts, noting only their presence, resulting in binary outcomes. The final phase classified these attributes by industrial revolution periods and compared them over time. Attributes' occurrences were counted, but data was simplified to indicate mere presence or absence. This phase assessed the FIR's impact on leadership using a "dominance ratio" to determine attribute prevalence, varying by analysis type. Figure 4 illustrates the tagging and analysis process using the NLP tool, covering machine training, production, data analysis, and converting raw data into a readable file for examination.

Figure 4 - *Natural Language Processing Steps Overview*



Source: Own model

The process of identifying attributes in the texts was conducted in three stages, ensuring that the process was controlled and would yield expected results:

- The first step involved a manual preliminary process of attribute identification, without the use of computerized tools, in front of five selected company managers. The purpose of this stage was to assess the general applicability of the research method.
- The second stage also consisted of a manual process of attribute identification, defined as part of the literature survey, against a list of 30 company managers (25 new and 5 from the first stage). This involved a manual scan of the texts and identification of the characteristics. The aim of this step was to test the applicability of attribute identification using a mechanized method. Following this stage, the attributes were sifted and consolidated, resulting in approximately 53 identified attributes in the texts.

- The third stage involved the full realization of the NLP natural language processing (NLP) capability in a mechanized manner. This step was performed according to the process outlined above. To facilitate control and monitoring, the process was carried out in a graded manner, using groups of 50 managers. In total, 921 text documents of various types were automatically processed, an average of 6.3 documents per manager in each company.

This comprehensive process entailed a substantial investment of time and resources to ensure thorough and extensive results, adhering to the saturation principle of GTM. The development of a novel AI-powered NLP tool for analyzing leadership attributes, meticulous data collection from diverse sources, and careful selection of a heterogeneous sample of leaders and organizations across various historical periods and industry sectors necessitated extensive resources and dedication. This rigorous approach ensured that the research encompassed a wide range of perspectives and experiences, contributing to the depth and richness of the analysis. The commitment to achieve saturation, a fundamental tenet of GTM, ensured that the research continued until no new or relevant data emerged, thereby enhancing the comprehensiveness and validity of the findings.

3. Research Results

The Dissertation Theses

The Fourth Industrial Revolution has precipitated substantial technological advancements, necessitating businesses to adapt and innovate to maintain their competitive advantage. This study corroborates that in this volatile, uncertain, complex, and ambiguous environment, entrepreneurial leaders must possess adaptability, risk tolerance, and collaborative competencies to achieve success. These leaders must demonstrate proficiency in integrating emerging technologies, fostering collaboration within technology-driven ecosystems, and navigating the unpredictable landscape of disruptive innovation. This research provides strong support for the notion that visionary strategic capabilities are essential for leaders in the FIR. These leaders must be agile and decisive, exhibiting resilience in the face of setbacks and a penchant for experimentation. Additionally, they should foster a collaborative and motivating management approach that empowers employees to contribute their creative ideas and take initiative. This research confirms that disruptive and open innovation are crucial for FIR's success, which demands leaders with a mix of risk-taking, decisiveness, openness, and networking. These leaders must embrace diverse viewpoints, integrate external ideas, and

foster a creative environment that empowers employees to contribute to innovation. To thrive in the FIR, organizations must adapt their practices by implementing flexible structures that can respond to rapid change, promoting continuous learning and development, and fostering a culture of collaboration and experimentation. It is crucial to quickly identify opportunities, assess risks, and make data-driven decisions in this fast-paced environment. Furthermore, companies must effectively operate within their ecosystems, accelerate the go-to-market phase, and integrate external systems and technologies to drive innovation. Finally, ethical leadership and empathy toward stakeholders are essential. Business leaders must evaluate the societal and environmental consequences of their strategic decisions and exhibit dedication to ethical and sustainable corporate practices.

The main scientific outcomes of this dissertation are as follows:

- The Fourth Industrial Revolution (FIR) has profoundly influenced innovation, necessitating a transition from traditional, closed models to open, collaborative ecosystems. Entrepreneurs must adapt by fostering collaboration, embracing calculated risks, and prioritizing rapid growth and organizational flexibility.
- The FIR has significantly transformed the innovation landscape, necessitating entrepreneurial leaders who demonstrate adaptability, risk tolerance, and collaborative tendencies. These leaders must integrate emerging technologies, promote collaboration within technology-driven ecosystems, and navigate the uncertainties inherent in disruptive innovation.
- Visionary leadership is vital in the context of the FIR, requiring entrepreneurs to navigate a rapidly evolving technological landscape. Leaders must exhibit agility, decisiveness, resilience in the face of setbacks, and an inclination towards experimentation. Additionally, they should promote a collaborative and motivating management style that empowers employees to contribute creatively and exercise initiative.
- The FIR necessitates an innovation model emphasizing agility, collaboration, and data analysis. Leaders endorsing disruptive and open innovation are crucial, requiring qualities such as risk-taking, decisiveness, open-mindedness, and networking proficiency. They should welcome diverse perspectives, incorporate external ideas, and cultivate a creative atmosphere that enables employees to contribute to innovation processes.
- Organizations must adapt to the FIR by implementing flexible structures, promoting continuous learning, and fostering a collaborative and experimental culture. Identifying

opportunities, assessing risks, and making data-driven decisions expeditiously are crucial in this dynamic environment.

- Operating effectively within an ecosystem is critical in the FIR. Companies must accelerate go-to-market strategies, integrate external technologies, and prioritize ethical leadership and stakeholder empathy. Leaders must consider the social and environmental implications of their decisions, demonstrating a commitment to responsible and sustainable practices.
- This research underscores the significance of ethical leadership and empathy in managing the complexities of the FIR.

This dissertation contributes to the field of innovation studies by examining the relationship between technological advancements, entrepreneurial leadership, and the innovation paradigm. The findings provide significant insights for entrepreneurs, investors, and policymakers regarding the promotion of innovation and addressing the challenges and opportunities presented by the Fourth Industrial Revolution. Furthermore, it emphasizes the necessity for additional research on the evolving dynamics of innovation and leadership in the context of rapid technological changes.

This study examines the varying prominence of entrepreneurial leadership traits across different time segments, including the First, Second, and Third Industrial Revolutions, as well as the period following the FIR. Several attributes stand out more prominently after the FIR, including Risk-taker (ratio of 3.55), Prioritize (3.19), Empathy (2.96), Motivation (2.39), Integrator (2.28), Listener (2.22), Open-minded (2.13), and Courage (2.0). However, some traits do not demonstrate any clear dominance in either of the two-time segments. Among these non-dominant traits, some can be highlighted, such as Assertive, Autonomous, Changes Related, Communicate, Idea Generation, Innovative, Proactiveness, Resource Manager, Strategic Thinker, and Team-Builder.

Research Question 1 (RQ1) - What have been the effects of the FIR on entrepreneur leadership attributes?

The most dominant leadership attributes in successful firms after the FIR are: risk takers, prioritize, empathy, motivation, integrator, listener, open-minded, and courage, with dominance ratios of 3.55, 3.19, 2.96, 2.39, 2.28, 2.22, 2.13, and 2, respectively, as the next Figure demonstrated.

Research Question 2 (RQ2) - Which leadership attributes are more common in technology firms nowadays?

As we concentrate on the technology sector and its impact from the FIR, several attributes stand out among the technology firm's leaders after the FIR, as described in Table 29, among those –Prioritize, Decisive, Integrator, Motivation, Patience, and Prioritize (all with ratios of 4.38). The next most dominant attributes were courage and Freedom (3.29), Charisma and Listener (2.92), Ethics and Flexibility (2.74), Inspiring (2.56), Coaching and Risk Taker (2.19), Forecast Future (2.01), and Empathy, Assertive, Self-Confident, Self-Control (all with N/A).

Research Question 3 (RQ3) - How have these leadership attributes influenced the innovation paradigm of technological firms?

To succeed in this environment, leaders must possess a unique set of attributes tailored to the dominant innovation paradigms, including open innovation, disruptive innovation, and e-leadership. The outcomes were consistent with the initial hypothesis that had been previously formulated. Advocates of open innovation promote collaboration and knowledge sharing among diverse stakeholders, in contrast to the traditional approach of maintaining closed doors (Chesbrough, 2003). In this regard, several key leadership attributes have been identified as essential. Research has confirmed the importance of these attributes, particularly in the context of the FIR. These attributes include collaboration, the ability to dismantle internal barriers and build relationships with external entities such as startups, universities, and research institutions. This involves fostering a culture of openness, trust, and transparency, in which employees feel empowered to share ideas and work together across boundaries. The research has also highlighted the importance of attributes such as integrator, listener, open-mindedness, holistic view, and networking, which have a higher dominancy ratio of 2.28, 2.22, 2.13, 1.98, and 1.77 respectively. The necessity for companies to engage in extensive cooperative efforts has become increasingly evident in order to foster synergies during the development stages, particularly in the areas of interfaces and customer sales. This collaboration enables companies to expedite their go-to-market strategy and effectively navigate the rapid pace required in the current market. Leaders who recognize the value of interconnectedness and possess the ability to construct robust innovation ecosystems must identify key stakeholders, establish efficient communication channels, and align shared objectives and incentives for mutual success.

The research indicates that visionary leaders, who articulate how new technologies can disrupt existing markets and create new ones, are more prevalent in technology firms than non-

technology firms (ratio of 3.05). These leaders understand emerging trends and take calculated risks to pursue them. Leaders who promote experimentation, rapid iteration, quick decision-making, and learning from failures are crucial for navigating uncertainties in disruptive innovation. Agility in adapting to market changes and perseverance in adversity are vital (ratio of 3.29 in technology firms post-FIR). Leaders with courage and resilience, who make tough decisions and handle setbacks, are essential for overcoming resistance from established players. Table 5 links leadership attributes to innovation paradigms, such as open innovation, disruptive innovation, and e-leadership, validating the study's findings and reinforcing its theoretical foundation. This connection underscores the practical relevance for leadership development and innovation management.

Table 5 - *The Connection between the Findings to the Innovation Paradigm*

Entrepreneurial Leadership Attributes	Ratio Of Dominancy of Entrepreneurial Leadership Attributes	Link To Innovation Paradigm	Remarks
Integrator	2.28	Open Innovation[1]	[1] Correlation with open innovation, which highlights collaboration, idea sharing, external idea implementation, and integrating diverse viewpoints to enhance innovation (Chesbrough, 2003).
Listener	2.22	Open Innovation[1]	
Open-minded	2.13	Open Innovation[1], Disruptive Innovation[2]	
Holistic view	1.98	Open Innovation[1]	
Networking	1.77	Open Innovation[1]	
Risk-taking	3.55	Disruptive Innovation[2]	[2] Focused on disrupting existing markets and creating innovative products/services that challenge traditional business models (Christensen, 1997).
Freedom	1.95	Disruptive Innovation[2], E-Leadership[3]	
Courage	2.00	Disruptive Innovation[2]	
Visionary	1.77	Disruptive Innovation[2], E-Leadership[3]	
Idea generation	2.16	E-Leadership[3]	[3] Linked to E-Leadership, emphasizes fostering innovation via inspiring creativity, encouraging experimentation, and championing new ideas (Avolio&Kahai, 2003).
Creative	1.52	E-Leadership[3]	

Source: Own edition

$$Ratio = \frac{\%\ attributes\ existence\ in\ the\ 4th\ Industrial\ Revolution}{\%\ attributes\ exsitence\ in\ the\ 1st, 2nd, 3rd\ Industrial\ Revolutions}$$

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