

Mapping the job potential of the industrial engineer: a web-investigation

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PREFACE

When I was in school, I never knew what I wanted to study at university. What I did know was that I wanted to study something that would allow me to “make the world a better place” (as cliché as it sounds). I was inclined towards the humanities, but I had also developed a proclivity for mathematics. However, when I would investigate different degree options, I failed to pinpoint which one would be the ideal fit for me. I wanted to study something interesting enough to keep me engaged, challenging enough to stimulate me intellectually, varied enough to broaden my horizons, and practical enough to secure my professional future.

One day, my brother Hasan (an industrial engineering student at the time) suggested industrial engineering to me. I had never heard of such a discipline until he started studying it. I only started finding out more about it when he was explaining it to me. He expressed much enthusiasm for it and thought it would be perfect for me. Initially, I was not so convinced. I had never envisioned myself as an engineer, and the term “industrial” intimidated me. However, the more Hasan explained, the more intrigued I was. My perception of what “industrial” and “engineering” meant started to clarify. Eventually, I was captivated enough by industrial engineering that I chose to study it at university.

In the first two years of my undergraduate industrial engineering program, my peers and I mostly took general engineering subjects like mathematics and physical sciences. Even though we were industrial engineering students, we hardly knew what our degree really entailed until the final years of our studies. We also faced much teasing from the other engineers who seemed to think that industrial engineering is not really engineering. However, the more we learned, the more we were able to appreciate the variety, flexibility, broadness, and power of our degree.

Studying industrial engineering made me able to see the “behind the scenes” of our world and to envision all of the ways that it can be improved. The industrial engineering degree introduced me to a plethora of ways where “making the world a better place” could be an achievable (and even measurable) reality.

Every time I get asked “What is industrial engineering?”, I find myself struggling to answer the question – I usually don’t even know where to start! However, every time I do manage to answer, I find that the questioner is intrigued and immediately able to appreciate the need for such a discipline. My intention for writing this dissertation is to increase the awareness and appreciation for the underrecognized yet highly needed discipline of industrial engineering.

I want to thank my family, friends, fiancé, and supervisor for their continuous support throughout this process. My brother, Hasan, gets a special thank you for introducing me to industrial engineering and for guiding me throughout my dissertation. I also want to give a special thank you to my supervisor, Dr. Teresa Hattingh. Dr. Hattingh’s support, advice, and insights helped me tremendously in learning about the research process and in finishing off my dissertation.

ABSTRACT

The industrial engineering discipline is inherently interdisciplinary and broad, with many areas of specialization. It interfaces with both the hard sciences and the soft sciences to solve a wide variety of problems in all sorts of industries. However, the discipline's broadness has been both beneficial and problematic for its development. On one hand, it has kept industrial engineering flexible, dynamic, and timeless. On the other hand, it has led to misunderstanding, confusion, and a lack of recognition of the discipline. To clarify the misperceptions surrounding the discipline, the potential job titles of the industrial engineer were gathered through web-scraping. These job titles were then categorised based on job role/function and areas of concern. The categories that were based on areas of concern were: Method/Process/Operation/System/Project, Supply Chain/Logistics, Manufacturing/Production, Business/Management, Data/Information/Technology, Quality/Reliability/Safety, Lean/Six-Sigma/Continuous Improvement, Ergonomics/Human Factors, Facility/Field/Plant, and Procurement/Purchasing/Investment. The categories that were based on job role/function were: Engineer, Analyst, Manager, and Consultant. Ultimately, the job potential of the industrial engineer can be summarized as a vast and flexible combination of job roles/functions, areas of concern, and industries or contexts.

Keywords: industrial engineering, web-scraping, body of knowledge, job potential, job categories, job titles

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CHAPTER 1: INTRODUCTION

Each academic discipline can converge and diverge. An academic discipline converges through specialization – that is, the discipline concentrates on a specific area of knowledge within its boundaries (Arekkuzhiyil, 2017). An academic discipline diverges through interdisciplinarity – that is, the discipline interacts with one or more other disciplines in some way, usually to combine or integrate knowledge (Augsburg, 2016). Although divergence and convergence are opposing orientations, academic disciplines can converge and diverge simultaneously. Consequently, subdisciplines and interdisciplines emerge.

The boundaries of disciplines are flexible, variable, and relative. The boundary may expand when knowledge from one discipline is fully integrated into that of another (Arekkuzhiyil, 2017). The boundary may be divided when a specialization in a discipline develops enough to warrant the creation of its own standalone discipline (Arekkuzhiyil, 2017). Finally, the relativity of the disciplines depends on how one chooses to place the boundaries and relate them to each other. Thus, specializations can happen within interdisciplines, and vice versa.

Interdisciplinarity and specialization are both important features when it comes to reinforcing the function of a discipline. They usually develop when a discipline, in its current form, does not have enough knowledge to complete its function. Therefore, it uses knowledge from other disciplines (interdisciplinarity), and/or uses expert knowledge within its own boundaries (specialization), to better complete its function (Arekkuzhiyil, 2017). In turn, the jobs associated with such disciplines also converge (to create specialized jobs) or diverge (to create more generalized jobs).

The discipline of engineering can be used as an example to illustrate the concepts of interdisciplinarity, specializations, and jobs.

Some of the most common engineering subdisciplines are mechanical, electrical, civil, and chemical engineering (Yoder, 2011). Although these engineering disciplines are subdisciplines of the engineering discipline, they are usually considered as standalone disciplines with their own subdisciplines. They also have interdisciplinarity. For example, while mechanical engineering is a subdiscipline of engineering, it can also be considered as a standalone discipline with its own subdisciplines. Some of these subdisciplines are unique to mechanical engineering (such as mechanics), while others (such as mechatronics) combine one or more other disciplines (Mcklein, 2017). Therefore, mechatronics is both a subdiscipline and an interdiscipline of mechanical (or electronic) engineering.

A person who decided to specialize in mechatronics could represent the evolution of their speciality in the following ways:

Engineer → Mechanical Engineer → Mechatronics Engineer, or

Engineer → Electronic Engineer → Mechatronics Engineer

For many engineering disciplines, their nomenclature gives a good idea of what types of work they do and in what domain they operate. For example, Savory's (2005) descriptions of some types of engineers and their areas of concern can be tabularized in the following way:

Table 1: Types of engineers and their areas of concern (Information from Savory (2005))

Engineer	Areas of Concern
Electrical engineer	Electrical systems and designing circuits
Mechanical engineer	Mechanical systems and building devices
Chemical engineer	Chemical systems and exploring chemical processes
Civil engineer	Physical systems and building structures
Industrial engineer	Designing processes and systems that improve quality and productivity

For the case of the electrical, mechanical, and chemical engineer, their respective area of concern is self-evident and intuitive: mechanical, electrical, and chemical systems. This pattern is broken for the civil engineer, as the area of concern of a civil engineer is not described as “civil systems.” Rather, a civil engineer is concerned with the physical systems and structures that aid civilian life. Interestingly, the term “civil” has historic significance. Civil engineers and military engineers were grouped together because they both did the same type of work, such as constructing bridges and other physical structures (Okumu, 2014). However, the term “civil engineer” was coined to indicate that civil engineers applied their work in civil, not military, environments (Okumu, 2014). Thus, instead of having a more intuitive name such as “construction engineering” or “structural engineering” to reflect an area of concern, civil engineering has a name that reflects its roots.

Like civil engineering, industrial engineering has a name that reflects its roots: that is, the industrial revolution (Lucas, 2014). Furthermore, like the civil engineer, the industrial engineer breaks the pattern of Table 1. Like the mechatronics engineer, the industrial engineer can adopt more specific job titles to give an indication of their speciality and/or their interdisciplinarity. However, compared to many other engineering and non-engineering disciplines and professions, the industrial engineering discipline and profession does not seem to be as uniformly established and societally understood (Greene, 2001). This may be, in part, because industrial engineering was only officially established about a century after mechanical, electrical, and civil engineering were established (Greene, 2001). However, it may also be due to the uniqueness of the industrial engineering discipline.

1.1 Background

Industrial engineers often encounter people who do not know what industrial engineering is or what an industrial engineer does (Billings *et al.*, 2001). Even industrial engineers themselves may struggle to define what industrial engineering is. Thus, to introduce the industrial engineering discipline, both an official and a colloquial definition are presented and discussed.

1.1.1 The definition of industrial engineering

The Institute of Industrial and Systems Engineers (IISE), founded in 1948, is “...the world’s largest professional society dedicated solely to the support of the industrial engineering profession and individuals involved with improving quality and productivity” (IISE, 2021). The Institute defines industrial engineering in The Industrial Engineering Body of Knowledge (IEBoK) in the following way:

“Industrial Engineering is concerned with the design, improvement and installation of integrated systems of people, materials, information, equipment and energy. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.” (IEBoK Authors, 2019)

In simpler and more colloquial terms, an industrial engineer figures out “how to make or do things better” (Lucas, 2014). To link this definition back to the IISE definition, “things” could refer to certain aspects of people, materials, information, equipment, energy, and/or integrated systems. “Better” could refer to some form of improvement, such as reducing the waste of resources, increasing production efficiency, or enhancing product quality (Savory, 2005; Lucas, 2014).

From the IISE’s definition, it is evident that industrial engineering is inherently interdisciplinary and broad, with many areas of specialization. This interdisciplinarity spans within and across the disciplines of the mathematical sciences, the physical sciences, the social sciences, and engineering. The specialization is indicated since industrial engineering “draws upon specialized knowledge and skill” from these disciplines. However, while both definitions give a general idea of industrial engineering, they are usually insufficient for describing what an individual industrial engineer does.

The broad nature of the definitions already sets the scene for the challenges faced by the industrial engineer when it comes to their identity and recognition. Furthermore, the nomenclature of “industrial engineer” itself can be misleading, especially since the industrial engineering identity is unclear and evolving (Darwish, 2018).

1.1.2 The nomenclature of the industrial engineer

There have been discussions since the 1950s about whether the term “industrial engineer” is appropriately representative of industrial engineering or whether it has become obsolete (Greene, 2001). The term, by itself, gives little insight into what an industrial engineer is. Furthermore, there are embedded societal perceptions of what “industry/industrial” and “engineering/engineer” mean that may be limiting in the case of the industrial engineer. Thus, a person hearing the term “industrial engineer” for the first time may not be able to intuitively deduce what an industrial engineer does (Greene, 2001). Alternatively, they may form an inaccurate or limiting perception.

To begin, the term “industrial” is often linked to manufacturing and production, which gives off the impression that an industrial engineer works only in factories or the manufacturing industry (Darwish, 2018). This impression is consistent with the early form of industrial engineering. After all, it is generally agreed upon that industrial engineering had its roots in the first industrial revolution and that the early industrial engineer focused on making improvements in manufacturing and production (Martin-Vega, 2001; Lucas, 2014). However, despite being a “child of the [first] Industrial Revolution” (Chaffin, 2015), industrial engineering has evolved since then.

The term “industrial” has broadened to encompass all sorts of industries, not just manufacturing and production industries (Greene, 2001; Stan, Tulcan and Cosma, 2010). “Industry” could mean anything from “entertainment industry” to “healthcare industry”, both of which are unexpected industries to associate with engineers. However, industrial engineers are present in virtually any industry all over the world (Greene, 2001). Furthermore, industrial engineering methods are being applied to humanitarian aid, disaster relief, the military, public policy, and sports – all of which are not usually thought of as industries (Mackenzie, 2016).

As was the case with the word “industrial”, the meaning of “engineer” for the case of the industrial engineer is atypical and nuanced. According to The US Department of Labor (2009), the typical engineer uses the hard sciences to solve technical problems. The industrial engineer, however, uses both the hard sciences and the soft sciences to solve a wide variety of problems, not just technical problems (Hicks, 2001). When it comes to the public perception of an engineer, the most common one is that an engineer is someone related to construction and mechanics, “[associating] the profession into the role of fixing things rather than design or creativity” (Marshall, McClymont and Joyce, 2007). However, the reality of engineers is different from the public perception. While an industrial engineer can be working in construction and mechanics, they can also be working in many other types of industries. Furthermore, the industrial engineering definition mentions the design, improvement, and installation of systems as core functions of the discipline – not simply fixing things. Finally, contrary to the public perception, creativity is valued and encouraged not only in industrial engineering (Holt, 1977) but also in engineering in general (Cropley, 2016).

1.1.3 The predicament of the industrial engineer

To introduce the industrial engineer's predicament with regards to their identity, Greene (2001) draws an analogy with medicine: "From a layperson's viewpoint, a medical doctor works in a medical facility helping to make or keep people well. The role of the physician is fairly crisp and well defined. Unfortunately, for our concern about the [industrial engineer]'s image, [their] multiple roles result in [their] image being hard to define for industry or society."

Greene (2001) expands extensively on the state of the industrial engineer in one of the chapters of Maynard's *Industrial Engineering Handbook* (Zandin and Maynard, 2001), attributing the concern about the image and recognition of the industrial engineer to the fact that industrial engineering, from its inception, has been broad and is broadening and evolving even more with time. The industrial engineer is even described as a "master of change" (Billings *et al.*, 2001). In the Handbook, there is a claim that the industrial engineering profession is best summed up by the word "diversity", since it seems to be the most broadly defined profession and discipline in engineering (Billings *et al.*, 2001). This broadness is seconded by defining the industrial engineer's identity as someone who "...is connected to all fields of knowledge and is a master of some" (Darwish, 2018).

By being connected to all fields of knowledge and taking on so many diverse roles, it is challenging to pinpoint what exactly an industrial engineer does (Greene, 2001). Thus, it is understandable that industrial engineering is not very well understood by society. It is also understandable that employers rarely hire based on the job title "industrial engineer", but rather something more specific to the company's recruitment requirements, such as "supply chain manager" (Darwish, 2018).

Some other job titles that industrial engineers can have are: quality engineer, systems consultant, production supervisor, and inventory controller (Savory, 2005). These job titles are not exclusive to or reserved for a professional with an industrial engineering background. Thus, industrial engineers have yet another predicament: even when they adopt more specific job titles, their original industrial engineering identity is not highlighted. This risks the industrial engineer being under-recognized in the job market (Pun and Yiu, 2010). Yet, the industrial engineering title by itself remains vague, as it "...says more about the training and degree, and less about the actual role played in most organizations" (Billings *et al.*, 2001).

It seems that the broadness of industrial engineering results in both challenges and opportunities for its development. On one hand, it keeps the industrial engineering profession flexible, diverse, and able to adapt to the needs of any place at any time (Billings *et al.*, 2001). On the other hand, it may result in confusion over the roles of industrial engineers in the world (Billings *et al.*, 2001).

1.1.4 Macro challenges and opportunities for the industrial engineer

Several challenges are facing industrial engineering, one of which is “a lack of appreciation for the discipline” (Billings *et al.*, 2001), leading industrial engineers to struggle with their professional recognition and with marketing themselves (Greene, 2001). These challenges may seem abstract since they relate to identity and perceptions, but they have had real-life implications for the industrial engineer. In 1949, for example, letters were sent “...to the editor in the first issue of the *Journal of Industrial Engineering*...about the necessity of selling industrial engineers” (Leake, cited in Billings *et al.*, 2001). Furthermore, misconstrued perceptions of industrial engineering posed a significant threat to its professional recognition and its capacity for application in industry (Pun and Yiu, 2010). The struggle for recognition extends to academia, too. Studies done on the perceptions of industrial engineers in universities found that many misconceptions were surrounding the discipline, to the point that it was being ridiculed (Trytten *et al.*, 2004; Murphy *et al.*, 2006; Specking, Kirkwood and Yang, 2015).

It is worth noting that the challenges are magnified since the industrial engineering discipline is getting even broader with time (Greene, 2001). However, despite the challenges facing the industrial engineering discipline, there are also many opportunities (Billings *et al.*, 2001).

The career outlook for industrial engineering is promising and growing. According to the American Bureau of Labor Statistics (2021), “Employment of industrial engineers is projected to grow 10 percent from 2019 to 2029, much faster than the average for all occupations.” This percentage has already increased by 2% from the estimate of 2020, which stated that employment was projected to grow 8 percent from 2018 to 2028 (Bureau of Labor Statistics, 2020). The growth in employment demand is paralleled in other areas too, such as China, Colombia, Australia, South America, and South-East Asia (Pun and Yiu, 2010). In South Africa, “industrial engineer” is listed as one of the occupations with the highest demand, along with many other occupations that an industrial engineer could potentially do, such as “process engineer”, “logistics manager”, “production/operations manager”, and “quality systems manager” (DHET, 2018). Furthermore, industrial engineering is becoming a popular university study choice in many countries in North America, Europe, and Asia (Pun and Yiu, 2010). The increase in popularity is beneficial and necessary since it seems that there are not enough industrial engineering graduates to supply the job demand for them. In South Africa, for example, “Industrial and Production Engineers” was listed as 8th on the National Scarce Skills List in 2014 (DHET, 2014). In the United States of America, the projected number of industrial engineer openings per year for a decade was three times the number of graduates at the time (Pun and Yiu, 2010).

To maximize the opportunities and minimize the challenges, there is a pressing need to rectify the misunderstood perception of industrial engineering (Pun and Yiu, 2010).

1.2 Research rationale and focus: job titles, the web, and industrial engineers

There are many ways that one could address the need to rectify the misunderstood perception of industrial engineering. For example, one could launch a campaign to educate human resource departments or high schools about industrial engineering. Alternatively, one could interview individuals from inside and outside the industrial engineering community to uncover misalignments in perceptions. For both of those approaches, it would be necessary to first have a clear and comprehensive understanding of what the industrial engineering discipline entails. Examining this understanding (or lack thereof) is another way that one could address the need. In the case of the industrial engineer, one can start this examination by inspecting the job title(s) of the industrial engineer – as was started briefly in the Background of this study.

Job titles can be seen as labels for employees that describe what type of work they do (Doyle, 2021). Grant, Berg, and Cable (2014) describe job titles as “identity badges.” Typically, a job title describes job responsibilities, the job level, or both (Doyle, 2021). Job titles may also indicate knowledge, competencies, status, and values (Grant, Berg and Cable, 2014). Employers use job titles to advertise and categorise jobs, while employees and job seekers use job titles to market themselves and find jobs (Doyle, 2021). Thus, job titles play an important role in the recognition and marketing of professions. They also serve a more personal function by helping people form and communicate their identities, both inside the workplace and outside of it (Grant, Berg and Cable, 2014).

When one shares their job title, a public perception is immediately formed – whether that is by a prospective employer who would consider hiring someone with that job title, a recent graduate who is looking for jobs, or a member of society who wants to learn more about the world. However, “[...] job] titles do not always reflect the unique value that employees bring to their jobs” and this may lead to negative psychological implications (Grant, Berg and Cable, 2014). It may also lead to negative social and professional implications, as is the case for the industrial engineer, who faces challenges when it comes to the appreciation, recognition, and marketing of their discipline (Greene, 2001). However, given the broad career opportunities of the industrial engineer, there may be many other job titles that better represent the specific work that one industrial engineer may be doing (Greene, 2001).

Creating a repository of industrial engineering-related job titles would be beneficial for industrial engineering. One of the best places to find these job titles would be on the internet, given that it is the largest data source available to humans and it is growing larger every day (Persson, 2019). After all, the internet has revolutionized the job market (Denzer, Schank and Upward, 2018). It is also known that people interested in engineering prefer to use the internet to find out more about it (Marshall, McClymont and Joyce, 2007).

1.3 Problem statement

The problem statement is that the job title of “industrial engineer” is misleading, vague, and variable. The job title is misleading because industrial engineering has evolved from its roots in the industrial revolution to encompass industries in the broader sense (Stan, Tulcan and Cosma, 2010); this makes it difficult to explain. The job title is vague because industrial engineering has broad and flexible applications (Greene, 2001); this makes it difficult to navigate. The job title is variable because the industrial engineer can adopt many other job titles that still reflect industrial engineering competencies (Greene, 2001); this makes it difficult to capture. Although there exist many sources describing the types of jobs associated with industrial engineering, these sources are scattered across the web and are not consolidated. Therefore, more direction is needed to navigate the discipline.

1.4 Research aim

This research aims to investigate the job potential of industrial engineers based on web-scraped job titles. The intention of this investigation is to provide guidance and clarity on how to navigate the industrial engineering profession.

1.5 Research questions

This research intends to answer questions related to what a person with an industrial engineering qualification *can* theoretically do in the job market, not what people with industrial engineering qualifications *are* doing in the job market. The focus on the theoretical is to capture the essence of industrial engineering and its job potential without the bias of independent human choices and circumstances.

To investigate the job potential of industrial engineers based on web-scraped job titles (as per the first part of the aim), the following research questions (RQ) were posed:

RQ 1: What job titles are associated with the industrial engineering discipline on the internet?

RQ 2: What patterns emerge from the job titles that are associated with industrial engineering on the internet?

To provide guidance and clarity on how to navigate the industrial engineering profession (as per the second part of the aim), the following research questions were posed:

RQ 3: How can the job titles that are associated with industrial engineering on the internet be categorised and visualized?

RQ 4: What do the job titles that are associated with industrial engineering on the internet reveal about the job potential of the industrial engineer?

1.6 Overview of dissertation

The Introduction Chapter started by introducing the concepts of interdisciplinarity and specialization. Then, the industrial engineering discipline was introduced, as it is an inherently interdisciplinary field with many areas of specialization. The capacity for interdisciplinarity and specialization of this discipline is so broad that it has caused some confusion as to what an industrial engineer does in practice. Thus, a need was identified to investigate the industrial engineering profession, specifically highlighting its job potential and how to navigate it.

To investigate the job potential of the industrial engineer, a methodology involving web-scraping relevant job titles was applied. This methodology led to results, which were analysed to produce a categorisation system for the job titles. Then, the results were discussed to extract meaning and insight. Finally, the study was concluded with a summary and recommendations.

Figure 1 provides an overview of the dissertation layout going forward.

Chapter 1: Introduction	The Introduction Chapter introduces and defines the research topic. Then, the problem statement, research aim, and research questions are stated.
Chapter 2: Literature Review	The Literature Review Chapter expands on and contextualizes the Introduction Chapter. Also, similar studies to the one being conducted are shared and discussed.
Chapter 3: Methodology	The Methodology Chapter explains how the research topic was addressed. The limitations, validity, and reliability of the study are also discussed.
Chapter 4: Results & Analysis	The Results & Analysis Chapter shares and analyses the results that came from applying the methodology. These results address the problem statement, research aim, and research questions.
Chapter 5: Discussion	The Discussion Chapter is dedicated to extracting insights from the results, explaining their importance, and contextualizing them within the literature found from the Literature Review.
Chapter 6: Conclusion & Recommendations	The Conclusion & Recommendations Chapter summarizes and consolidates the most important parts of Chapters 1-5. Also, recommendations are made for future research.

Figure 1: Dissertation layout

The next chapter, the Literature Review, expands on the Introduction Chapter by exploring the industrial engineering discipline further.

CHAPTER 2: LITERATURE REVIEW

Thus far in the dissertation, several concepts relating to the industrial engineering discipline have been introduced: its history, evolution, interdisciplinarity, broadness, and challenges. These concepts, among others, are expanded on and contextualized in the Literature Review Chapter.

2.1 The history and evolution of industrial engineering

When examining the history of engineering disciplines in general, it is important to note that these disciplines may have existed long before they were named and officially established in universities or popularized by the public. The Great Wall of China and the Pyramids of Egypt are examples of engineering works that were completed centuries ago, yet the first engineering schools only appeared in the eighteenth century (Martin-Vega, 2001). It is no coincidence that the appearance of the first engineering schools coincided with the time period of the first industrial revolution. The industrial revolution brought with it many technological developments that revolutionized the way the world ran. Compared to agrarian society, industrial society was much more production-focused and complex (Crossman, 2019). Thus, along with the industrial revolutions came advancements in the engineering disciplines to handle the changes in society (Martin-Vega, 2001). Eventually, disciplines such as civil engineering, mechanical engineering, electrical engineering, and chemical engineering were beginning to be officially established and taught at universities (Martin-Vega, 2001). The birth of industrial engineering was analogous to its engineering predecessors in the sense that it resulted from a need to manage the newly and rapidly developing world (Martin-Vega, 2001).

In the Background to this study, it was stated that industrial engineering had its roots in the industrial revolution and that this explains where the term “industrial” comes from. To investigate this observation further, the following links were made by Stan, Tulcan and Cosma (2010):

manufacturing ↔ industrial ↔ engine ↔ engineer
or: (to produce) (mass production) (automation) (leader)

“Engineer” was also defined as “...the person who directs and manages a manufacturing process” (Stan, Tulcan and Cosma, 2010). However, despite having roots in the first industrial revolution, the industrial engineering discipline was not officially established until much after it. While most engineers at that time were concerned with the physical concepts of industrialisation (such as mechanics and chemical processes), there was a more abstract concept being formed: the production system (Martin-Vega, 2001). This concept of the production system lay at the core of industrial engineering, at least in its beginnings (Martin-Vega, 2001).

2.1.1 Major contributors to early industrial engineering

The concept of the production system led to several individuals developing concepts about how to improve the production *system* itself. The focus was on the operational attributes of the system, not its physical attributes (Martin-Vega, 2001). For example, in 1746, Adam Smith formalized the concept of division of labour, which proposed that a task should be split up into multiple smaller tasks that should be completed by different workers (Bennett, 2015). The concept of division of labour along with the concept of interchangeability of parts meant that a worker was no longer responsible for creating a full product, but rather only a single part of a product (Martin-Vega, 2001). Both concepts were applied in Henry Ford's assembly line in the early 1900s and improved productivity drastically (Nye, 2010).

As concepts relating to production systems were emerging, industrial engineering began to grow its roots. Some of its earliest roots can be traced back to Frederick Taylor's theory of scientific management (Savory, 2005).

The theory of scientific management studied the "science of work" and attempted to improve factory workers' productivity by altering their work methods (Savory, 2005; Lumen Learning, 2021). Scientific management and industrial engineering share two common themes, according to Savory (2005): "interfaces among people and machines within systems and the analysis of systems leading to improved performance." Due to the connected history of scientific management and industrial engineering, Frederick Taylor is considered to be one of the earliest founders of industrial engineering (Holstein, 2017). He was "...the first man in recorded history who deemed work deserving of systematic observation and study" (Drucker, 1973).

Frank and Lillian Gilbreth are also considered to be early founders of industrial engineering (Holstein, 2017). The Gilbreths, like Taylor, studied the work methods of factory workers with the aim of improving their productivity (Lumen Learning, 2021). They expanded on Taylor's work on scientific management. While Taylor mostly conducted time-studies to reduce the time it took to complete tasks, the Gilbreths conducted time-and-motion studies to reduce both the time and the motions involved in completing tasks (Lumen Learning, 2021). The Gilbreths' also took worker welfare, stress, and fatigue into account (Lumen Learning, 2021). Lillian Gilbreth had written a book called "The Psychology of Management", which proposed a new way of management that encouraged individual development rather than having a central authority figure that stifled development (Martin-Vega, 2001). Thus, along with being pioneers of industrial engineering, the Gilbreths were pioneers of ergonomics (Kimble, Wertheimer and White, 1996). They even extended their work on productivity to the household (Lumen Learning, 2021).

The concepts developed by Taylor and the Gilbreths were gaining traction. Other industrial engineering pioneers began emerging, introducing more concepts related to production systems (specifically mass production systems) and their efficiency. Some of these pioneers, such as Henry Towne and Henry Gantt, began to broaden these concepts further. Gantt, for example, created the Gantt Chart, which is a graphic tool that aids in the planning and scheduling of activities (Martin-Vega, 2001).

Both Towne and Gantt introduced economics as part of their work. Gantt made suggestions about worker remuneration rewards and incentive plans (Martin-Vega, 2001). Towne suggested that increases in profit due to increases in worker productivity should be reflected in higher wages for the workers (Martin-Vega, 2001).

In 1886, Towne wrote a paper for the American Society of Mechanical Engineers (ASME) titled “The Engineer as an Economist” (Towne, 1886). In this paper, Towne stated:

“There are many good mechanical engineers; – there are also many good “business men;” – but the two are rarely combined in one person. But this combination of qualities, together with at least some skill as an accountant...is essential to the successful management of industrial works, and has its highest effectiveness if united in one person, who is thus qualified to supervise...the operations of all departments of a business, and to subordinate each to the harmonious development of the whole.”

The need expressed by Towne for a new type of professional eventually began to actualize. Due to Towne’s work, the ASME eventually created a Management Division dedicated to the art and science of management (Martin-Vega, 2001).

2.1.2 Timeline of important events for early industrial engineering

The first few decades of the 1900s had important developments for early industrial engineering:

- In 1901, James Gunn formally introduced the term “industrial engineering” in the Engineering Magazine (Posteucă and Sakamoto, 2017).
- During 1910-1920, several individuals in America were becoming scientific management practitioners, scientific management societies such as the Taylor Society were being formed, and scientific management courses were being introduced into large universities (Nelson, 1992).
- In 1907-1908, Hugo Diemer changed the mechanical engineering curriculum at Pennsylvania State College by adding a “Factory Planning” course and a specialization in “Industrial Engineering” (Nelson, 1992). One year later, Diemer started the first

undergraduate industrial engineering department at the College (Nelson, 1992). He made scientific management a central feature of the curriculum (Nelson, 1992).

- In 1912, many adopters of Taylor and the Gilbreths' concepts (along with Frank Gilbreth and Frederick Taylor themselves) met at the annual meeting for the ASME to discuss industrial engineering-related concepts (Nelson, 1992; Martin-Vega, 2001)

Industrial engineering continued becoming more established during the 1900s, as more universities began to offer it (whether as a course, postgraduate degree, or undergraduate degree) and more professionals began to work in it (Nelson, 1992; Martin-Vega, 2001; Chaffin, 2015). Industrial engineering was finally becoming its own entity rather than an offshoot to mechanical engineering or an amalgamation of productivity-related concepts (Greene, 2001). It was also broadening in knowledge and scope (Greene, 2001).

2.1.3 Evolution of interdisciplinarity and scope

Early industrial engineering was mostly concerned with manufacturing and production (Lucas, 2014). However, the 1920s began to expand industrial engineering beyond the scientific management of manufacturing and production (Martin-Vega, 2001). Industrial engineering was becoming concerned with concepts such as methods engineering, work simplification, and industrial psychology (Martin-Vega, 2001). By 1934, "...the Management Division of ASME included under the term *industrial engineering* functions such as budgets and cost control, manufacturing engineering, systems and procedures management, organization analysis, and wage and salary administration" (Martin-Vega, 2001).

Industrial engineering became more interdisciplinary in the following decades. Operations research was introduced to industrial engineering in the 1940s and drastically changed it (Martin-Vega, 2001). Operations research made mathematical modelling a key part of decision-making and problem-solving in industrial engineering (Chaffin, 2015). By the mid-1960s, linear programming, queuing theory, stochastic modelling, and other operations research approaches were being integrated with industrial engineering (Martin-Vega, 2001). Martin-Vega (2001) states that, in the 1960s and 1970s, "...the field became modelling-oriented, relying heavily on mathematics and computer analysis for its development" and that "...industrial engineering was advancing along a very appropriate path, substituting many of the more subjective and qualitative aspects of its early years with more quantitative, science-based tools and techniques." In turn, its newly found approach was being applied to all sorts of industries, such as the healthcare industry and banking industry (Chaffin, 2015). Industrial engineering was no longer limited to the manufacturing and production industries. It was also no longer as associated with management as it used to be, given that its scientific base strengthened its association to the more traditional engineering disciplines.

The broadening of the industrial engineering discipline, both in terms of its interdisciplinarity as well as its scope, can be seen in Figure 2. The increase in interdisciplinarity and scope is represented by the increase in the number of blocks of disciplines (or concepts within disciplines) by 1980 compared to 1960. The increase in scope is also represented by the recognition that, in 1980, the industrial engineering “systems design” function was being applied in “non-manufacturing areas.” In recent years, “non-manufacturing areas” have even become more prominent than manufacturing areas in industrial engineering work and research (Dastkhan and Owlia, 2009; van Dyk, 2014). The shift from being manufacturing/production-focused to being systems-focused was a significant change in industrial engineering history.

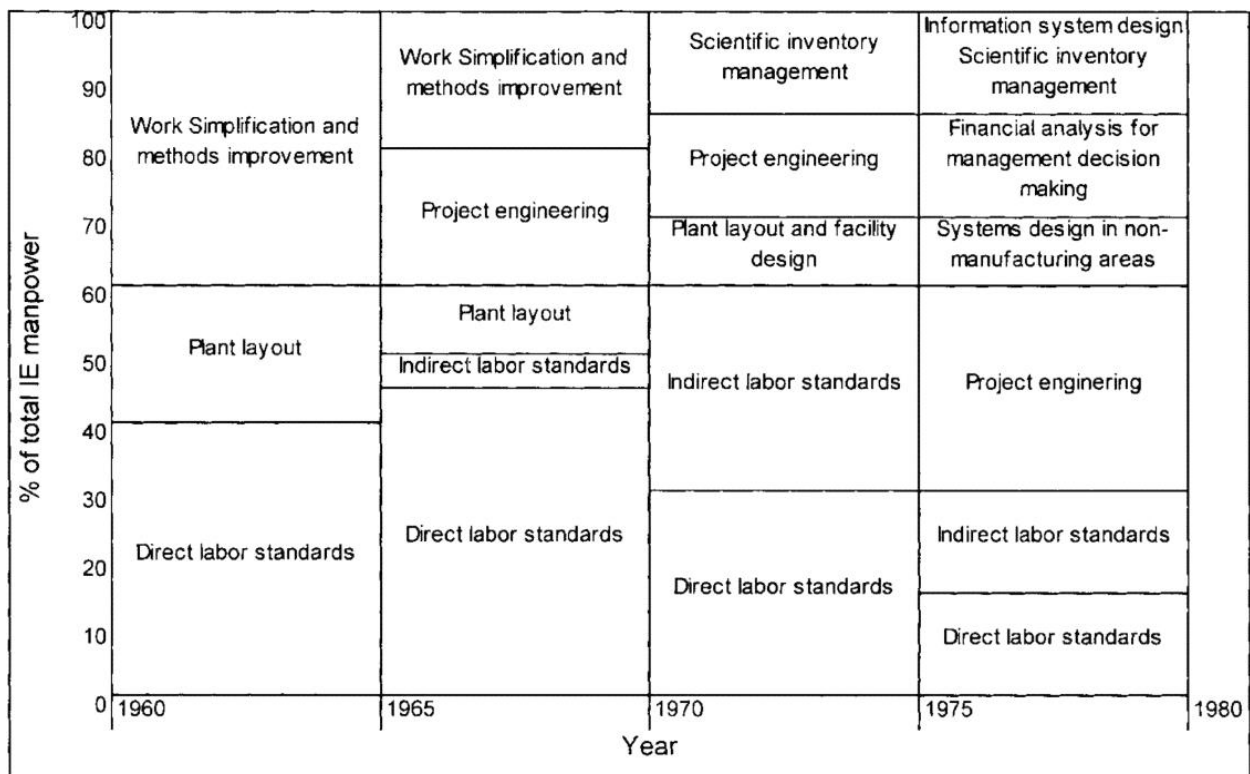


Figure 2: Industrial engineering functions in 1960-1980 (Pristker, cited in Martin-Vega, 2001)

Industrial engineering continued to evolve in the 1980s-2000s. During these times, industrial engineering began to include organizational leadership responsibilities, the design and integration of information systems, automation, robotics, and computer-aided design (Martin-Vega, 2001). Furthermore, the “production system” that formed the core of the industrial engineering discipline in its early years was now expanding to include the service sector (Martin-Vega, 2001). The service sector can still be viewed as a form of production, where the product is a service. Thus, industrial engineering methods and techniques can still be applied to it.

By 1990, the industrial engineer was "...caught between the Industrial Revolution and the Information Revolution. He is confronted with choosing between pragmatic improvements in productivity and efficiency of a single operation or the opportunistic modelling and reshaping of the networked "virtual enterprise" to become more competitive in a global marketplace" (Du Preez and Pintelon, 1994).

The industrial engineer had evolved to have a more systems-oriented role by the end of the 20th century (Martin-Vega, 2001). This change in orientation is mirrored by the evolution of the industrial engineering institution and its definition.

2.1.4 Evolution of an institutional definition

Any industrial engineering definition is an attempt to capture the industrial engineering discipline in a few sentences. One of the earliest definitions of industrial engineering comes from the American Institute of Industrial Engineers in the 1960s (Martin-Vega, 2001):

"Industrial engineering is concerned with the design, improvement, and installation of integrated systems of men, materials, equipment and energy. It draws upon specialized knowledge and skill in the mathematical, physical and social sciences together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems."

This definition, along with the Institute it came from, has evolved since the 1960s. For one, the American Institute of Industrial Engineers is now called the Institute of Industrial and Systems Engineers. Consequently, the IISE website no longer defines industrial engineering alone, but industrial and systems engineering. The current definition on the IISE website is almost identical to the one quoted from the 1960s, with the only differences being "Industrial and systems engineering" replacing "Industrial engineering", "people" replacing "men", and adding the word "information" after the word "materials."

The evolution of the definition has significance in the broadening of the discipline since both "information" and "systems" are broad terms. The evolution also indicates the adaptability of the discipline to external developments. For example, including the word "information" in the definition may be paying tribute to the information revolution of the 1990s. Furthermore, including systems engineers to industrial engineers represents the interface between the two types of engineers and the systems orientation of the industrial engineer by the end of the 20th century.

The industrial engineering definition may continue to evolve in the future. However, examining the evolution of the definition helps to uncover insights about the evolution of the discipline itself.

2.1.5 Summary of the history and evolution of industrial engineering

To summarize industrial engineering history, Du Preez and Pintelon (1994) divide industrial engineering history into 5 phases. These phases are shown in Table 2 and can be linked to the history and evolution of the industrial engineer presented thus far in the Literature Review.

Table 2: Main phases in industrial engineering history (Du Preez and Pintelon, 1994)

Phase	Time Period	Phase in industrial engineering history
1	1746-1901	Initiation and establishment
2	1875-1950	Establishment of a pragmatic base
3	1930-1960	Establishment of a scientific base
4	1960-1989	Establishment of a virtual laboratory
5	1990-current*	Empowerment of systems experimentation through mature modelling and computing

*This table was adapted from an article published in 1994. Thus, “current” likely means 1994.

Phase 1 represents the initiation of the industrial engineering discipline alongside the first industrial revolution. It was officially established by the end of this phase, in 1901 (likely when James Gunn formally introduced the term “industrial engineering” in the Engineering Magazine in 1901). In the next phase, the industrial engineer was mostly focused on making pragmatic productivity improvements for single operations (Du Preez and Pintelon, 1994).

Phase 3 represents industrial engineers implementing more theory and science into their practice (namely: scientific management). Industrial engineers at this stage advanced from being purely pragmatic problem solvers to having more varied roles, such as scientific designers, improvers of production systems, and integration engineers (Du Preez and Pintelon, 1994).

Phases 4 and 5 represent the evolution of the industrial engineer into a modeler and experimenter with the rise of electronics, computing, and the information revolution (Du Preez and Pintelon, 1994). Industrial engineers had evolved to be able to manage and design full systems and enterprises, once again highlighting their systems orientation by the end of the 20th century (Du Preez and Pintelon, 1994).

The systems orientation of the industrial engineering discipline by the end of the 20th century had enough significance to popularize the term “industrial and systems engineering” in the 21st century (Salvendy, 2001). Including the word “system” was a natural progression of industrial engineering and aided in making industrial engineering more successful (Salvendy, 2001).

2.2 Industrial (and systems) engineering

Going forward in the Literature Review, it is important to discuss the term “industrial and systems engineering” and its implications for industrial engineering and systems engineering.

One of the biggest indicators of the close relationship between industrial engineering and systems engineering is the change of the name of the Institute of Industrial Engineers to the Institute of Industrial and Systems Engineers. This change of name happened in 2016, after a vote from the members of the Institute (IISE, 2021). Other institutions, such as universities and authors of industrial engineering handbooks, also adopted the name “industrial and systems engineering.”

2.2.1 Industrial (and systems) engineering definition

When this research first started in 2020, the 2019 Industrial Engineering Body of Knowledge was used as one of the main references. It defined “industrial engineering” as:

“Industrial Engineering is concerned with the design, improvement and installation of integrated systems of people, materials, information, equipment and energy. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.” (IEBoK Authors, 2019)

This was in contradiction with the website of the IISE, which defined “industrial *and* systems engineering” as:

“Industrial and systems engineering is concerned with the design, improvement and installation of integrated systems of people, materials, information, equipment and energy. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.” (IISE, 2019)

When comparing the IEBoK’s definition of “industrial engineering” with the IISE’s definition of “industrial and systems engineering”, it is evident that they are identical. This implies that the IISE may view the “industrial engineering” and “industrial and systems engineering” terms as interchangeable. Furthermore, the name change has been so recent that the IISE may not have decided on a standard convention to use across all of its content.

However, the name change does not necessarily imply that the IISE views industrial engineering and systems engineering as the same discipline. Rather, they are defining a new entity called

“industrial and systems engineering” that highlights the systems-elements of industrial engineering. It seems that the terms “industrial engineering” and “industrial and systems engineering” are interchangeable from the IISE’s perspective since industrial engineering’s systems orientation has become so potent. However, these terms are *not* necessarily interchangeable with “systems engineering” alone.

By officiating industrial and systems engineering, the IISE may be setting a pattern for other industrial engineering institutions. This pattern can be seen in multiple major universities.

2.2.2 Departmental names and industrial (and systems) engineering

Like the IISE, many universities adopted the term “industrial and systems engineering.” To depict the prominence of this term, Table 3 shows the top ten industrial engineering universities of 2021 in the United States of America (College Factual, 2021). Next to each university name is its school/department/degree name.

Table 3: Industrial engineering universities with their program names

Ranking	University	School/Department/Degree Name
1	Georgia Institute of Technology – Main Campus	Industrial and Systems Engineering
2	University of Michigan – Ann Arbor	Industrial and Operations Engineering
3	Leigh University	Industrial and Systems Engineering
4	Purdue University – Main Campus	Industrial Engineering
5	Northwestern University	Industrial Engineering & Management Sciences
6	Virginia Tech	Industrial and Systems Engineering
7	University of Southern California	Industrial and Systems Engineering
8	North Carolina State University	Industrial and Systems Engineering
9	Pennsylvania State University – University Park	Industrial and Manufacturing Engineering
10	University of Wisconsin - Madison	Industrial and Systems Engineering

Of the ten universities listed in Table 3, six of them use the term “industrial and systems engineering” as the IISE does. Other universities worldwide – such as the Hong Kong Polytechnic University, the National University of Callao, the Indian Institute of Technology Kharagpur, and the University of Pretoria – also use this term.

The change in name of many prominent industrial engineering programs indicates that the term “industrial and systems engineering” is trending even more than “industrial engineering” alone. In fact, of all ten universities in Table 3, only one of them named their department “industrial engineering” alone.

Like industrial engineering universities, prominent handbooks of industrial engineering also sometimes use the term “industrial and systems engineering” or “industrial engineering” alone.

2.2.3 Handbooks of industrial (and systems) engineering

According to Demmel and Sillitto (2021), two prominent industrial engineering handbooks are:

- Handbook of Industrial Engineering (Salvendy, 2001)
- Maynard's Industrial Engineering Handbook (Zandin and Maynard, 2001)

The handbook of Salvendy (2001) uses the term “industrial and systems engineering” throughout its handbook, while the handbook of Zandin and Maynard (2001) uses the term “industrial engineering.” However, both use the same IISE definitions of industrial engineering and discuss systems and non-systems aspects of industrial engineering. Once again, this represents the seeming interchangeability of the terms “industrial engineering” and “industrial and systems engineering.” Both of these handbooks were cited frequently in this dissertation and are frequently cited in other industrial engineering literature.

2.2.4 The body of knowledge of industrial (and systems) engineering

In 2019, the IISE released a body of knowledge titled “The Industrial Engineering Body of Knowledge” (IEBoK Authors, 2019). By the end of this research in 2021, the IISE had released an updated body of knowledge. This body of knowledge was titled “The Industrial and Systems Engineering Body of Knowledge” (ISEBoK Authors, 2021). Besides some formatting changes and extra sentences in the Foreword and Introduction, the two bodies of knowledge were nearly identical. They used the same definition for industrial engineering (not industrial *and* systems engineering, despite the title change of the 2021 body of knowledge). Once again, this implies that the IISE may view these terms as interchangeable, or that the name change has been so recent that the IISE may not have decided on a standard convention to use across all of its content. To differentiate industrial (and systems) engineering from systems engineering, there also exists a standalone Systems Engineering Body of Knowledge (SEBoK Editorial Board, 2021).

The IEBoK (2019) and ISEBoK (2020) also use the same 14 knowledge areas. These knowledge areas are shared in Figure 3 in Section 2.3.1. However, one notable difference between the bodies of knowledge was that the IEBoK segmented the knowledge areas into 12 main knowledge areas and 2 related knowledge areas. The ISEBoK listed the 14 knowledge areas as main ones. This is notable from a systems engineering perspective because the 14th knowledge area of the 2019 IEBoK was: System Design & Engineering. By 2021, this knowledge area was no longer considered as a related topic to industrial engineering, but as a main one, further highlighting the importance of the systems orientation to modern industrial engineering.

2.2.5 Comparing industrial engineering and systems engineering

The institutional changes in the definition and title of industrial engineering to include systems engineering may imply that the two disciplines are merging into one. However, it also may imply that the systems engineering aspects of industrial engineering are becoming more important in industrial engineering. It may even be that the term “systems” better captures what an industrial engineer is concerned with since industrial engineers have moved past being concerned with “industry” in the traditional manufacturing sense. Nevertheless, the term “industrial and systems engineering” does not necessarily imply that industrial engineering and systems engineering are the same discipline. In fact, they are different.

The overlaps are noted in the SEBoK by stating that “Industrial engineering (IE) encompasses several aspects of systems engineering (SE) (i.e., production planning and analysis, continuous process improvement, etc.) and also many elements of the engineered systems domain (production control, supply chain management, operations planning and preparation, operations management, etc.)” (Demmel and Sillitto, 2021).

Furthermore, several concepts of systems engineering, such as system architecting and requirements analysis, are noted in the IEBok (IEBoK Authors, 2019).

Ultimately, despite the strong overlaps between industrial engineering and system engineering, they are still different disciplines. Their differences are evident from comparing their definitions. One definition of systems engineering is:

“[Systems engineering is an] interdisciplinary approach governing the total technical and managerial effort required to transform a set of customer needs, expectations, and constraints into a solution and to support that solution throughout its life.” (SEBoK Editorial Board, 2021)

Compared to the definition of industrial engineering, the definition of systems engineering is more concerned with customer requirements and lifecycle maintenance for solutions. Industrial engineering is more focused on the analysis and improvement of a system, or parts of that system, in a certain context.

Going forward in this dissertation, literature using the term “industrial and systems engineering” was still included since modern industrial engineering does have a systems orientation. However, the research notes that systems engineering is its own discipline and cannot be used interchangeably with industrial engineering or even industrial and systems engineering.

2.3 The knowledge base of industrial engineering

Thus far in the dissertation, the industrial engineering discipline was defined and described. However, its body of knowledge has not yet been officially introduced. In this section, representations of the industrial engineering discipline's knowledge base are depicted.

2.3.1 The industrial engineering body of knowledge

The creation of an industrial engineering body of knowledge was being explored in 2007, to maintain the integrity of the discipline, as well as to distinguish it from other engineering disciplines (Matson *et al.*, 2007). At the time, there were no official requirements or criteria (according to the Accreditation Board for Engineering and Technology) distinguishing industrial engineering from the other engineering disciplines, besides a requirement for systems integration (Matson *et al.*, 2007). Thus, there was a need to better define industrial engineering. After all, there was a body of knowledge for other engineering disciplines, such as civil engineering and mechanical engineering (Matson *et al.*, 2007). A question naturally follows – what about a body of knowledge for industrial engineering?

To try to combat the potential fragmentation of the industrial engineering discipline, academics were posing the following questions: “Can industrial engineers agree on a Body of Knowledge or at least on outcomes that distinguish [industrial engineering] from other engineering disciplines?” and “Can the program criteria for industrial engineering assist in defining the [industrial engineering] discipline without loss of flexibility to academic programs?” (Matson *et al.*, 2007).

The Institute of Industrial and Systems Engineers ended up creating The Industrial Engineering Body of Knowledge with the voluntary help of several of its members (IEBoK Authors, 2019). The IEBoK is an evolving document that identifies 14 knowledge areas. Each knowledge area is expanded on in the document with a description and a list of competencies required to master that specific knowledge area. These knowledge areas also represent a way of categorising industrial engineering. The document acknowledges overlaps between the knowledge area categories but does not depict this visually.

The IEBoK is a comprehensive, extensive outline of industrial engineering, acknowledging that the “Body of Knowledge associated with Industrial Engineering is as broad and varied as the Industrial Engineering profession itself” (IEBoK Authors, 2019). The IEBoK does not provide specific examples of how industrial engineering is applied in certain industries (IEBoK Authors, 2019). Rather, it describes all of the knowledge needed to achieve mastery of the discipline (IEBoK Authors, 2019).

Figure 3 depicts the 14 knowledge areas of the industrial engineering discipline. These knowledge areas are also representative of the industrial and systems engineering discipline, as they are shared in the Industrial and Systems Engineering Body of Knowledge (ISEBoK Authors, 2021).

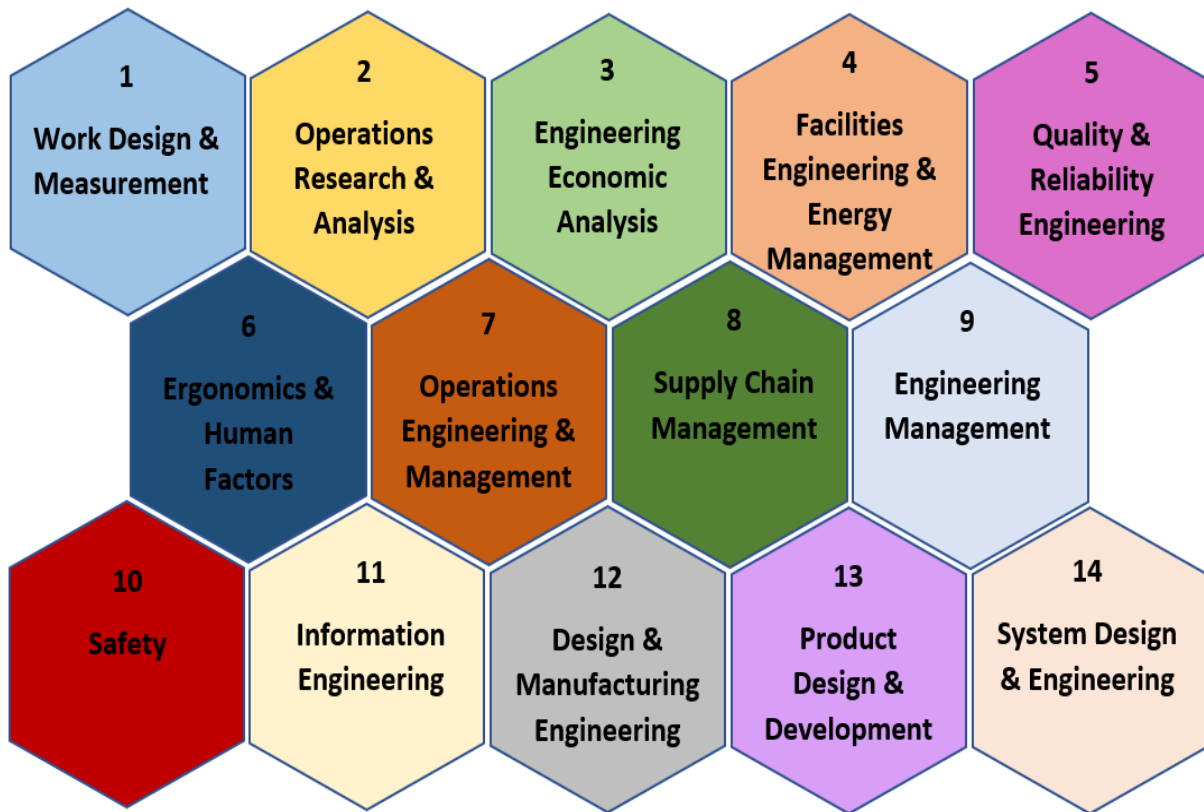


Figure 3: Knowledge areas of industrial engineering, adapted from the Institute of Industrial and Systems Engineers (2019)

Not all industrial engineering universities or institutions may abide by the IEBoK's representation of industrial engineering. However, the IEBoK provides a holistic and all-inclusive representation of the discipline. Thus, it acts as a guiding representation of what industrial engineering entails (in its most broad and generic form).

Other industrial engineering literature, such as handbooks of industrial engineering, also provide representations of the industrial engineering discipline's knowledge base or knowledge areas.

2.3.2 Handbooks of industrial engineering

As mentioned previously, two prominent industrial engineering handbooks are the Handbook of Industrial Engineering (Salvendy, 2001) and Maynard's Industrial Engineering Handbook (Zandin and Maynard, 2001) (Demmel and Sillitto, 2021). Both of these handbooks provide representations of the knowledge base of industrial engineering. These representations can be related to the IEBoK's representation, but they also provide unique insights into the knowledge base of the discipline.

2.3.2.1 Salvendy's Handbook of Industrial Engineering (2001)

One of the most important ways that industrial engineering stands out from other engineering disciplines is the breadth of its knowledge base and its interdisciplinarity. While most engineering disciplines fall within the hard sciences (US Department of Labor, 2009), the interdisciplinarity of industrial engineering extends to the soft sciences too (Hicks, 2001).

To depict the industrial engineer's broadness and interdisciplinarity, the Handbook of Industrial Engineering by Salvendy (2001) created a Venn Diagram to show how many disciplines industrial and systems engineering (ISE) interfaces with. The diagram also applies to industrial engineering by itself, as is evident from industrial engineering's definitions and other literature.



Figure 4: The academic domains of industrial and systems engineering, adapted from Salvendy (2001)

Figure 4 depicts the interdisciplinarity, broadness, and capacity for specialization of industrial engineering. The four blue circles surrounding the "ISE" circle can be considered as specializations since they are focus areas of industrial and systems engineering. The orange words surrounding the circles can be considered as indications of interdisciplinarity. The broadness of the knowledge base is evident as the academic domains of industrial and systems engineering range from mathematics to economics to psychology and beyond.

2.3.2.2 Maynard's Industrial Engineering Handbook (2001)

Maynard's Industrial Engineering Handbook (2001) has a chapter titled "Fundamentals of Industrial Engineering" which covers the application areas, procedures, and methods of industrial engineering (Hicks, 2001). The chapter also discusses industrial engineering's interface with the hard sciences and the soft sciences. Some elements of the hard sciences would be physical entities (such as equipment and buildings) and informational entities (such as time and space) (Hicks, 2001). The soft elements are considered to be the management-related factors of work, such as motivation, improvement, and participation (Hicks, 2001).

Hicks (2001) lists the following areas and sub-areas as part of the fundamentals of industrial engineering:

- Operations Analysis and Design
 - Methods Engineering
 - Work Measurement
 - Ergonomics
 - Facilities Planning and Design
 - Simulation
 - Material Handling
- Operations Control
 - Production
 - Just-in-Time
 - Inventory Control
 - Quality Control
- Operations Management
 - Team Based Management
 - Continuous Improvement

These areas share many similarities with the IEBoK's knowledge areas. Both cover topics such as work measurement, ergonomics, facilities planning, production, operations management, and quality control.

The chapter concludes by explaining that, despite all of the knowledge and techniques available for industrial engineers, the most important aspect is the "...ability to think like an industrial engineer" (Hicks, 2001). This sentiment implies that an industrial engineer is not necessarily tied to a specific set of knowledge areas, tools, or techniques. Rather, the industrial engineer has a *way of thought* that can be applied anywhere.

2.4 Capturing industrial engineering in the 21st century

The evolution of the industrial engineering discipline may seem like a series of historic events, but it is actually an ongoing process continuing into the 21st century. Also, industrial engineering, despite its inherent broadness, is broadening even more with time (Greene, 2001). Thus, researchers are often trying to “capture” the state of industrial engineering at a certain point in time or in a certain area – whether that is by conducting a census on industrial engineers, or analysing the trends emerging within the discipline.

2.4.1 South African census

To give a quantitative indication of the spread of industrial engineers in industry, as well as their perceived skills, a recent census was conducted on South African industrial engineers based on LinkedIn data (van Dyk, 2014). The census showed who employs industrial engineers and for what skills. The study found that, based on the data of 363 industrial engineers, the top ten industries with industrial engineering employment were: Oil and Energy, Information and Communication, Industrial Engineering Consultation, Food and Beverages, Mining, Logistics and Supply Chain, Banking, Management Consulting, Automotive, and Aviation and Aerospace. The top ten skills groupings attributed to them were (in descending order): Industrial Engineering, Supply Chain Management, Business Process Analysis/Design/Mapping, Process Improvement/Optimization, Project Engineering/Planning/Management, Business Analysis/Development/Engineer/Architecture, Continuous Improvement/Kaizan/Six Sigma, Data Analysis/Data Modelling/Analytics/Operations Research, Strategy Management/Planning, and Management. The study listed even more than the top 10 industries and skills cited here, along with other statistics on the status of industrial engineers in South Africa at that point in time. This study empirically proves the variety of industries and skills associated with industrial engineering.

2.4.2 Trends in research topics

The first two studies that are reviewed were written for the South African Journal of Industrial Engineering (SAJIE). Both were investigating trends in research topics but from different angles.

In the first study, Dastkhan and Owlia (2009) analysed thousands of articles from 27 years' worth of research. This led to various findings on trends related to industrial engineering, such as where industrial engineering research is being conducted and on what topics. It was noted that “[industrial engineering] research topics are spreading in other management and engineering departments and so there is a need to redefine the discipline and its specific areas of interest. According to the prediction made using time series analysis, the most favorite fields of [industrial engineering] research in future will be on subjects related to information technology, intelligent systems, optimization, quality, and supply chain management.”

In the second study, a textual information analysis was conducted by Uys, Schutte, and Esterhuizen (2010) on SAJIE's publications. This study identified the current research topics in industrial engineering and aligned South Africa's trends with publication trends in other countries. Using statistical topic modelling, the study identified and categorised themes from the documents. Long withstanding topics included "Systems Availability and Reliability" and "Productivity Measurement." Recent topics included "Sustainable Development" and "Strategies and Models for Business Operations." The best-covered topic was "Business Management Approaches & Strategies", and the least-covered topic was "Reliability of Electricity Supply." The study concluded with a comparison between the topics found in SAJIE publications versus those found in international trends.

2.4.3 Trends in curricula

In the United States of America, Rabelo et al. (2006) and Eskandari et al.(2005) were investigating emerging trends in undergraduate industrial engineering education. Both were essentially trying to bridge the gap between academia and industry by suggesting changes to the industrial engineering curriculum so that industrial engineering education would better match industry's needs. They both used questionnaires and the modified three-rounded Delphi technique to process their results. The studies yielded very similar results. Rabelo et al. (2006) listed 11 desired characteristics, 9 of which were in common with the 16 desired characteristics that Eskandari et al. (2005) had listed. Both had "adaptable problem-solving" as the number 1 desired characteristic. Rabelo et al. (2006) listed 51 emerging topics, while Eskandari et al.(2005) listed 25. Eskandari et al.(2005) had 23 of its 25 topics in common with the 51 topics that Rabelo et al. (2006) had listed, although with a different ranking of importance.

While these two studies were mostly identifying and ranking trends in industrial engineering education, other studies were making recommendations for amending the industrial engineering curriculum. In the Caribbean, industrial engineering education and research needed to be revisited and updated to bridge the gap between theory and practice and to maximize the potential of industrial engineering (Benjamin et al., 2008). A "Quality Function Deployment Framework" was suggested to facilitate an ongoing, strategic modernizing and reform of the industrial engineering programme.

In South Africa, modernization and reform of the industrial engineering curriculum were also suggested to handle the implications of Industry 4.0 (Sackey and Bester, 2016). The study proposed a "set of curriculum enrichment items" to enhance the curriculum. These items included advanced analytics and system simulation and novel human-machine interfaces.

2.5 The identity and perceptions of industrial engineering

The industrial engineering discipline began to officially establish its identity in the early 1900s (Du Preez and Pintelon, 1994). Yet, over a century later, its identity remains vague (Darwish, 2017).

2.5.1 The industrial engineering identity

In 2008, a PhD thesis titled “Expanding Industrial Thinking by formalizing the Industrial Engineering identity for the knowledge era” was published (Darwish, 2018). As part of this thesis, a corresponding article titled “The Industrial Engineering Identity: From Historic Skills to Modern Values , Duties , and Roles” was published (Darwish, 2017). The thesis and the article were both concerned with the industrial engineering identity, as is evident by their titles. More specifically, these works were tackling the vagueness of the industrial engineering identity by proposing a way to formalize it (Darwish, 2017). Before presenting one of the main deliverables for the thesis and article (a formalized identity model for industrial engineering in the knowledge era), it is important to discuss the concept of identity more generally. It is also important to discuss how the thesis and article link with this dissertation.

Professional identity is defined as “...the concept which describes how we perceive ourselves within our occupational context and how we communicate this to others” (Neary, 2014). Thus, identity is closely tied to perceptions. Our perception of our own identities will influence how well we communicate this perception to others (in turn influencing others’ perceptions of our identities).

Professional identity is often represented and communicated through job titles (Neary, 2014). Thus, job titles can be viewed as “identity badges” that express an employee’s knowledge and skills (Grant, Berg and Cable, 2014). Furthermore, job titles serve many functions beyond communicating identity. These functions include the selection, appraisal, compensation, and comparison of employees (Grant, Berg and Cable, 2014).

The concepts of identity and perceptions become complicated when there is no clear, common, or formal sense of identity – as is the case for the industrial engineer (Darwish, 2018). The case is also similar for systems engineering, which is going through an “identity crisis” (Emes, Smith and Cowper, 2005). Systems engineers, like industrial engineers, struggle to define and communicate themselves (Emes, Smith and Cowper, 2005). Thus, systems engineering needs to be branded better so that it can be more recognised and appreciated by the external world (Emes, Smith and Cowper, 2005). The same can be said for industrial engineering, which needs to be continuously marketed and sold (Billings *et al.*, 2001). For both industrial engineering and systems engineering, the complications are furthered when examining the broad and elusive nature of the job titles “systems engineer” (Emes, Smith and Cowper, 2005) and “industrial

engineer” (Greene, 2001). Both disciplines would benefit from a formalized identity so that they can be distinguished as holistic disciplines, rather than being confused with other disciplines.

The rationale behind the thesis “Expanding Industrial Thinking by formalizing the Industrial Engineering identity for the knowledge era” (Darwish, 2018) is similar to the rationale behind this dissertation. The thesis, along with this dissertation and other industrial engineering literature, share many views:

- The industrial engineering discipline is broad, flexible, variable, and evolving, making it difficult to capture and communicate (Billings *et al.*, 2001)
- The term “industrial engineering” can be misleading because the word “industrial” has broadened to encompass industry in the broader sense of the word (Stan, Tulcan and Cosma, 2010; New World Encyclopedia contributors, 2018)
- Job titles that are more specific than “industrial engineer” (such as “quality engineer”) or more descriptive adjectives are often used when recruiting individuals with an industrial engineering qualification (Greene, 2001)
- More awareness and understanding are needed for industrial engineering, both for the sake of the discipline itself and for the sake of society (Pun and Yiu, 2010)
- There are inaccurate and harmful perceptions of industrial engineering that need to be mended (Trytten *et al.*, 2004; Shehab, Rhoads and Murphy, 2005; Specking, Kirkwood and Yang, 2015)

In the thesis, Darwish's (2018) main problem was the lack of a formal industrial engineering identity and the main purpose was to formalize this identity. To formalize this identity, an identity model was created. This model was created based on guidelines from other identity models. Its content mostly came from incorporating and consolidating key inputs from the literature relating to the industrial engineering identity.

The industrial engineering identity model can be seen in Figure 5 on the next page. It consists of eight identity levels. Each identity level concisely summarizes an aspect of the industrial engineering identity. The identity levels are denoted by the level “L” in Figure 5.

The use of a tree in Figure 5 is metaphoric to represent the “...idea of resources, value extraction, and balance with the ecosystem” (Darwish, 2018). The type of tree depicted, the Pando tree, is also metaphoric. The Pando tree is considered to be the world’s single largest organism since it has an underground root system that connects each seemingly different tree together (Kotecki, 2018). Similarly, the industrial engineering discipline is an amalgamation of seemingly different disciplines. Furthermore, the tree represents the interconnectedness, adaptability, and growth of the industrial engineering discipline (Darwish, 2018).

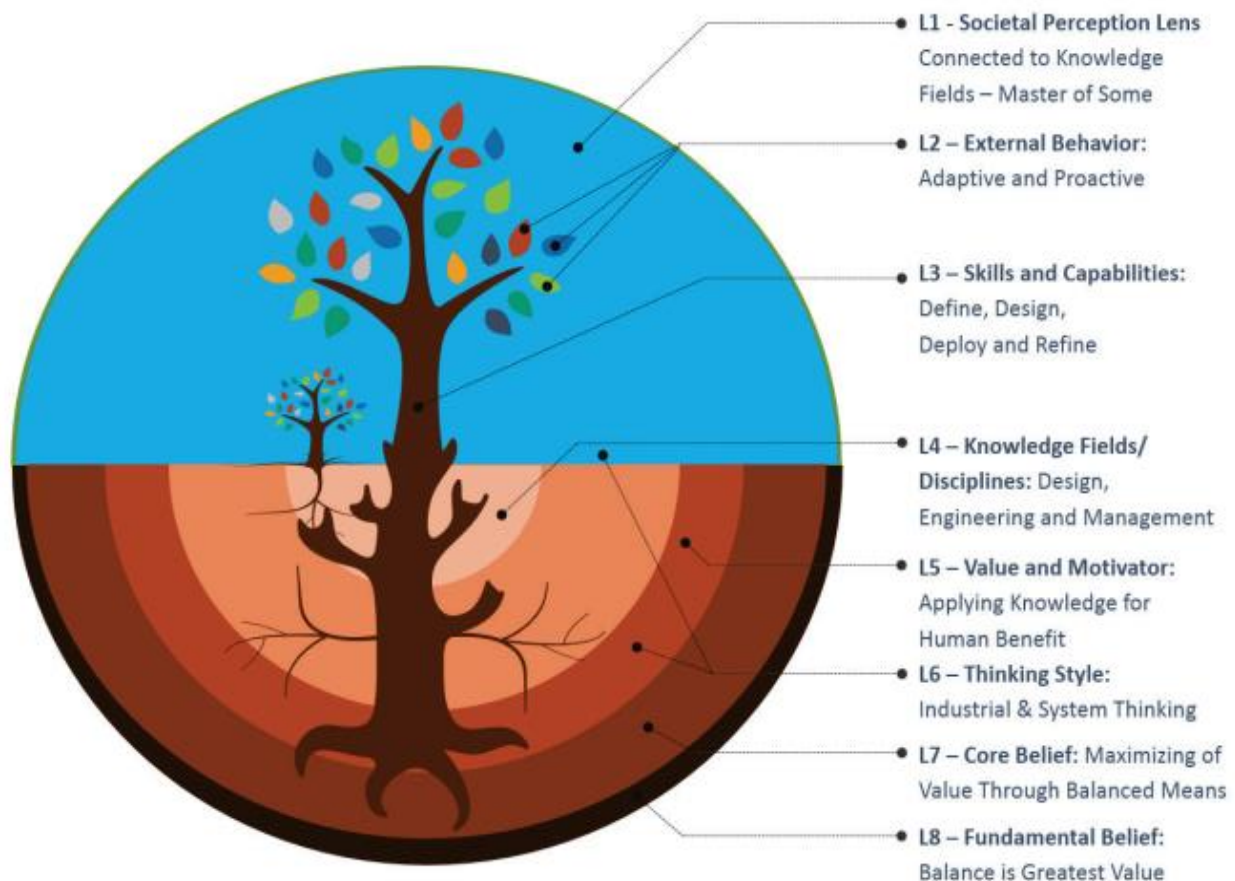


Figure 5: Industrial engineering identity model (Darwish, 2018)

Figure 5 depicts internal and external elements of the industrial engineering identity. The internal elements can be seen in the bottom half of the circle, with the soil and roots of the tree. These are metaphoric of the fundamental elements of the industrial engineering discipline, such as its beliefs, thinking style, value and motivators, and knowledge fields. The external elements can be seen in the top half of the circle with the trunk, leaves, and ambient environment of the tree. The trunk represents the skills and capabilities of the discipline, while the leaves represent the external behavior, and the sky represents the societal perception.

Through Darwish's (2018) thesis and the diagram in Figure 5, identity's link with perceptions (specifically societal perception) is made explicit. According to Darwish (2018), the societal perception of industrial engineers should be that they are "...connected with all fields of knowledge and masters of some." However, this perception does not necessarily match the societal perception of industrial engineering in real life – whether from inside or outside of the industrial engineering community.

2.5.2 Perceptions

Perceptions have hidden importance, given that they drive much of our decision-making in life (Specking, Kirkwood and Yang, 2015). Naturally, perceptions vary from person to person. However, there are often general perceptions that become widespread in society. These types of perceptions can be tracked and understood through research.

Several studies have been conducted on perceptions of engineering in general and on industrial engineering. In the following sections, these studies are summarized and consolidated.

2.5.2.1 Perceptions of engineering

In 2007, a study was conducted trying to capture public attitudes and perceptions to engineering and engineers (Marshall, McClymont and Joyce, 2007). This study used a quantitative survey as well as a qualitative workshop to produce its results (Marshall, McClymont and Joyce, 2007). The survey was completed by 1000 individuals over the age of 16, along with a boost sample of individuals between the ages of 16-19 (Marshall, McClymont and Joyce, 2007). The qualitative workshop consisted of 48 participants (Marshall, McClymont and Joyce, 2007).

The study was covering the engineering discipline in general, although it did mention some specific perceptions of mechanical, civil, chemical, and electrical engineering (Marshall, McClymont and Joyce, 2007). Industrial engineering was not covered. However, the results that were produced from the study are still applicable for industrial engineering since perceptions of industrial engineering may be influenced by the broader perceptions of engineering in general.

One of the main findings of the study was that there was a limited awareness and understanding of engineering and engineers (Marshall, McClymont and Joyce, 2007). Participants noted that engineering could be confusing to define for the “average” person, due to the many different types of engineers (Marshall, McClymont and Joyce, 2007). However, despite the lack of knowledge and understanding, engineering was generally viewed positively and optimistically; participants believed that engineers are involved in important issues and can make significant contributions to society (Marshall, McClymont and Joyce, 2007). Another key finding was that participants associated engineers with technical job functions (such as “fixing things”) and technical environments (such as construction), rather than more creative, innovative, and design-oriented domains (Marshall, McClymont and Joyce, 2007).

The study concluded that more public awareness and understanding are needed for engineering, specifically for the youth and for people with lower levels of education (Marshall, McClymont and Joyce, 2007). This conclusion is seconded by studies on perceptions of industrial engineering.

2.5.2.2 Perceptions of industrial engineering

Perceptions of industrial engineering are an area of interest in literature. Several studies have been conducted that are either directly or indirectly capturing these perceptions. These studies (listed in Table 4) have been reviewed to uncover these perceptions.

Table 4: Studies related to perceptions of industrial engineering

Title	Citation
A Multi-Institutional Study of Student Perceptions of Industrial Engineering	(Murphy <i>et al.</i> , 2006)
'Inviteful' Engineering: Student Perceptions of Industrial Engineering	(Trytten <i>et al.</i> , 2004)
Perceptions and Misconceptions of Industrial Engineering from First Year Engineering Students	(Specking, Kirkwood and Yang, 2015)
Students' Perceptions of the Influence of a Degree in Industrial Engineering on Their Performance	(Costa, 2009)
"Imaginary Engineering" or "Re-imagined Engineering": Negotiating Gendered Identities in the Borderland of a College of Engineering	(Foor and Walden, 2009)
Women in Industrial Engineering; Stereotypes, Persistence, and Perspectives	(Brawner <i>et al.</i> , 2012)
Unravelling the Stereotypes of Women in Industrial Engineering	(Marquez <i>et al.</i> , 2020)
Industrial Engineering: Why Students Come and What Makes Them Stay?	(Shehab, Rhoads and Murphy, 2005)
Intrinsic and Extrinsic Motivators to Study Industrial Engineering: A Focus Group Approach	(Morales and Medina-Borja, 2014)
Exploring the Challenges Facing Industrial Engineers in the Employment Market of Trinidad and Tobago: Some Findings	(Pun and Yiu, 2010)

Some of the studies in Table 4 are connected. Also, many of them share some of the same researchers or feature the same citations. For example, Murphy *et al.*'s (2006) study is an extension of Trytten *et al.*'s (2004) study. It started with 26 interviews from one institution and then expanded to 117 interviews at four institutions with 12 faculty members (Murphy *et al.*, 2006).

Some of the main findings of these studies were that interviewees perceived industrial engineering to be people-oriented, systems-oriented, related to business, broad, and focused on efficiency and problem solving (Trytten *et al.*, 2004; Murphy *et al.*, 2006). These perceptions, among others (such as dealing with logistics), were seconded by another study on perceptions of industrial engineering from first-year engineering students (Specking, Kirkwood and Yang, 2015).

Multiple studies found that the business aspect of industrial engineering was a significant factor in drawing students to study it (Shehab, Rhoads and Murphy, 2005; Morales and Medina-Borja, 2014; Specking, Kirkwood and Yang, 2015). There were other intrinsic and extrinsic factors drawing students to industrial engineering. Some of the intrinsic factors were: having personal goals of success, being good at math and physics, and being people-oriented (Morales and Medina-Borja, 2014). Some of the extrinsic factors were: pressure from family, school, or society as well as a desire for prestige, money, and success (Morales and Medina-Borja, 2014). Students were also enthusiastic about the broad and varied job opportunities that a qualification in industrial engineering would offer (Shehab, Rhoads and Murphy, 2005). In a study examining students' perceptions of the influence of a degree in industrial engineering on their performance, students had positive perceptions about their employability and problem-solving abilities post-graduation (Costa, 2009).

In studies where faculty members were interviewed along with students, the perceptions of students generally matched those of the faculty (Murphy *et al.*, 2006; Specking, Kirkwood and Yang, 2015). However, the faculty members emphasized the mathematical and statistical elements of industrial engineering, whereas students did not (Murphy *et al.*, 2006). In fact, first-year students often had a misconception that industrial engineering was not mathematically rigorous (Specking, Kirkwood and Yang, 2015). Alumni and industry partners had some contradictory misconceptions, as some considered industrial engineering to be just statistics (Specking, Kirkwood and Yang, 2015).

Other misconceptions that individuals within the industrial engineering community had were:

- Industrial engineering is “business engineering”, the “business of engineering”, or a “glorified business degree” (Specking, Kirkwood and Yang, 2015)
- Industrial engineering is “easy engineering”, “not really engineering”, or “not as rigorous as other engineering specialities” (Specking, Kirkwood and Yang, 2015)
- Industrial engineering is “the same as mechanical engineering” or “just for manufacturing” (Specking, Kirkwood and Yang, 2015)
- Industrial engineering is “only applicable in big industries” or has “not broad applicability” (Specking, Kirkwood and Yang, 2015)

In addition to the interviewees' perceptions of industrial engineering, some studies asked the interviewees about how non-industrial engineers perceived industrial engineering (Trytten *et al.*, 2004; Murphy *et al.*, 2006). These perceptions were largely negative and inaccurate, contrasting the generally positive perceptions from within the industrial engineering community (Trytten *et al.*, 2004; Murphy *et al.*, 2006). However, they also matched some of the misperceptions from within the industrial engineering community. Interviewees noted that non-industrial engineers often perceived industrial engineering to be "imaginary", "easy", "stupid", or "invisible" engineering (Trytten *et al.*, 2004; Murphy *et al.*, 2006).

The perception of industrial engineering as "invisible" engineering is tied to its "relative anonymity" (Shehab, Rhoads and Murphy, 2005). Many students only learned about industrial engineering after they arrived at university (Shehab, Rhoads and Murphy, 2005). Furthermore, many people from outside the industrial engineering community lack awareness and understanding of what industrial engineering is and what industrial engineers do (Murphy *et al.*, 2006). This lack of awareness and understanding leads people to perceive industrial engineering in inaccurate and sometimes derogatory ways.

The perceptions of industrial engineering as "imaginary", "easy", or "stupid" are related to the perceptions of it having a "distance from technology" and a "less rigorous curriculum" compared to the other engineering disciplines (Foor and Walden, 2009; Brawner *et al.*, 2012). These perceptions are also related to industrial engineering interfacing with the soft sciences (Brawner *et al.*, 2012). Traditionally, the hard sciences are viewed as superior to the soft sciences (Brawner *et al.*, 2012). Furthermore, industrial engineering is often described as being "feminine" in nature (due to its interface with the soft sciences and the belief that women are more inclined towards these sciences), contributing to its perception of it as being "easy" (Foor and Walden, 2009; Brawner *et al.*, 2012; Marquez *et al.*, 2020). These perceptions come in contrast with traditional engineering, which is typically perceived to be masculine and concerned with the hard sciences (Marshall, McClymont and Joyce, 2007). Consequently, industrial engineering is marginalized when compared to other engineering disciplines (Foor and Walden, 2009; Brawner *et al.*, 2012).

Some jokes have surfaced to ridicule industrial engineering. One of the jokes is that the "BEng (Bachelor of Engineering) Industrial Engineering" should be called "BCom (Bachelor of Commerce) Engineering" (R Griessel, 2020, personal communication, 20 May). This joke can be linked to the perception of industrial engineering as being "business engineering" or "a glorified business degree" (Specking, Kirkwood and Yang, 2015). Yet another joke is that industrial engineering was referred to as the "BA (Bachelor of Arts) Engineering" (T Hattingh, 2020, personal communication, 20 April). This joke can be linked to the perception of industrial engineering having a people orientation (Trytten *et al.*, 2004; Murphy *et al.*, 2006).

The misunderstandings and misconceptions of industrial engineering extend to industry, too. For example, in Trinidad and Tobago, a study found that the principles of the industrial engineering degree are not as well-known, understood, and appreciated as they are in other parts of the world, such as in North America (Pun and Yiu, 2010). This led to:

- A flawed understanding of industrial engineering applications by industry respondents
- The marketing/hiring of non-industrial engineers to perform industrial engineering jobs
- A deterioration in the competitiveness of organizations
- Not enough industrial engineers available to meet the market demand for them
- Weak representation and growth of the industrial engineering department over 24 years

Similar consequences are faced in academia. For example, the slow growth and low enrolment in industrial engineering relative to the other engineering disciplines may be attributed to the discipline's "relative anonymity" (Shehab, Rhoads and Murphy, 2005). Furthermore, the misinformation and negative perceptions surrounding industrial engineering may discourage prospective students from pursuing it (Trytten *et al.*, 2004; Morales and Medina-Borja, 2014). Even the students that do choose to pursue it may choose to leave it due to misconceptions and inaccurate expectations, such as expecting it to be "easy" and then being unable to face the rigour of the curriculum (Morales and Medina-Borja, 2014).

Despite the negative perceptions and consequences surrounding industrial engineering, many members of the industrial engineering community maintain a positive perception of the discipline. They maintain that industrial engineering is not necessarily easier than the other engineering disciplines, but simply different (Trytten *et al.*, 2004). A student summarized industrial engineering as "inviteful engineering" (Trytten *et al.*, 2004). The discipline seems to "invite" individuals into it, such as those who do not think of themselves as "traditional engineers", those who were inclined towards business degrees, or those who desire a work-life balance (Trytten *et al.*, 2004). Furthermore, industrial engineering is "inviteful" of both women and men (Foor and Walden, 2009).

Many of the studies in Table 4 originated from a realization that industrial engineering was surrounded by misperceptions that were negatively influencing its development. As a result, they recommend increasing awareness and correct understanding of industrial engineering. For example, it was strongly advised to correctly inform students early on about industrial engineering as a degree option and a career (Shehab, Rhoads and Murphy, 2005). It was also suggested to develop a more understandable definition of industrial engineering for high school students (Specking, Kirkwood and Yang, 2015). Furthermore, there is a need to emphasize the roles and contributions that industrial engineers could have in industry so that industrial engineers can be appropriately recognized and employed accordingly (Pun and Yiu, 2010).

2.6 The job potential of the industrial engineer

It is often mentioned in literature that industrial engineering has broad and varied job opportunities. The following quotes from literature describe the job potential:

- “Much of the attractiveness of industrial engineering lies in the fact that it is an engineering field that provides its members with a broad spectrum of career options” (Martin-Vega, 2001)
- “The role and career of the industrial engineer in the modern organization can best be summed up by the word *diversity*, for there is hardly a profession, much less a discipline within engineering, that is so broadly defined” (Billings *et al.*, 2001)
- “One of the great challenges of the [industrial engineering] profession is communicating the distinct roles that industrial engineers play when the roles are so diverse and varied across organizations” (Billings *et al.*, 2001)
- “The Body of Knowledge associated with Industrial Engineering is as broad and varied as the Industrial Engineering profession itself” (IEBoK Authors, 2019)
- “With its diversity, [industrial engineering] appeals to a wide cross section of employers and [industrial engineers] will have the opportunity to work in lots of different types of businesses. The most distinctive aspect of industrial engineering is the flexibility that it offers” (Savory, 2005)
- “...“IE is the most flexible out of all the engineering programs which gives many career opportunities in every industry that there is after graduation”...” (Marquez *et al.*, 2020)

2.6.1 Job title options for industrial engineers

Understandably, the broadness and variety of potential industrial engineering jobs can lead to confusion or difficulty in finding commonality (Darwish, 2018). Thus, it is usually necessary to provide extra adjectives or descriptions to explain what exactly an individual industrial engineer is responsible for in a given industry (Greene, 2001). This could be done in the form of job titles, where an industrial engineering graduate adopts a job with a title other than “industrial engineer.” Examples of these job titles are scattered across literature and are usually used as examples of the industrial engineer’s potential jobs. Savory (2005) lists some examples of these job titles:

- Quality Engineer
- Manufacturing Manager
- Project Manager
- Inventory Controller
- Systems Consultant
- Process Engineer

2.6.2 Changes in nomenclature

As was mentioned in Section 2.2.2 and Table 3, many industrial engineering institutions are changing their departmental/degree names to “industrial and systems engineering.” Some other institutions are changing their departmental/degree names to include terms such as “operations research”, “manufacturing engineering”, “manufacturing systems engineering”, or “management” (Greene, 2001). These name changes do not necessarily mean that industrial engineering is dying and they are not necessarily simply indications of the degree focus (Greene, 2001). Rather, these changes indicate that industrial engineering is getting broader and that, perhaps, it is the term “industrial” that is dying (Greene, 2001). As such, new terms (such as management engineer, productivity engineer, improvement engineer, innovation engineer, integration engineer, implementation engineer, and intellectual engineer) have been suggested to better represent the industrial engineering profession and its future (Greene, 2001). These types of terms may serve a better function than the term “industrial” in the “...immediate recognition of the profession by the layperson” (Greene, 2001).

2.6.3 Categorisations of job types

Rather than explicitly listing job titles, it is more common to find categorisations of industrial engineering job functions in literature. Savory (2005), for example, provides 5 main focus area categories for industrial engineers in an undergraduate curriculum: Production, Management, Ergonomics, Manufacturing Processes and Systems, and Operations Research. These categorisations narrow down the broadness of the discipline and make it easier to navigate.

Another example of a categorisation would be the one created by The National Aeronautics and Space Administration (NASA). In its perception of the scope of industrial engineering, NASA listed the following as the six “core industrial engineering capabilities”: process analysis and modelling, management support systems, human factors engineering, work measurements/methods engineering, planning and scheduling systems, and quality management (IE Solutions, cited in Zandin and Maynard 2001). Billings *et al.* (2001) suggest the following five categorisation groups for predominant roles of industrial engineers: process improvement expert, system integrator, change agent, productivity expert, and model developer. Similarly, Salvendy (2001) mentions the following potential roles for industrial engineers in an organization:

- Roles for **strategy and positioning**, which are concerned with the value proposition and strategic planning processes
- Roles concerned with **conditions for success**, which analyse the conditions of the environment and establish whether they support success and drive results

- **Driver** roles that drive **operations improvement** by making sure that operations are being done correctly

Another categorisation system can be found in a study that attempted to define the professional profile for industrial and engineering management (IEM) (Lima *et al.*, 2017). In this study, an innovative methodology using job advertisements was used (Lima *et al.*, 2017). To create professional profiles, 1391 job advertisements from a Portuguese newspaper were gathered over 7 years (Lima *et al.*, 2017). These job advertisements were used to characterise areas of professional practice and transversal competencies for industrial and engineering management (Lima *et al.*, 2017). The results of the analysis for the areas of professional practice can be seen in Figure 6.

The areas of professional practice in Figure 6 were: Production Management, Supply Chain Management, Project Management, Quality, Economics Engineering, Product Design, Marketing, Maintenance, Ergonomics and Human Factors, Automation, and Industrial Optimization (Lima *et al.*, 2017). Even though the study was conducted for industrial and engineering management, some of the areas of professional practice can be representative of industrial engineering too. These areas provide yet another way to categorise the industrial engineering discipline from a job function perspective.

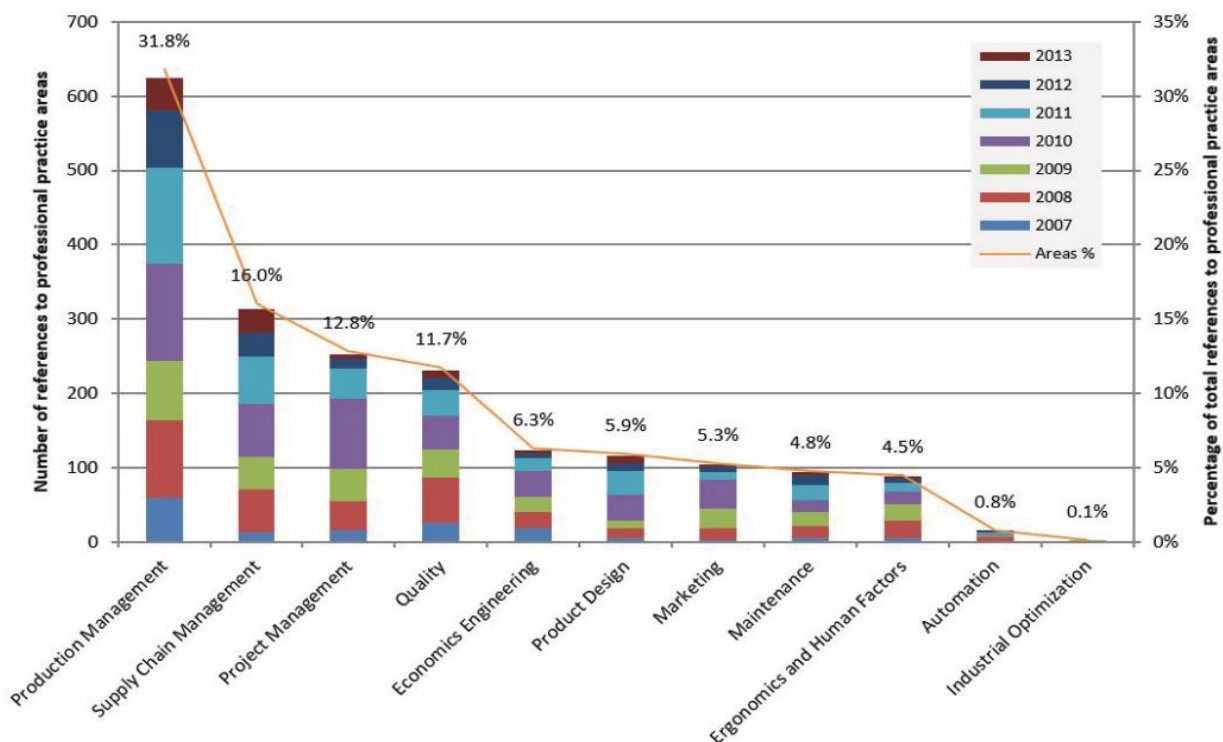


Figure 6: Job advertisements analysis: professional practice areas (Lima *et al.*, 2017)

The same way the job potential for the industrial engineer is broad and varied, the perceptions and representations of the job potential are broad and varied. There is no one definitive way to categorise the job potential. However, a few of the attempts at categorisations were shared in this part of the Literature Review. Many other attempts can be found in grey literature or across the internet in career websites, university websites, blogs, videos, or forums.

2.6.4 The uniqueness of the industrial engineering job

To avoid the industrial engineering profession becoming so broad and variable to the point that “anything goes” as industrial engineering, it is important to always abide by the industrial engineering definition and body of knowledge when assessing whether something is or is not industrial engineering. Furthermore, it is important to differentiate industrial engineering from its related professions.

There are many differentiators between industrial engineering and the more traditional engineering disciplines. The first of these has been mentioned previously in the dissertation, and that is the difference in the types of sciences used. The traditional engineering disciplines use the hard sciences to solve technical problems (US Department of Labor, 2009), while industrial engineers use both the hard and soft sciences to solve a wide variety of problems (Hicks, 2001).

Industrial engineers, unlike traditional engineers, focus on how people interact with systems and technology (Savory, 2005). That makes them more concerned with the conceptual aspects of the *system* itself (such as resource usage, productivity, and quality) rather than the technical or physical aspects (such as mechanics, chemistry, and electricity) (Savory, 2005). Due to their understanding of people and their subsequent training in leadership, industrial engineers are more likely to be promoted to management positions sooner in their careers when compared to other engineers (Savory, 2005).

At a fundamental level, industrial engineering is not concerned with the physical sciences such as mechanics and chemistry (Savory, 2005). However, like all engineers, mathematics forms a central part of their work (Savory, 2005). The *type* of mathematics plays a key role in differentiating industrial engineers from other engineers and other similar professions. While other engineering disciplines tend to focus on continuous variable math, industrial engineering focuses on discrete variable math (Savory, 2005). Industrial engineering has a heavy curriculum focus on mathematics courses such as probability, statistics, and linear algebra (Savory, 2005).

When it comes to differentiating industrial engineering from other similar professions (such as some business or management professions), mathematics plays a role once again. Industrial engineers, being engineers at their core, are expected to be more proficient in mathematics than a non-engineer doing a similar type of work. Thus, it is expected that an authentic application of

industrial engineering would include some degree of mathematics or other traditional engineering functions, such as design. Industrial engineers will also have a familiarity with the hard sciences that business/management professions may not. Although industrial engineers may not be primarily concerned with some of these hard sciences, they at least would have had exposure to them as part of their core engineering curriculum in their undergraduate studies (Savory, 2005). Similarly, non-engineers would be expected to have more exposure to other subjects.

Perhaps the most prominent differentiating factor between industrial engineers and other professions is that it focuses on the way work is done, rather than on specific academic subjects (Savory, 2005). The industrial engineering “way” becomes clearer when examining some examples of jobs that industrial engineers can do in real life.

2.6.5 Practical examples of jobs

To illustrate the job potential of the industrial engineer in a more practical and distinct way, a few specific examples of its potential real-life applications are provided:

- **Healthcare industry**
 - Determining ordering timings and quantities of medical supplies (Mackenzie, 2016)
 - Assigning schedules to hospital staff (Savory, 2005)
- **Retail industry**
 - The design and implementation of a warehouse management system, distribution network, and labour management system (Billings *et al.*, 2001)
 - Planning how often the sales department of a company should contact its customers to receive feedback on a product (Savory, 2005)
- **Entertainment industry**
 - Analysing productivity, guest flow, capacity, and labour forecasts/schedules in amusement parks (Billings *et al.*, 2001)
 - Reducing queuing times for rides (Savory, 2005)
- **Transportation industry**
 - Creating a system for the tracking and efficient routing of truck shipments (Savory, 2005)
 - Supply forecasting, inventory management, and truck scheduling for food aid distribution (Sackey and Bester, 2016)
- **Manufacturing industry**
 - Investigating the effects of adding robots to a manufacturing line (Savory, 2005)
 - Designing a new way to assemble products to avoid worker injuries (Savory, 2005)

2.7 Summary of literature review

The Literature Review started by expanding on the history and the evolution of the industrial engineering discipline. This led to a discussion of the term “industrial and systems engineering” and its popularity in literature. Then, the industrial engineering body of knowledge was outlined.

After industrial engineering was fully defined and placed in its historic context, more recent studies were shared. These studies included a census of industrial engineering and multiple other studies capturing trends in research topics and curricula. These studies gave a snapshot of the state of industrial engineering in the 21st century across the world.

In the Introduction Chapter, several mentions were made about the challenges that industrial engineers face when it comes to their identity, perceptions, and recognition. These challenges were expanded on and unpacked in the Literature Review, as the industrial engineering community realized that they were an area of concern for industrial engineers.

The Introduction Chapter mentioned the broad nature of the industrial engineering discipline, leading to broad job potential and career opportunities. To expand on this, part of the Literature Review expanded on the broadness and variability of the industrial engineer’s job potential. In this part of the Literature Review, several ways to categorise the industrial engineer’s different roles/functions in industry were provided. Finally, the Literature Review Chapter ended with some practical examples of industrial engineering applications in different industries.

2.8 Revisiting the research topic

The industrial engineering discipline is generally well-covered in literature. The rationale behind this research did not necessarily stem from a knowledge gap found in literature, but rather from a realization that industrial engineering could be framed in a new way to address its challenges. This way was through a comprehensive web search, compilation, and categorisations of its many associated job titles.

Job titles are a simple and clear way to explain what an industrial engineer could do. These job titles are present across industrial engineering sources, whether through formal literature, grey literature, or websites on the internet. In fact, in the case of job titles, it is more common to find examples of them on the internet (specifically through career websites) than from formal literature. Also, it is expected that people would use the internet to find out more about industrial engineering. Thus, the idea to use the internet as a searching ground for job titles came about.

The research topic for this dissertation was inspired by the literature on similar topics. The methodology, however, was innovative.

CHAPTER 3: METHODOLOGY

The methodology for this research is outlined through the research context and research design. The limitations, validity, and reliability of the study are also explained.

3.1 Research context

In this research, the nature of the industrial engineering discipline is being studied. Therefore, the research context is conceptual rather than physical. The context for this research could thus include any place or time that industrial engineering exists (even in times or places that the specific nomenclature of “industrial engineering” is/was not used). However, due to the impracticality of operating in a purely conceptual and universal context, the context is narrowed down and described.

3.1.1 Research subject

In terms of “what” is being studied, “industrial engineering” is specified as the overarching research subject. More specifically, the job potential of the industrial engineering discipline is being studied through an investigation of job titles that a person with an industrial engineering qualification could potentially adopt.

3.1.2 Research time and place

Since the research subject is intangible, it did not involve any interactions with the physical world. The study was conducted online and remotely, which was appropriate not only due to the conceptual nature of the research subject but also due to the various and ample sources that offer information on industrial engineering online. Any data was restricted by its online availability in the 2020-2021 time frame, which was when the study was being conducted. However, the research outputs will likely be applicable for as long as the industrial engineering discipline exists in its current form. The outputs are also applicable for comparative purposes in research. The results from this dissertation can be seen as a representation of the state of the industrial engineering discipline on the web in the 2020-2021 time frame.

3.1.3 Research audience

The audience for this research is anyone interested in understanding or communicating industrial engineering. It will be especially relevant for members of the industrial engineering community (such as students, graduates, and professionals) and employers of industrial engineers.

3.1.4 Research perspective and guidelines

Although there is a unifying research subject (industrial engineering), there exist many variations in its definition, curriculum, or job prospects. After all, there are many institutions, publications, and individuals who may view industrial engineering in a slightly different way. Some might even define industrial engineering in a way that is incompatible with this research. Thus, among the plethora of industrial engineering-related data, it is necessary to define the research perspective as part of the research context. That way, further work could be checked for consistency based on the guidelines of the research perspective.

In this research, the perspective of the Institute of Industrial and Systems Engineers was used. This institutional perspective was chosen for several reasons. As mentioned in the Background, the IISE is “...the world’s largest professional society dedicated solely to the support of the industrial engineering profession and individuals involved with improving quality and productivity” (IISE, 2021). The IISE has been identifying as an international institution since 1981, after dropping the word ‘American’ from its original name, the American Institute of Industrial Engineers (IISE, 2021). As such, the Institute is inclusive not only to individuals who are qualified specifically as industrial or systems engineers in America but to individuals all over the world who have the same core drivers as industrial and systems engineers. Finally, like this research, the IISE intends to share timely information to members of the industrial engineering community, employers of industrial engineers, and members of the general public who are interested in industrial engineering.

From the IISE, the main guiding document that was used for this research was The Industrial Engineering Body of Knowledge (IEBoK Authors, 2019). The IEBoK provides a definition of industrial engineering (which can be found in Section 1.1.1) as well as an outline of the knowledge areas that need to be known to master the discipline of industrial engineering (which can be found in Figure 3). This definition and these knowledge areas served as the pillars upon which the rest of the dissertation was built.

The IEBoK also served a function in terms of the validation of the study. The IEBoK (2019) has contributions from 18 individuals, all volunteers of the IISE. There is also a Body of Knowledge Governing Board that oversees the updating of the document, given that it is evolving. The involvement of members of the industrial engineering community in the compilation and publication of the IEBoK is reassuring from a validity standpoint. It implies that there was mutual agreement between the members that the IEBoK is an accurate representation of industrial engineering.

3.2 Research design

The research design is the strategic plan to address the research aim, covering the overall framework for collecting and processing data (Oshagbemi, 2017). In the following sections, the methods for collecting, filtering, and analysing data are explained.

3.2.1 Data collection

To address the aim and questions of this research, a list of job titles needed to be collected. These job titles must represent the types of job titles that a person with an industrial engineering qualification could pursue or the types of job titles associated with the industrial engineering discipline. Going forward in this dissertation, these job titles will be referred to as “IE job titles.”

Multiple methods were considered to gather the data on job titles. For example:

- sending out a survey to practicing industrial engineers to collect their past and present job titles
- conducting a census to collect past and present job titles of practicing industrial engineers
- conducting interviews with industrial engineering graduates on their experiences with job titles in their job search
- conducting interviews with employers who are advertising jobs to industrial engineering graduates, focusing on which job titles they associate with an industrial engineering qualification

The methods above would have produced data on how individual industrial engineers are choosing to label themselves and/or how individual employers interested in hiring industrial engineers are choosing to label their job advertisements. However, this research dissertation is not focusing on the individual cases but rather on a general, conceptual trend; it is exploring the nature of the industrial engineering discipline first and foremost, independent of personalized career choices and/or marketing. The focus on the theoretical is to capture the essence of industrial engineering and its job potential without the bias of independent human choices and circumstances. As such, the data collection processes needed to make use of already-existing data on industrial engineering instead of generating new, personalized data.

To find this already-existing data, the internet was used. The internet is not only the largest data source known to humans, it is also ever-growing and constantly updating (Persson, 2019). Job titles could be found on multiple types of websites across the internet. The data collection process, in summary, needed to allow for the search and compilation of a sample of these job titles available on the web.

3.2.1.1 Data type

The job titles that were collected were of the secondary data type since they already exist on the internet.

Job titles are composed of words, making them text data. Text/word data types are usually considered to be qualitative data (Oshagbemi, 2017). However, in the case of this research, the data has both qualitative and quantitative elements to it. Job titles are qualitative because they have embedded meaning in them that could be unpacked. They are quantitative because they can produce numerical text statistics.

3.2.1.2 Data collection method

Since this research is a web-investigation, web-scraping was chosen as the compatible data-collection method. The web-scraping method is a form of data mining that aims to transform scattered, unstructured data from websites into a structured form (Saurkar and Gode, 2018). It is focused on original analysis rather than original data. This made it an ideal method for the purposes of this research, which was to compile the IE job titles that were scattered across the web and to analyse them in an original way.

Studies on the web-scraping method often include the use of an automated process or program as part of the definition of web-scraping (Haddaway, 2016; Persson, 2019). However, automation is not necessarily a part of web-scraping; it just may make the process of web-scraping more efficient. Simply and generally put, web-scraping is the process of extracting data from websites, regardless of the technique that was used to gather this data (Perez, 2020). The technique could be manual scraping, which is manually copying and pasting information from websites into a spreadsheet, or automated scraping, which makes use of an automation tool to extract data from websites (Perez, 2020).

Manual scraping was used in this research because the types of data sought out were gathered from multiple websites that did not follow any standard, consistent, or structured format that could be automated. For example, the data types sought would be in list form on some websites, and in sentence or paragraph form on other websites. Manual scraping was advantageous over automated scraping since the data types that were being sought were in word-format. Thus, it was beneficial for a human mind to inspect each entry and make sure it made meaningful sense to include it into the dataset.

The data that was scraped off the internet eventually created a sample of IE job titles. The sampling method that was chosen is discussed in the next section.

3.2.1.3 Population and sampling

There was no definitive way to measure or even estimate the population for this study. The type of data sought to create a sample (job titles) could be found all over the internet – whether it be on one of the websites of universities offering industrial engineering, career websites, or the YouTube Channels, blogs, and forums discussing industrial engineering. Some sources were dedicated to discussing career paths and thus listed dozens of job titles, while others only mentioned a job title or two in passing. Furthermore, the internet is expanding along with the industrial engineering discipline, so the population will constantly be expanding.

Due to the inability to define the population size, this study did not choose a sample size based on a percentage of the population. It also did not involve random selection of data for inclusion, as is done in probability sampling (McCombes, 2019). Rather, it used a non-probability sampling technique, where data was selected for inclusion in a non-random way based on certain criteria (McCombes, 2019).

There are multiple forms of non-probability sampling: convenience sampling, voluntary response sampling, purposive sampling, and snowball sampling (McCombes, 2019). Convenience sampling and purposive sampling were both considered as potential sampling techniques for this research. In convenience sampling, data is gathered from the sources which are most accessible to the researcher (McCombes, 2019). In the case of this research, the most accessible sources would have been the websites that appear first after searching; these websites would be most convenient to scrape for data. The sample would stop after a certain sample size or number of sources is reached, or after the researcher decides that the sample has been saturated with data. However, just because a website appears first in a search engine does not necessarily mean that it is better than another website that appears later with more searching. Sometimes, the less accessible websites offer the best data. To allow for more flexibility and a more strategic sample, purposive sampling was considered instead.

Purposive sampling is also known as judgement sampling or deliberate sampling because the researcher uses their own judgement and knowledge to select a sample that is most appropriate for the research (Glen, 2015; McCombes, 2019). It is used when “...the researcher wants to gain detailed knowledge about a specific phenomenon rather than make statistical inferences” and it requires a clear justification for choosing to include some sources over others (McCombes, 2019). In this research, “detailed knowledge about a specific phenomenon” is an appropriate way to describe the type of data sought out; the detailed knowledge was “job titles” and the specific phenomena was “industrial engineering.” Further, the intent of gathering this data was to gain a better understanding of industrial engineering rather than to make statistical inferences. Thus, purposive sampling was deemed the appropriate sampling method for this research.

One of the main advantages of purposive sampling is that it is easier to make generalizations about a non-random sample than it is to make generalizations about a random sample (Glen, 2015). Also, human judgement may be able to make better decisions than an algorithm when it comes to web-based searches. Using purposive sampling meant that the sources were judged based on their appropriateness for the study, rather than their accessibility or convenience.

One of the disadvantages of non-probability sampling is that it has a higher risk of sampling bias than probability sampling (McCombes, 2019). Although there is no intended bias in purposive sampling, there still may be selection bias and errors (Glen, 2015). To mediate this bias, multiple measures were taken. The first of these measures was to justify the inclusion and exclusion of each data source. The second of these measures was to ensure that the included data reached saturation. The third of these measures was to triangulate the data collection process.

Triangulation is a method for verifying and validating research (Patton, 1999). It usually involves collecting data from multiple (more than 2) sources or using multiple methods to check for consistency of findings (Patton, 1999). However, triangulation can also be analyst triangulation (where multiple analysts review findings) and theory/perspective triangulation (where multiple theories/perspectives are used to interpret data) (Patton, 1999).

A mix of source triangulation and theory/perspective triangulation were used in combination with purposive sampling. The source triangulation was implemented in that the data was gathered from three different sources. The theory/perspective triangulation was not used to interpret the data per se, but it was used to gather data from different types (or perspectives) of sources. The source and perspective triangulation was used to ensure variety and reduce bias in the final sample of job titles. That way, bias from each perspective was limited, and consistency across the different sources could be examined to determine if saturation was reached or not.

To find sources (websites) to scrape job title data from, a search strategy had to be created. This search strategy is explained in the following section.

3.2.1.4 Search engine, search terms, and search strategy

To find data online, one must use a search engine. Google was chosen as the search engine since Google is the most popular and largest search engine in the world, with a worldwide search engine market share of 92.18% (Law, 2020). Thus, it is probable that most people who will do an online search on industrial engineering will use Google, especially if they are trying to find practical and up-to-date information on it, such as job advertisements. Furthermore, people interested in engineering in general prefer to use the internet when they want to learn more about it (Marshall, McClymont and Joyce, 2007).

The search terms on Google were:

- Industrial engineer job titles
- Industrial engineering jobs
- Industrial engineering careers
- Industrial engineering job potential
- Industrial engineering job prospects

In the search terms, a synonym of “job” (career) and a synonym of “potential” (prospects) were included in the search for job titles to cater for nomenclature differences in websites.

Each one of the search terms was entered into Google, producing many search results. Many of the results were the same for each search, given the similarity in the search terms and the popularity of some websites on the internet. Each website on Google’s first page for each search was inspected for inclusion, given that the first page tends to give the best and most relevant results. Several of Google’s subsequent pages were also scanned for promising websites to include, but the more pages that were scanned, the less relevant the websites were.

3.2.1.5 Sources

When scanning Google’s search results for relevant sources, it was noted that different types of websites from different types of perspectives appeared. These were:

- Career websites: websites that describe and advertise jobs to the public
- Academic websites: websites that describe degree options and the jobs associated with such degrees
- Community websites: websites such as videos, blogs, and question-and-answer forums that share personal or non-formal accounts of a certain topic, such as job potential

Some websites in the search results did not list any job titles. These websites were automatically excluded. Appendix A shows a table with all of the sources that did list job titles and thus were considered for inclusion. The job titles from the websites were typically repeated across different websites, but some websites had many more job titles than others.

The three sources that were ultimately chosen for inclusion can be seen in Table 5. Each of them had the highest number of job titles when compared to the other websites coming from the same perspective; this can be seen in Appendix A. The number of job titles from each source, along with the qualitative reasons for choosing the source, can be seen in Table 5.

Table 5: Triangulated sources

Perspective	Source and URL	Reason for choice of source
Academic Perspective	University of Washington: Industrial and Systems Engineering Department website with PDF https://ise.washington.edu/sites/ise/files/ISE-Job-Titles_0.pdf (Screenshots of the web-page can be found in Appendix C)	This document was the most populated and diverse source of all the sources considered. It offered 100 data entries and contributed the most to the final dataset of job titles. It was also compiled by industry leaders on the University's Executive Advisory Board, which supports internal validation.
Career Perspective	Zippia: job and career website https://www.zippia.com/industrial-engineering-major/ (Screenshots of the web-page can be found in Appendix D)	While many career websites were describing IE job titles and career paths, Zippia did so in a unique way. Zippia visually showed multiple career paths that an industrial engineering graduate could take, listing 2-3 job titles per path. It offered 55 data entries, making it the 2 nd most populated source that was considered for inclusion.
Community Perspective	Quora: question-and-answer website Question: "What are the job prospects for an industrial engineer?" https://www.quora.com/What-are-the-job-prospects-for-an-industrial-engineer (A screenshot of the chosen answer in the web-page can be found in Appendix E)	Most of the answers to this Quora question were in paragraph form, describing industrial engineering job prospects rather than providing concrete examples. The chosen answer listed a variety of job titles, offering 20 data entries. It was also one of the highest-rated answers for the question by Quora users, supporting internal validation.

Screenshots of each web-page were included to reinforce validity by capturing the web-pages in 2021, given that they may change in the future.

The term "data entries" was used to describe the amount of data scraped from these sources since not all of the data entries were singular job titles. Some data entries included multiple job titles, while others were not in a job title format. Each data entry from each source was then subject to filtration criteria to create the final list of job titles. The filtration process is described in the upcoming sections.

3.2.2 Data filtration

The data entries found from the sources of Table 5 were manually scraped and copied verbatim into a spreadsheet of raw data. Before the data entries could be included in a final spreadsheet and analysed, they needed to be filtered. The filtration was conducted based on a set of inclusion, alteration, and exclusion criteria. These criteria aimed to transform the data entries into a standardized and consistent list of job titles that could be easily analysed. Each criterion is listed and explained in the following sections. One example of these criteria was to get all the data entries into a preferred job title format.

3.2.2.1 Preferred job title format

The preferred job title format was derived from the raw dataset. It was evident that the majority of job titles followed a similar format; they were composed of two parts and were capitalized. The first part was one to three words that described the area of concern, such as “Human Factors.” The second part was one word that described the type of job function or role, such as “Engineer.” Combined, a conventional job title (such as “Human Factors Engineer”) would be formed. This two-part format of an Area of Concern + Job Function (both capitalized) was the preferred job title format, shown in Figure 7. This format also proved to be useful in data analysis since the job titles could be split up and analysed based on their separate parts.

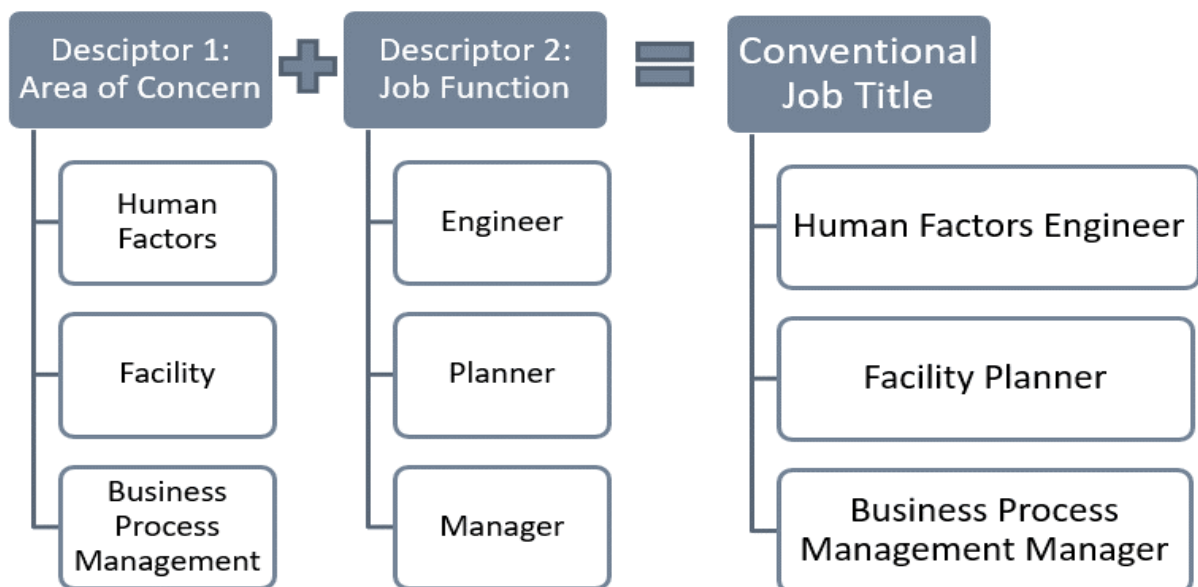


Figure 7: Conventional and preferred job title format

The preferred job title format is referred to in the following sections describing the inclusion, alteration, and exclusion criteria.

3.2.2.2 Filtration process

All data entries went through the same filtration process. First, the data entry was inspected for inclusion. If it did not meet all inclusion criteria, it was inspected for alteration. After alteration, it was inspected for either inclusion or exclusion. This process is visualized in Figure 8.

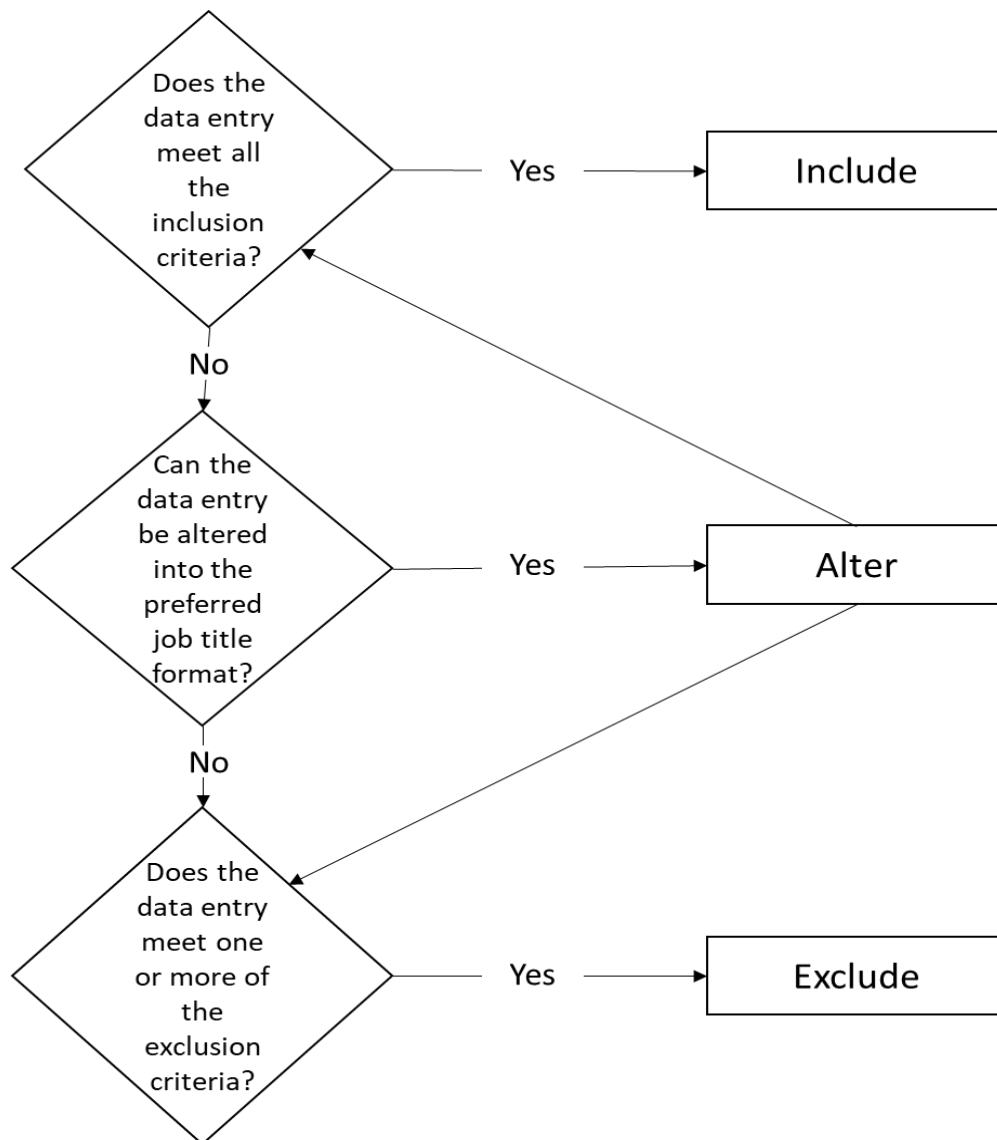


Figure 8: Flowchart for the inclusion, alteration, and exclusion process

There were some borderline cases of data entries that did not reach a resolution using the filtration process of Figure 8. For these cases, it was debatable whether the data entry should be included or not. These cases, along with the reasoning behind including/excluding them, can be seen in Appendix B.

3.2.2.3 Inclusion criteria

To be included in the final dataset, a data entry had to meet all inclusion criteria. These inclusion criteria are stated and described in Table 6.

Table 6: Inclusion criteria

No.	Inclusion criterion	Justification
1	The data entry is in the preferred job title format.	The raw data entries came in a variety of forms. Most were in the preferred job title format as per Figure 7. Others were in a job title format but included extra information such as degree of seniority or specialization requirements. Some were not in a job title format at all and were not appropriate to include. Thus, the first inclusion criterion required that each data entry must be in the preferred job title format. This made the final dataset standardized and consistent. It also made the data analysis process more organized.
2	The data entry is a single job title.	Some data entries consisted of multiple job titles in one. To distinguish each job title by itself, the second inclusion criterion required that each job title be a single job title.
3	The data entry fits into at least one of the 14 knowledge areas identified by the IEBoK.	The IEBoK was the guiding document for this research. As such, the included data needed to abide by its guidelines. Data entries that do not fit into at least one area of the IEBoK are considered irrelevant or outside the IISE's institutional scope of industrial engineering.

Some data entries fit almost all the inclusion criteria but needed some alteration before they were included. These alterations did not change the meaning of the data, they simply made the dataset more standardized and consistent. They were mostly grammatical in nature, as can be seen in Table 7 in the next section.

3.2.2.4 Alteration types

Table 7 lists all the alteration types with their justifications. Also, an example of a data entry from the results is included for each alteration type.

Table 7: Alteration types

No.	Alteration type	Justification	Example from results
1	All job titles were capitalized.	Capitalization is part of the preferred job title format, given that most job titles were capitalized in their raw form anyway. Thus, for consistency and distinction of the job titles, all were capitalized.	production engineer → Production Engineer
2	Descriptors of professional rank or speciality such as “Senior”, “Principal”, “Specialist”, or “Intern” were removed.	Indications of rank or speciality reduce the genericness of the job titles and are not necessarily relevant for this study. They also reduce consistency.	Advanced Quality Engineer → Quality Engineer
3	Easily identifiable abbreviations or acronyms were expanded.	There is a certain set of well-known abbreviations and acronyms in industrial engineering that could easily be expanded to avoid ambiguity.	ERP Consultant → Enterprise Resource Planning Consultant
4	Joint data entries were split up into separate entries.	Some data entries in their raw form listed multiple job titles. These entries were split up into individual job titles for consistency and distinction so that each data entry in the final dataset represented one job title.	Supply Chain Analyst, Engineer, or Manager → Supply Chain Analyst Supply Chain Engineer Supply Chain Manager

Data entries that were altered were either included or excluded based on the inclusion criteria in Table 6 or the exclusion criteria in Table 8.

3.2.2.5 Exclusion criteria

Table 8 lists the exclusion criteria with their justifications, as well as examples from the results.

Table 8: Exclusion criteria

No.	Exclusion criterion	Justification	Example from results
1	The job title includes the term “industrial engineer” or “industrial engineering.”	Since the research topic is about finding the job titles associated with industrial engineering, it would be redundant to include job titles with “industrial engineer(ing)” in them.	Industrial Engineering Manager
2	The job title is a specialist, senior or expert position requiring further training or job promotion.	Job titles based solely on speciality, seniority, or rank require that an individual has further training or job promotions. Thus, they are not necessarily job titles that any generic industrial engineer could adopt post-graduation.	Finance Employee Development Specialist
3	The job title is an academic position.	Academic positions can be pursued by any professional. They do not necessarily reflect the functions of a discipline since the primary function would be educating or researching. The job titles sought needed to reflect the discipline.	Associate Professor
4	The job title is a personal or an entrepreneurial endeavour.	The job titles sought needed to be generic and a reflection of the functions of the discipline. Personal and entrepreneurial endeavours draw in a personalized bias that does not necessarily reflect the industrial engineering qualification.	Independent Researcher/Author

No.	Exclusion criterion	Justification	Example from results
5	The job title includes abbreviations that could not be easily expanded.	Some abbreviations and acronyms lead to ambiguity. If it was not a well-known or easily deduced abbreviation or acronym, the data entry was removed to reduce ambiguity.	EHS Multi Family Manager
6	The job title is ambiguous and does not hint at the type of work.	The included job titles are meant to add more clarity and specificity to industrial engineering since the industrial engineering job title is already ambiguous. Including more ambiguous job titles would expand on the problem instead of mediating it.	President
7	The job title seems to require knowledge from outside of the IEBoK.	The IEBoK is the guiding document, so including jobs that seem to require knowledge from outside the knowledge areas would be trespassing the guidelines and misrepresenting the generic job prospects of the industrial engineer.	Sales Engineer
8	The data entry is not written in the preferred job title format and could not be rewritten as such.	All the job titles had to be in the preferred job title format to keep the dataset consistent and standardized.	Technical Sales
9	The data entry is a repetition of another data entry.	Many data entries were repeated. These repetitions were noted but excluded from the final dataset to avoid redundancy. Only one job title of each repeated set was kept.	“Manufacturing Engineer” was repeated four times; three repetitions were excluded and one was kept.

3.2.3 Saturation

Data saturation is “...when no new information or new themes are emerging from data analysis” (Cohen and Crabtree, 2006). Table 9 describes the saturation criteria that were applied to the data.

Table 9: Saturation criteria

No.	Saturation criterion	Description
1	The data was triangulated from at least three different sources with different perspectives.	Having a variety of sources, as well as a higher sample of data, increases the chances of reaching data saturation.
2	There is at least one job title to represent each knowledge area in the IEBoK.	Since the IEBoK was the guiding document for the data collection process, the data itself needed to be representative of the IEBoK as a whole. Although industrial engineering is more traditionally associated with some knowledge areas over others, the job titles needed to provide a holistic and varied representation of industrial engineering.
3	The data repeats itself often within and/or across the different sources.	Repetition or similarity of data is a hallmark sign of data saturation.
4	There is enough data to address the research aim and research questions.	Patterns needed to be extracted from the data to address the research aim and research questions. This could only be done if there was enough data so that the patterns are not random and are actually representative of the data.
5	It can be reasonably and logically deduced that adding more data would be redundant for the purposes of the study.	Having more data is not necessary or beneficial once a reasonable degree of saturation is reached. Too much data would redundantly overcrowd the dataset.

3.2.4 Data analysis

By the end of the filtration process, there was a dataset of job titles ready to be analysed. Two forms of analysis were used to analyse the data and extract patterns from it: text analysis and logical reasoning. The text analysis represented the quantitative part of the analysis since it produced numerical text statistics. The logical reasoning represented the qualitative part of the analysis since it produced insights and connections. As part of data analysis, the saturation of the data could also be examined.

3.2.4.1 Text analysis

Since the dataset of job titles consisted of text data, text analysis was an appropriate method to analyse the data. Several text analysis methods and tools were used: calculating word frequencies, identifying word collocations, text visualization, and text classification. Word frequencies are the number of times a word appears in the data (Duke University, 2017). Word collocations are words that commonly occur together (Duke University, 2017). Text visualization is the transformation of structured or unstructured text data into a graphic or visually illustrative form (Risch *et al.*, 2008). Text classification (also known as text categorization or text tagging) is grouping text into categories based on its content (Srinivasan, 2020).

To begin the text analysis, each job title was split up into its two parts: Descriptor 1 terms and Descriptor 2 words (as per the job title format in Figure 7). The word frequencies of each part were then calculated. Word collocations were noted for the Descriptor 1 terms since some of these terms were made up of two to three words that commonly co-occurred. Then, words were tagged and categorised based on their similarities. Logical reasoning was also used to create the categories. Throughout the analysis, the data was visualized with word clouds, graphs, and other diagrams.

3.2.4.2 Logical reasoning

When it comes to data analysis, deductive and inductive reasoning are two common approaches (Streefkerk, 2019). Deductive and inductive reasoning are both forms of logical reasoning, but they differ in their goal; they can be considered as reverse processes of each other. While deductive reasoning aims to test an existing theory by moving from the general to the specific, inductive reasoning aims to develop a theory by moving from the specific to the general (Streefkerk, 2019).

In this study, inductive analysis was used. The starting point for analysis was the “specifics”: job titles. The goal was to create a “theory” or “generalization”: categories of the job titles and a summary of the industrial engineer’s job potential based on those categories.

3.3 Validity and reliability

Validity and reliability are related concepts (Middleton, 2019a). If data is valid (as in, accurate) then it is usually reliable (as in, consistent and repeatable) (Middleton, 2019a). However, reliability is not necessarily an indicator of validity since the repeatability of results does not mean that the results were being measured accurately or that they reflect the real world (Middleton, 2019a). Thus, validity is crucial in ensuring reliability (Middleton, 2019a).

3.3.1 Validity

The validity of the research depends on how accurately the research measured what it intended to measure (Middleton, 2019a). There are many different types of validity, one of which is known as “construct validity” (Middleton, 2019b). Construct validity asks “Does the test measure the concept that it’s intended to measure?” (Middleton, 2019b). This research intended to “measure” and indeed “measured” the job titles of the industrial engineer by gathering a sample of these job titles from the web. However, the accuracy of this sample is another part of validity that needed to be ensured and then assessed.

3.3.1.1 Ensuring validity

To ensure the validity of the data, several measures were taken into place before the data was analysed:

- **Triangulation:** Triangulation is a method that enhances or ensures research validity (Fusch and Ness, 2015). The data was triangulated from three different sources, each coming from a different perspective. Having multiple sources from multiple perspectives promoted the validity of the research by limiting the bias that could be coming from one source or one perspective. Triangulation also increased the sample size.
- **Data saturation:** Data saturation demonstrates validity (Fusch and Ness, 2015). The criteria for data saturation were provided in Table 9.
- **Content:** The IEBoK was used as a guiding reference for the data collection process so that all of the data fit within officially defined bounds of what “industrial engineering” is. To ensure valid data in an industrial engineering context, each job title was subject to an inclusion criterion that required it to fit into at least one knowledge area in the IEBoK. That way, the job titles were representing industrial engineering as a whole. Using the IEBoK helped ensured content validity, which “...assesses whether a test is representative of all aspects of the construct” (Middleton, 2019b). Further supporting holistic validity, the IEBoK in and of itself is an internally validated documented since it was created by multiple members of the IISE.

- **Quantity, quality, and variety of sources and data:** Validity was promoted by prioritizing quality of data over quantity of data, but still including ample data from different sources to accommodate for varying perspectives. The sources that were chosen for inclusion were both the most populated and also the most diverse compared to their alternatives. The justifications for the inclusion of each source, as well as the justifications for the inclusion/exclusion/alteration of data, were provided in Table 5-8.
- **Documentation of the process:** The process for data collection and analysis was thoroughly documented to enhance validity.
 - **Screenshots of URLs:** The URLs, as well as screenshots of the web-pages of the URLs, were provided for each of the data sources that were web-scraped. Providing these screenshots allows any researcher to validate that the web-pages are relevant and that they were scraped accurately. Also, since these web-pages might change in the future, providing screenshots captured the state of the web-pages at the time they were web-scraped in 2020-2021.
 - **Screenshots of spreadsheets:** The web-scraped data was stored in a spreadsheet that was then subject to a filtration process. Screenshots of the raw data, as well as its exclusion and alteration processes, were provided.

The measures that were taken place to ensure validity occurred before and during the data gathering process. After the data was gathered, the validity needed to be assessed.

3.3.1.2 Assessing validity

Assessing the validity of the data occurred after the data was gathered. The assessment is discussed throughout the Results & Analysis and Discussion chapters in the following ways:

- **Consistency across results:** Since the data was triangulated, checking for consistency across the triangulated sources contributes to validity (Patton, 1999). Thus, this consistency was assessed.
- **Comparing against literature:** The validity of research can be assessed by comparing the degree of agreement of the results of the research with pre-existing knowledge (Middleton, 2019a). Thus, the results were compared against literature to show if the results were consistent or compatible with pre-validated, published works (such as the IEBok and the industrial engineering handbooks).
- **Data saturation:** Indicators of saturation were provided and discussed as an assessment of the validity of the dataset since data saturation demonstrates validity (Fusch and Ness, 2015).

The ensuring and assessment of validation serve as a starting point to ensuring reliability.

3.3.2 Reliability

If research is reliable, then it can be repeated consistently to get the same results (Middleton, 2019a). In the case of this research, the degree of reliability depends on what sources of data the researcher used and what analytical judgements were made. There may be some variation between datasets of job titles depending on the source they came from, the size of the sample, and the state of the industrial engineering discipline at a certain time or in a certain place. However, the general pattern and main insights that were extracted from this research's data should be consistent and repeatable if a similar methodology is followed by another researcher. Regardless of the variations that could result from different research approaches to the same topic, some measures were taken to ensure and assess the reliability of this research.

3.3.2.1 Ensuring reliability

To ensure the reliability of the research, or at least increase the degree of it, the process for data collection and analysis was thoroughly documented. That way, any researcher choosing to repeat this research could use the same data sources and methodology.

Other ways to ensure reliability are to apply methods consistently and to standardize the conditions of the research (Middleton, 2019a). This was done by creating standardized inclusion/alteration/exclusion criteria and applying them across all of the data entries. Any borderline cases were pointed out and explained.

3.3.2.2 Assessing reliability

Reliability can be assessed internally, externally, or across time. External reliability would be when another researcher conducts the same research and gets the same results (Middleton, 2019a). Reliability can also be assessed across time to see if the results repeat themselves at a different time point (Middleton, 2019a). In the case of this research, there is expected variability if the research is to be repeated at a different time point or by a different researcher. The variability is not necessarily detrimental to the research, however. Variability adds insight about the evolving nature of the industrial engineering discipline and the internet. External and time-bound reliability fall out of scope for this research. However, the reliability could be assessed internally.

To assess internal reliability, the same methodology was repeated with the remaining data sources that were considered as possible sources but were ultimately excluded due to finding better alternatives. These data sources are the non-highlighted rows in the table of Appendix A. The results from the repetition of the methodology are shared in the Results & Analysis Chapter. From this repetition process, the degree of reliability is assessed in the Discussion Chapter.

3.4 Limitations

Despite the measures taken to ensure validity and reliability, this research was subject to several limitations:

- **Human bias:** Both the researcher and the creators of the sources of data are subject to human bias and errors.
 - **Researcher bias:** The decisions behind choosing to include, alter, exclude, or categorise data are subject to interpretation and change based on the researcher's opinion or bias. An example of this type of limitation would be using the "preferred job title format."
 - **Source bias:** The sources of data themselves were created by humans, so they are subject to interpretation or change based on the creators' opinion or bias. An example of this type of limitation would be when websites list job titles that are not realistic options for industrial engineers.
- **Time and place:** The internet, along with the industrial engineering discipline, may change with time and place. This research was bound by the 2020-2021 time frame and its data was limited by the data available from the websites it used. The links that were used may be rendered inactive or irrelevant in the future, especially since the industrial engineering discipline is likely to evolve and change.
- **Conceptual research topic:** The conceptual nature of the research topic may not fully or accurately reflect the reality of industrial engineering.

These limitations were regulated as far as possible in the following ways:

- To counteract inevitable **human bias**, any debatable decision-making was justified. The decisions and justifications are not meant to be taken objectively. Rather, they offer one perspective of the research. Also, screenshots of the data collection and analysis processes were provided. Thus, there was full transparency during the application of the methodology.
- To counteract limitations of **time and place**, screenshots were provided of the web-pages as they appeared in 2020-2021. That way, the data on them can still be viewed and analysed.
- The limitation of the **conceptual research topic** could not necessarily be counteracted. Rather, the topic was explored through literature to try to make it as concrete as possible. Also, the methodology that was chosen to address the research problem does reflect some degree of reality.

There may always be a debate as to what industrial engineering is and what an industrial engineer does. Perspectives may differ from institution to institution, or from person to person. Realities also may differ based on time and place. However, despite the limitations, this research provided one perspective of the industrial engineer's job potential. This perspective aligned with the research aim of investigating the job potential of the industrial engineer.

3.5 Summary of methodology

The summary of the methodology can be seen in Figure 9. In the figure, the methodology is outlined in a generic step-by-step way. Each step corresponds to a section in the Methodology Chapter, which can be seen on the right-hand side of the figure. Each section explains how the steps were applied for this research topic's requirements.



Figure 9: Summary of methodology

As mentioned at the end of the Literature Review Chapter, the methodology for this research was innovative. The methodology was custom-made to address the research aim and research questions. By applying the methodology, the four research questions were addressed in the following ways:

- **Research Question 1** (What job titles are associated with the industrial engineering discipline on the internet?) was directly answered by the **web-scraping** part of the methodology. The answer was then refined by the **data filtration** part of the methodology.
- **Research Question 2** and **Research Question 3** were both addressed by the **data analysis** part of the methodology. More specifically,
 - **Research Question 2** (What patterns emerge from the job titles that are associated with industrial engineering on the internet?) was answered through the **text-analysis** part of the methodology. During the text analysis, the text-data was analysed to display the frequency, repetition, and collocation of words.
 - **Research Question 3** (How can the job titles that are associated with industrial engineering on the internet be categorised and visualized?) was answered by both the **text-analysis** and **logical reasoning** parts of the methodology. Job titles were categorised based on their similarities. Visuals were made on the basis of these categories.
- **Research Question 4** (What do the job titles that are associated with industrial engineering on the internet reveal about the job potential of the industrial engineer?) was a more open-ended question that could only be answered after the full application of the methodology. Elements from all three of the answers to the preceding research questions were used to answer Research Question 4. Thus, the methodology did not directly address Research Question 4. Rather, Research Question 4 was mainly addressed during the Discussion Chapter since it could only be answered after all of the results were uncovered and analysed (as was done in Chapter 4). Thus, the entirety of the methodology contributed to formulating the answer to Research Question 4, but the question could only be addressed after the results of the methodology were analysed.

To summarize, the methodology for this research allowed for the collection, filtration, and analysis of the job titles that are associated with industrial engineering on the internet. In turn, the research aim (“to investigate the job potential of industrial engineers based on web-scraped job titles”) and the research questions could be addressed.

The upcoming chapters – Results & Analysis and Discussion – were the products of the application of the methodology. During these chapters, the research questions will be linked with their corresponding results and analyses.

CHAPTER 4: RESULTS & ANALYSIS

The results of this research can be shared in consecutive sections that correspond with the research questions. The first section states the industrial engineering job titles, addressing Research Question 1. The second section extracts patterns from these job titles, addressing Research Question 2. The third section depicts an organized version of these job titles, addressing Research Question 3. Research Question 4 is mainly addressed in the Discussion Chapter since it is a more interpretative and open-ended question. As part of the sections of this chapter, there is much analysis and interpretation leading one section into another. Thus, there is some preliminary discussion in this chapter that is expanded on in the Discussion Chapter.

4.1 Overview of results

The Results & Analysis Chapter is closely linked to the Methodology Chapter, given that the results came from the application of the methodology. Before directly sharing the final results, the leading steps that were part of the methodology are summarized and linked to their corresponding appendices and figures.

The IE job titles were gathered through web-scraping three websites. The first was a document created by an academic website (the Industrial and Systems Engineering department at the University of Washington). The second of these was the industrial engineering page on Zippia, a career website. The third of these was an answer about the job prospects of the industrial engineer from Quora, a question-and-answer community website.

The raw dataset consisted of 161 data entries from the three sources; it can be seen in Appendix F. These data entries were filtered based on inclusion, alteration, and exclusion criteria. Of the 161 data entries, 33 were altered. The alterations can be seen in Appendix G. After alteration, the dataset consisted of 187 data entries (the increase from 161 to 187 occurred since some of the data entries that were altered were split up into two to four separate data entries). Of the 187 data entries, 72 were excluded. Exclusions can be seen in Appendix H. This left 115 data entries (all in the form of job titles) that were included in the final dataset, shown in Table 10.

The final dataset was then subject to analysis. Each job title was first split up into two parts: Descriptor 1 terms and Descriptor 2 words. The word frequencies for each part were then calculated and visualized through a graph and a word cloud. Word collocations were noted. These analyses can be seen in Figures 10-14.

Finally, the job titles were analysed further, categorised, and consolidated in a diagram. These categorisations can be seen in Tables 14 and 17. The consolidated diagram is in Figure 17.

4.2 Industrial engineering job titles

Table 10 shows the final list of job titles that were web-scraped after the filtration criteria were applied to them. These job titles answer the bulk of Research Question 1, which was: “What job titles are associated with the industrial engineering discipline on the internet?”:

Table 10: Dataset of industrial engineering job titles (after filtration)

Automation Engineer	Kaizen Promotion Officer	Program Analyst
Big Data Engineer	Lean Facilitator	Project Controls Engineer
Business & Systems Integration Analyst	Lean Manufacturing Consultant	Project Engineer
Business Analyst	Lean Manufacturing Engineer	Project Manager
Business Operations Manager	Lean Manufacturing Manager	Project Quality Manager
Business Process Analyst	Lean Practitioner	Purchasing Manager
Business Process Management Manager	Lean/Six Sigma Projects Leader	Quality Assurance Engineer
Business Program Manager	Logistics Coordinator	Quality Engineer
Business Transformation Consultant	Logistics Engineer	Quality Manager
Compliance Manager	Logistics Method Analyst	Reliability Engineer
Continuous Improvement Analyst	Management Engineer	Risk Advisor
Continuous Improvement Coordinator	Manufacturing Engineer	Robust Design Engineer
Continuous Improvement Engineer	Manufacturing Manager	Safety Engineer
Core Product Engineer	Manufacturing Supervisor	Sales and Operations Strategy Consultant
Corporate Value Consultant	Manufacturing Systems Engineer	Six-Sigma Consultant
Data Analyst	Manufacturing Technology Analyst	Spend Analyst
Data Engineer	Methods Engineer	Supplier Quality Engineer
Data Modeler	Methods Process Analyst	Supply Chain Analyst
Data Scientist	Operations Analyst	Supply Chain Consultant
Demand Planner	Operations Consultant	Supply Chain Engineer
Demand Planning Manager	Operations Engineer	Supply Chain Lead
Design and Development Engineer	Operations Program Analyst	Supply Chain Management Consultant
Engineering Operations Manager	Operations Research Analyst	Supply Chain Manager
Enterprise Resource Planning Consultant	Performance Analyst	Supply Chain Operations Director
Ergonomics Engineer	Plant Manager	Supply Chain Project Manager
Facilities Engineer	Plant Operations Supervisor	Supply Network Design Planner
Facility Engineer	Process Control Analyst	Supply Planner
Facility Planner	Process Engineer	Systems Analyst
Field Engineer	Process Improvement Analyst	Systems and Data Analyst
Fleet Scheduler	Process Improvement Engineer	Systems Engineer
Functional Consultant	Process Improvement Manager	Systems Integration Engineer
Health Informatics Consultant	Procurement Analyst	Technology Analyst
Human Factors Engineer	Procurement Engineer	Transport Planner
Information Technology Analyst	Product Development Program Manager	Transportation or Freight Analyst
Information Technology Manager	Product Manager	Value Stream Manager
Injury Prevention and Ergonomics Lead	Production Control Analyst	Warranty Analyst
Integration & Innovation Director	Production Control Supervisor	Workforce Optimization Manager
Inventory Deployment Analyst	Production Engineer	
Investment Analyst	Production Scheduler	
		Total: 115 job titles

4.2.1 Repeated job titles

Table 10 shows 115 unique job titles. However, during the filtration process, some repetitions appeared. The excess repeated job titles were removed based on Table 8's exclusion criterion number 9, which was: "The data entry is a repetition of another data entry." However, it is worth noting these repetitions as part of the results. Examining the repetitions reveals which job titles are most associated with industrial engineering on the internet.

As can be seen in Table 11, 16 job titles were repeated. The different colour of each job title represents which data source it came from.

Each job title in Table 11 repeated in at least two of the data sources. Some of those repetitions were internal within one data source, while others repeated externally across all three of the data sources. For example, the job title "Supply Chain Analyst" was repeated internally and externally; it appeared twice during the filtration process from Zippia's website, and it also appeared on the other two websites.

Table 11: Repeated job titles

Business Analyst	Process Engineer	Supply Chain Analyst
Business Analyst	Process Engineer	Supply Chain Analyst
Business Analyst	Process Improvement Manager	Supply Chain Analyst
Data Scientist	Process Improvement Manager	Supply Chain Analyst
Data Scientist	Production Engineer	Supply Chain Manager
Demand Planner	Production Engineer	Supply Chain Manager
Demand Planner	Quality Engineer	Industrial Engineer
Logistics Engineer	Quality Engineer	Industrial Engineer
Logistics Engineer	Quality Engineer	Senior Industrial Engineer
Manufacturing Engineer	Quality Engineer	Senior Industrial Engineer
Manufacturing Engineer	Quality Manager	<div>Key</div> <div>Green Font - University of Washington</div> <div>Blue Font - Zippia</div> <div>Orange Font - Quora</div>
Manufacturing Engineer	Quality Manager	
Manufacturing Engineer	Quality Manager	
Manufacturing Manager	Reliability Engineer	
Manufacturing Manager	Reliability Engineer	

There were many more similar, but not identical, job titles in the final dataset of job titles in Table 10. These include job titles such as "Facilities Engineer" and "Facility Engineer", or "Quality Assurance Engineer" and "Quality Engineer." However, these were not excluded.

The job titles of "Industrial Engineer" and "Senior Industrial Engineer" in Table 11 did not feature in Table 10. These two job titles were removed based on Table 8's exclusion criterion number 1, which was: "The job title includes the term "industrial engineer" or "industrial engineering.""

4.2.2 Other job titles

An individual with an industrial engineering qualification could follow multiple career paths and adopt many job titles. Research Question 1 asked what these job titles could be. The array of job titles in Table 10 offered an answer to this question. However, there were other options of job titles that were excluded from Table 10 but are still possible job titles for the industrial engineer. These job titles need to be stated as part of the results to fully answer Research Question 1.

To start, the self-evident “Industrial Engineer” job title is discussed. Then, some other potential job paths for industrial engineering graduates are discussed.

4.2.2.1 The job title of “Industrial Engineer”

Job titles including the word “industrial engineer” or “industrial engineering” appeared often when searching for IE job titles. Some of these job titles indicated the rank or seniority of an industrial engineer, such as “Industrial Engineer Intern” or “Senior Industrial Engineer.” Others were more descriptive of a certain type of job, such as “Industrial Engineering Manager.” These job titles were all excluded based on Table 8’s exclusion criterion number 1, which was: “The job title includes the term “industrial engineer” or “industrial engineering.”” The reason for exclusion was to avoid redundancy and to focus on more specific job titles. However, the exclusion of these job titles does not mean that these are not possible job titles for an industrial engineer.

4.2.2.2 Academic job titles

Academic job titles included words such as “Professor”, “Instructor”, or “Researcher.” These job titles were excluded from the final dataset of job titles based on Table 8’s exclusion criterion number 3: “The job title is an academic position.” It is important to note that academic professions are valid and realistic career options for industrial engineers. However, they are not specific to or descriptive of the industrial engineering discipline (whereas all of the job titles that were included in Table 10 were).

4.2.2.3 Personal/entrepreneurial job titles

Personal/entrepreneurial job titles were excluded based on Table 8’s exclusion criterion number 4: “The job title is a personal or an entrepreneurial endeavour.” There was only one job title that was excluded on the basis of it being a personal/entrepreneurial job title: “Independent Researcher/Author.” However, this job title, among other personal entrepreneurial job titles, still represent potential job options for the industrial engineer.

4.3 Patterns

Many insights and patterns can be drawn from Table 10. Extracting these insights and patterns addresses Research Question 2, which was: “What patterns emerge from the job titles that are associated with industrial engineering on the internet?” To extract patterns, the job titles were first split up into Descriptor 1 terms and Descriptor 2 words, as per the preferred job title format in Section 3.2.2.1. Then, analytical text statistics were conducted on these words.

4.3.1 Descriptor 1 terms and words

Descriptor 1 terms were the first 1-3 words in each job title. They gave an indication of the job title’s **area of concern**.

There were 82 unique words in the Descriptor 1 terms (excluding the words “and” and “or”). Initially, collocated words were split up and counted separately, since most of them appeared in both their collocated and non-collocated forms. Thus, keeping them in their collocated form would have led to double counting or undercounting individual words. An example of this is the word “Supply”, which was often collocated with “Chain” to form “Supply Chain.” However, it also appeared in “Supply Network Design” and by itself as “Supply”. Counting “Supply” while considering its collocations would have led to it needing to be counted in its three forms: when collocated with “Chain”, when collocated with “Network Design”, or when by itself. For simplicity and consistency across all words, each word was counted as it appeared individually first.

Of the 82 words, some appeared only once, while others appeared ten times. The ones that repeated two or more times were graphed in Figure 10. All of the 82 words (even the ones that appeared only once) were visualized in the word cloud in Figure 11. The font sizes and the word frequencies have a direct correlation in the word cloud: the higher the frequency of the word, the bigger the font size of the word in the word cloud.

Collocations that appeared two or more times are noted in Figure 12. Other compound words that appeared only once were: Big Data, Core Product, Health Informatics, Human Factors, Injury Prevention, and Inventory Deployment.

Figures 10, 11, and 12 give a visual indication of the words that are most frequently associated with the areas of concern of Table 10’s IE job titles. From Figures 10 and 11, it can be seen that “Operations” and “Supply” were the most common words, appearing ten times each. Figure 12 shows that “Supply Chain” was the most common collocated term, appearing eight times. Figure 12 also shows some other common collocated terms that appeared three times each: Process Improvement, Continuous Improvement, and Lean Manufacturing.

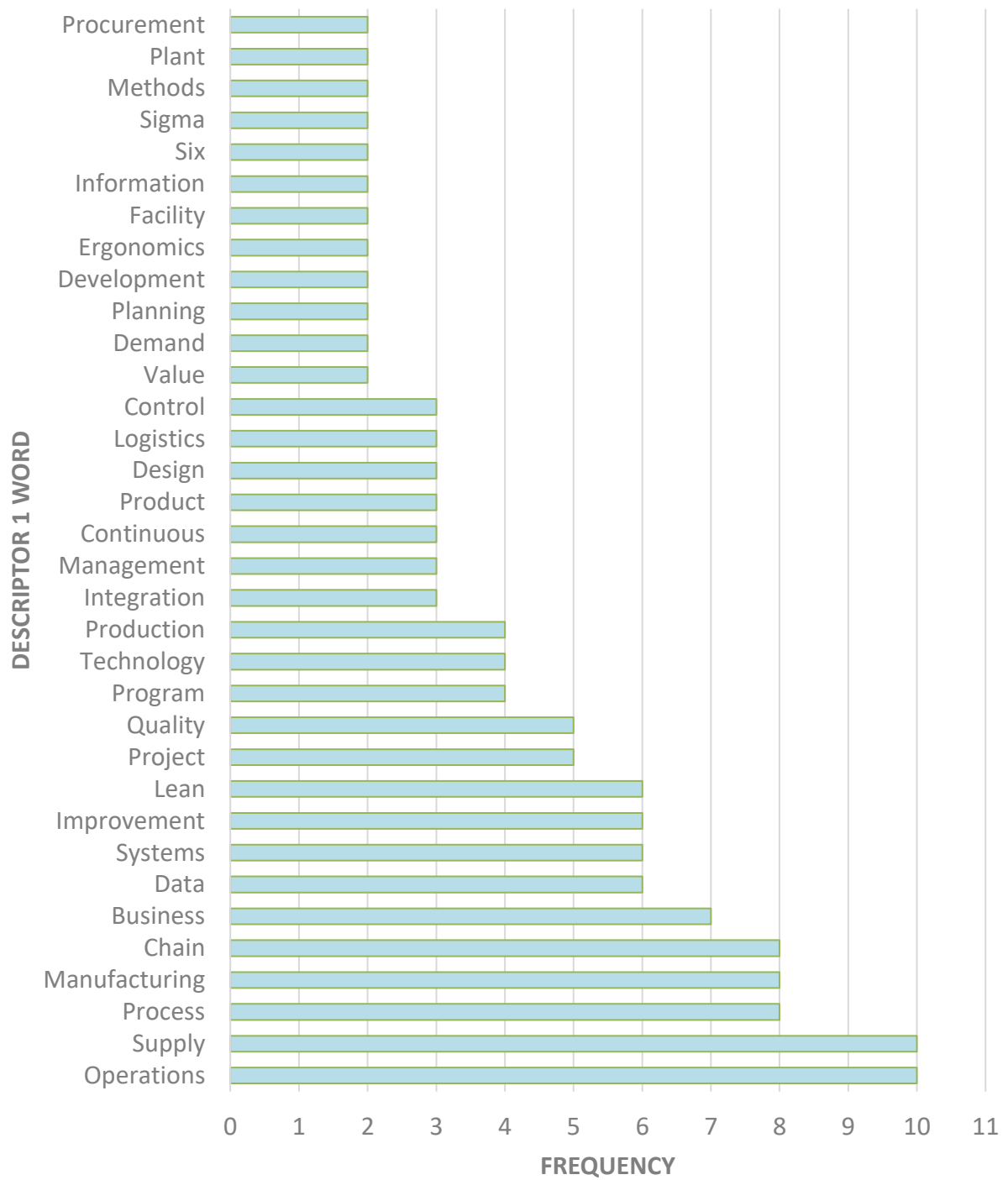


Figure 10: Frequencies of Descriptor 1 words



Figure 11: Word cloud of Descriptor 1 words

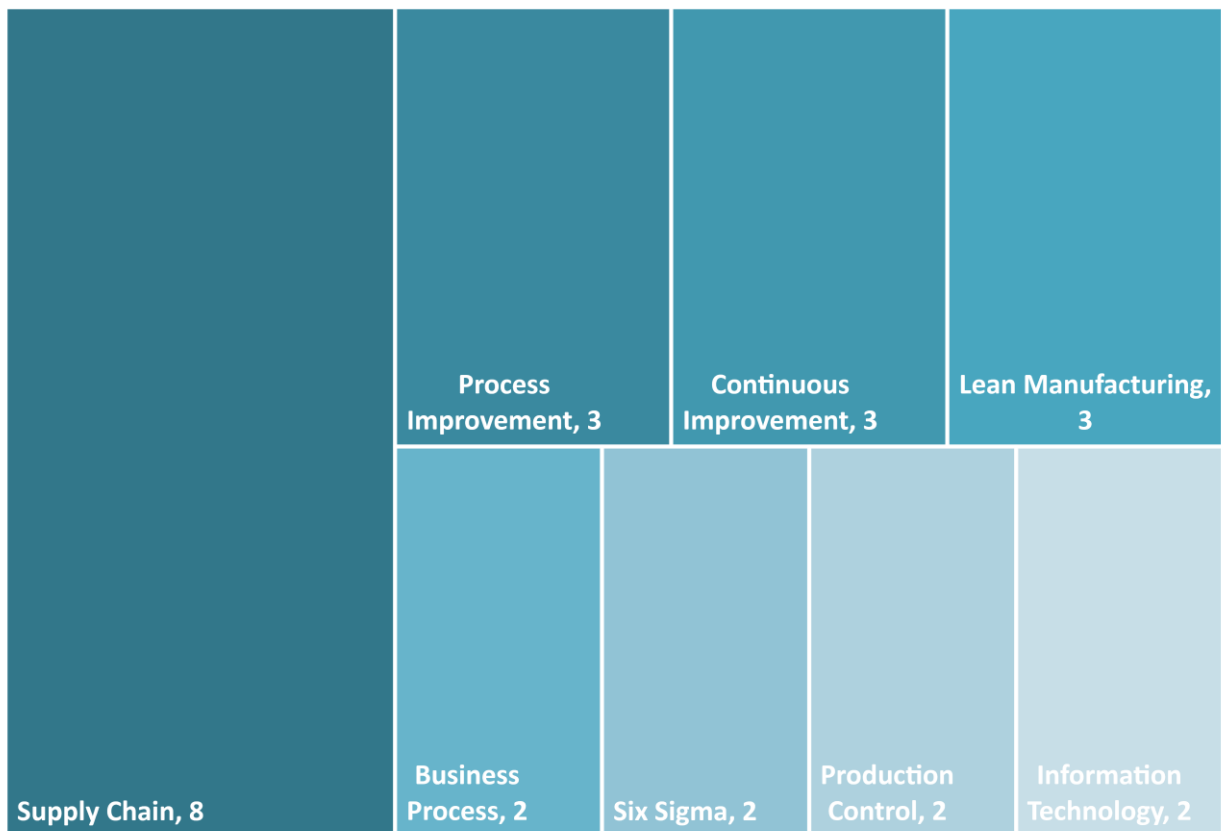


Figure 12: Collocated Descriptor 1 words with their frequencies

4.3.2 Descriptor 2 words

Descriptor 2 words were the last word in each job title. They gave an indication of the job title's **role or function**.

There were 17 unique words in the Descriptor 2 words (which is much lower in quantity and variation than the 82 Descriptor 1 words). These words, along with their frequencies, were graphed in Figure 13. They were also visualized in the word cloud in Figure 14.

Of the 17 words, 11 appeared once or twice. These words were: Coordinator, Scheduler, Lead, Leader, Director, Modeler, Scientist, Officer, Facilitator, Practitioner, and Advisor. The six remaining words with the highest frequencies were: Engineer, Analyst, Manager, Consultant, Planner, and Supervisor.

“Engineer”, “Analyst”, and “Manager” had notably high frequencies. “Manager” had a frequency of 21, which was almost double the frequency of “Consultant” with the next highest frequency of 11. Expectedly, “Engineer” had the highest frequency. “Engineer”, with a frequency of 33, was thrice the frequency of “Consultant.” “Consultant” also had a relatively high frequency (11) when compared to “Planner” as the next highest frequency (5).

The relative frequency percentages of the top five most frequent terms are as follows:

- Engineer: 29%
- Analyst: 23%
- Manager: 18%
- Consultant: 10%
- Planner: 4%

“Engineer”, “Analyst”, “Manager”, “Consultant”, “Planner”, “Director”, “Lead”, “Coordinator”, and “Planner” all appeared in at least two of the data sources. In fact, “Engineer”, “Analyst”, “Consultant”, and “Planner” appeared in all three of the data sources. Despite the varying frequencies of these words, the fact that they appeared in at least two of the data sources indicates that they are prevalently recognized as part of the job potential of the industrial engineer.

When examining the Descriptor 2 words, it becomes evident that many of the words are similar or related. Some are similar enough to be considered as synonyms. However, many of the words have different meanings and implications. These observations guide into the next section of the dissertation, which discusses possible ways to categorise the IE job titles. The categorisations were built off the Descriptor 1 words, the Descriptor 2 words, or the Descriptor 1 and 2 words combined.

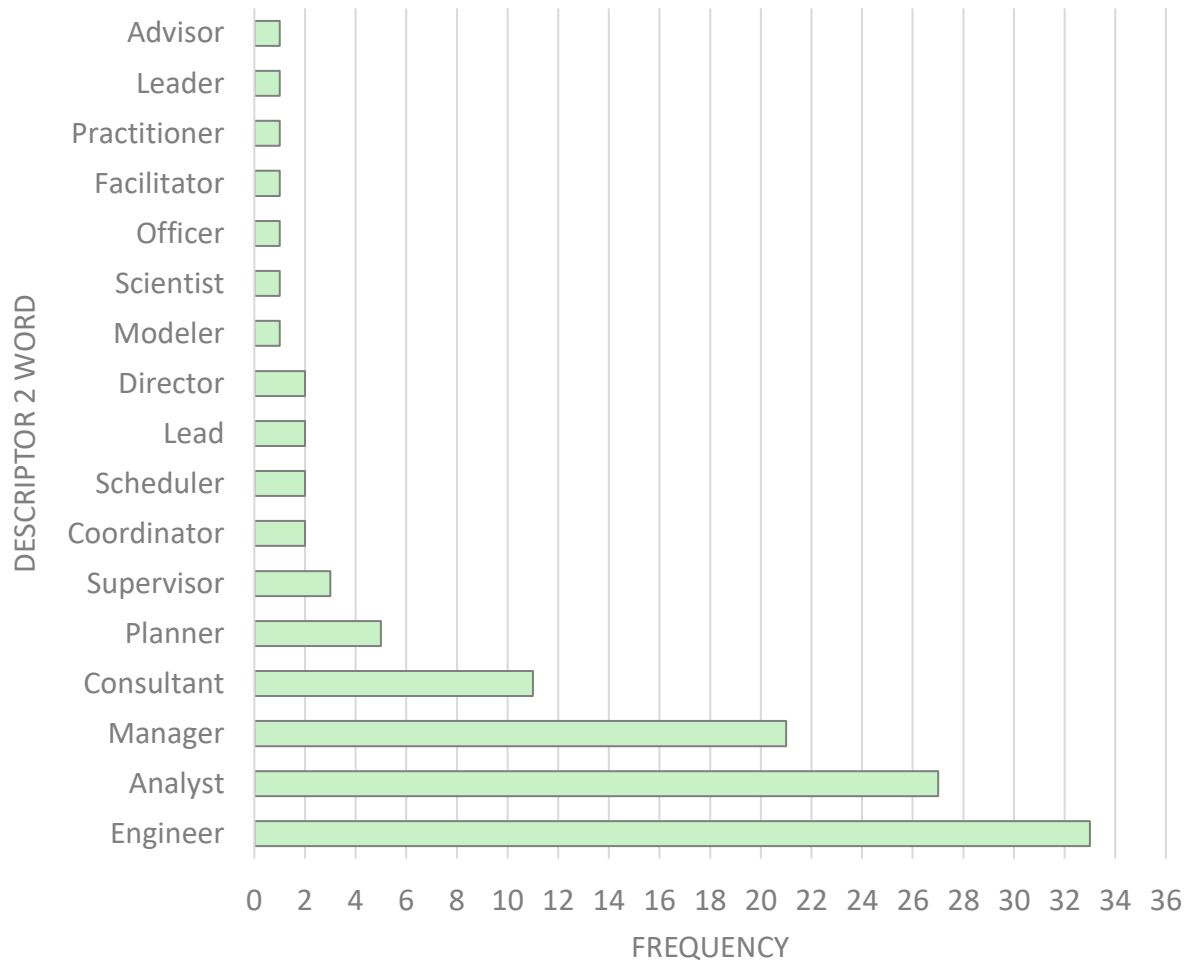


Figure 13: Frequency of Descriptor 2 words

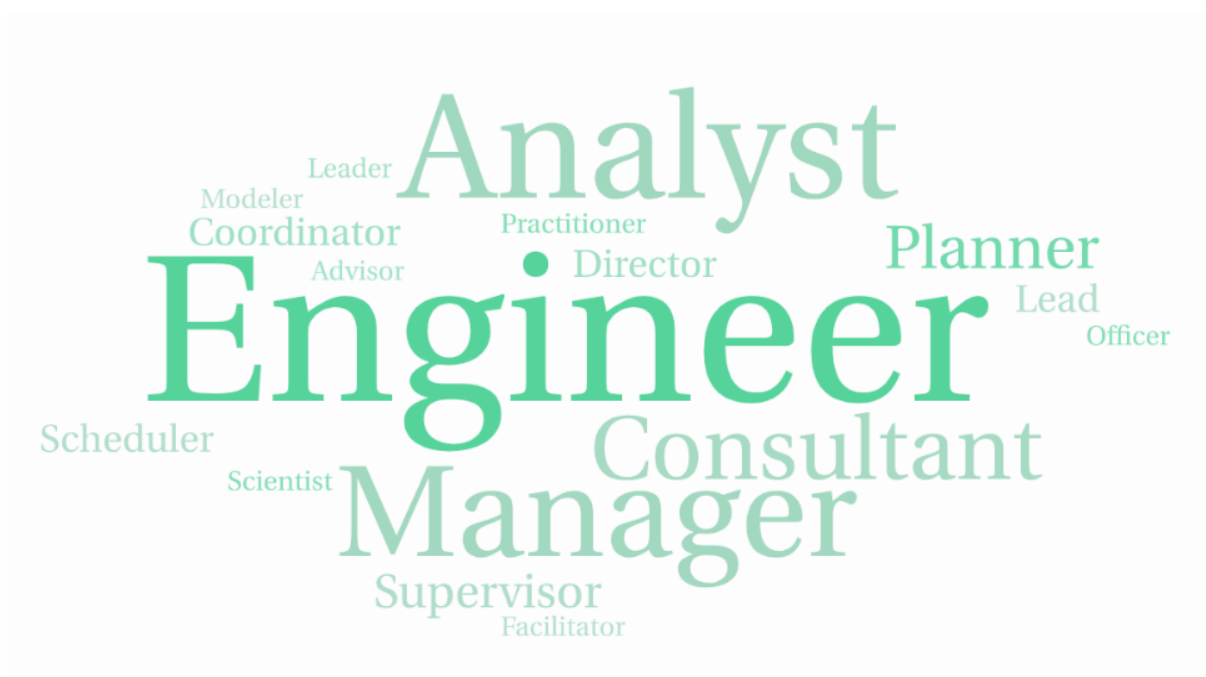


Figure 14: Word cloud of Descriptor 2 words

4.3.3 Indicators of saturation

There have been several indicators of saturation in the results, based on the saturation criteria in Table 9. The first of these criteria was: “The data was triangulated from at least three different sources with different perspectives.” This criterion was already met in the data collection stage. The second of these criteria was: “There is at least one job title to represent each knowledge area in the IEBoK.” The meeting of this criterion can be seen in Figure 15, which shows two examples of job titles to represent each knowledge area in the IEBoK.

Work Design and Measurement	<ul style="list-style-type: none">•Methods Engineer•Methods Process Engineer	Supply Chain Management	<ul style="list-style-type: none">•Supply Chain Manager•Logistics Engineer
Operations Research and Analysis	<ul style="list-style-type: none">•Operations Research Analyst•Operations Consultant	Engineering Management	<ul style="list-style-type: none">•Management Engineer•Project Manager
Engineering Economic Analysis	<ul style="list-style-type: none">•Procurement Engineer•Spend Analyst	Safety	<ul style="list-style-type: none">•Risk Advisor•Safety Engineer
Facilities Engineering and Energy Management	<ul style="list-style-type: none">•Facilities Engineer•Plant Manager	Information Engineering	<ul style="list-style-type: none">•Data Analyst•Enterprise Resource Planning Consultant
Quality and Reliability Engineering	<ul style="list-style-type: none">•Quality Manager•Reliability Engineer	Design and Manufacturing Engineering	<ul style="list-style-type: none">•Manufacturing Manager•Design and Development Engineer
Ergonomics and Human Factors	<ul style="list-style-type: none">•Ergonomics Engineer•Human Factors Engineer	Product Design and Development	<ul style="list-style-type: none">•Product Manager•Robust Design Engineer
Operations Engineering and Management	<ul style="list-style-type: none">•Engineering Operations Manager•Business Transformation Consultant	System Design and Engineering	<ul style="list-style-type: none">•Systems Engineer•System Integration Analyst

Figure 15: IEBoK knowledge area categories and examples of job titles

The third saturation criterion was: “The data repeats itself often within and/or across the different sources.” This criterion was illustrated in Section 4.2.1. The fourth criterion was: “There is enough data to address the research aim and research questions.” This criterion was demonstrated throughout the Results & Analysis and Discussion chapters.

4.4 Categorisations

Although each job title that was included in the final dataset was unique and different, there were still many similarities between the job titles. Thus, the job titles could be grouped together into job categories based on their similarities. To do this, text classification was used. Each word was tagged with one or more tag words as part of classifying the data. Then, the job titles were grouped into organized categories based on similarities in these tags.

Up until this stage of the Results & Analysis Chapter, only quantitative results were shown (such as the analytical text statistics in Figures 10 and 13). In this section, qualitative results are shown too, because they were based on insights and meanings. There was also a degree of subjective analysis and interpretation from the inductive reasoning of the researcher. Thus, the categorisations provided are not meant to be considered absolute or objective. Rather, they are one perspective on how to categorise the IE job titles. The reasoning behind the categorisations is explained and preliminarily discussed throughout the sections.

To start the job categorisation process, Descriptor 1 words and Descriptor 2 words were categorised separately. Then, the categorisations of the two parts were combined. These categorisations answer Research Question 3, which was: “How can the job titles that are associated with industrial engineering on the internet be categorised and visualized?”

4.4.1 Job categories based on job function

Creating categories of the Descriptor 2 words was simpler than creating categories for the Descriptor 1 words. It was simpler because there were fewer Descriptor 2 words than Descriptor 1 words. There was also much more repetition and similarity between the Descriptor 2 words, supporting the categorisation process.

“Engineer”, “Analyst”, “Manager”, and “Consultant” were the most frequently occurring words in the Descriptor 2 parts of the job titles. Combined, these words made up 80% of the Descriptor 2 words. As such, they were a convenient starting point to creating job categories based on similarity in job role/function.

“Planner”, having the 5th highest frequency, was also considered as a job category. However, the job function of planning overlaps heavily with the job functions of engineering, analysis, management, and consulting. Also, there were only five job titles with the word “Planner”; four of those job titles related to supply chain concepts (supply, demand, and transport). Thus, “Planner” was not deemed significant enough to become its own job category, due to the relatively low frequency, low variety, and lack of distinctness. The remaining Descriptor 2 words were not considered significant enough to become their own job categories for similar reasons.

The creation of the job categories was not only based on the high frequencies of the top four words, but also the meaning of each word. Each word was distinct enough to justify the creation of its own category instead of being grouped with another category. To illustrate the distinctness, Table 12 shows how each job category differs in terms of meaning (in an industrial engineering context). The meanings/synonyms were extracted from www.theasaurus.com. Logical reasoning was used to choose synonyms (or synonyms of synonyms) that best described the industrial engineering job functions or roles for each category. Also, logical reasoning and literature were used to provide an example of a job task for each job category. Examples were provided to further illustrate the differences between the job categories.

Table 12: Job function categories

Job category	Meaning/synonym	Example of job task
Engineer	Designer, builder, creator	The design and creation of a simulation model for a factory.
Analyst	Examiner, inspector, investigator	The collection and analysis of data on production efficiency.
Manager	Supervisor, director, officer, leader, conductor, controller	The implementation of a supply chain strategy.
Consultant	Advisor, guide, instructor	The detection and resolution of issues on the factory floor.

When examining the synonyms of the job categories in Table 12, it became evident that many of these synonyms were part of the results of the Descriptor 2 words. For example, the words “Advisor”, “Supervisor”, “Director”, “Officer”, and “Leader” all appeared in the Descriptor 2 words. As such, they could be grouped under their respective overarching job categories in Table 12. These groupings, along with an explanation of the relationships and examples of similar job titles from the results, can be seen in Table 13.

Table 13 also shows other ways that the Descriptor 2 words were categorised based on their relationships. This way was to investigate which Descriptor 1 words were part of the Descriptor 2 words. For example, both the words “Scientist” and “Modeler” appeared only once in the dataset. Their Descriptor 1 words were both “Data.” The word “Data” only showed up otherwise with “Engineer” and “Analyst.” Thus, “Scientist” and “Modeler” could potentially be grouped with “Engineer” or “Analyst.” It was decided to group these words with “Engineer”, as they seemed to be more compatible with the engineering function of designing and creating, among other reasons explained in Table 13. Table 13 shows the categorisations that were chosen going forward in this dissertation, with examples of the IE job titles (from Table 10) in each category.

Table 13: Job categories and their relationships

Job category	Related job role	Explanation of relationship	Examples
Engineer	Modeler	Engineers often design or build models of their work before real-world implementation.	Data Modeler
	Scientist		Data Scientist Data Engineer
Analyst	Planner	Planning and scheduling are both related to analysis. Also, plans and schedules are the product of organization-related analysis.	Transport Planner
	Scheduler		Fleet Scheduler Transportation or Freight Analyst
Manager	Supervisor	These job functions are all closely related to management. They have similar roles in that they oversee processes and guide their direction. They also represent leadership and high-level decision-making, which is characteristic of managers.	Production Control Supervisor
	Coordinator		Logistics Coordinator
	Officer		Supply Chain Operations Director
	Director		Supply Chain Lead
	Lead		Supply Chain Project Manager
	Leader		Kaizen Promotion Officer
	Facilitator	A facilitator and practitioner are similar to a manager in that both hold the responsibility to execute something.	Lean/Six Sigma Projects Leader
	Practitioner		Lean Facilitator
			Lean Practitioner Lean Manufacturing Manager
Consultant	Advisor	An advisor and a consultant both provide expert advice to improve a situation.	Risk Advisor
			Corporate Value Consultant

Table 13 can be used as a foundation for creating job categories based on job role/function. If each word in the “Related job function column” is categorised by its corresponding word in the “Job category” column of Table 13, then the job titles can be visualized in a more condensed and organized way than they were in Table 10. Table 14 shows how the job titles can be categorised based on similarities in job role/function. Each block is titled by its main job category (Engineer, Analyst, Manager, and Consultant) and the block is filled with the corresponding job titles.

Table 14: Job categories from the perspective of job function

Engineer		Analyst	
Automation Engineer	Methods Engineer	Business Analyst	Performance Analyst
Big Data Engineer	Operations Engineer	Business & Systems Integration Analyst	Process Control Analyst
Continuous Improvement Coordinator	Process Engineer	Business Process Analyst	Process Improvement Analyst
Core Product Engineer	Process Improvement Engineer	Continuous Improvement Analyst	Procurement Analyst
Data Engineer	Procurement Engineer	Data Analyst	Production Scheduler
Data Modeler	Production Engineer	Demand Planner	Production Control Analyst
Data Scientist	Project Engineer	Facility Planner	Program Analyst
Design and Development Engineer	Project Controls Engineer	Fleet Scheduler	Spend Analyst
Ergonomics Engineer	Quality Engineer	Information Technology Analyst	Supply Planner
Facilities Engineer	Quality Assurance Engineer	Inventory Deployment Analyst	Supply Chain Analyst
Facility Planner	Reliability Engineer	Investment Analyst	Supply Network Design Planner
Field Engineer	Robust Design Engineer	Logistics Method Analyst	Systems Analyst
Human Factors Engineer	Safety Engineer	Manufacturing Technology Analyst	Systems and Data Analyst
Lean Manufacturing Engineer	Supplier Quality Engineer	Methods Process Analyst	Technology Analyst
Logistics Engineer	Supply Chain Engineer	Operations Analyst	Transport Planner
Management Engineer	Systems Engineer	Operations Program Analyst	Transportation or Freight Analyst
Manufacturing Engineer	Systems Integration Engineer	Operations Research Analyst	Warranty Analyst
Manufacturing Systems Engineer			
Manager		Consultant	
Business Operations Manager	Manufacturing Supervisor	Business Transformation Consultant	
Business Process Management Manager	Plant Manager	Corporate Value Consultant	
Business Program Manager	Plant Operations Supervisor	Enterprise Resource Planning Consultant	
Compliance Manager	Process Improvement Manager	Functional Consultant	
Continuous Improvement Coordinator	Product Manager	Health Informatics Consultant	
Demand Planning Manager	Product Development Program Manager	Lean Manufacturing Consultant	
Engineering Operations Manager	Production Control Supervisor	Operations Consultant	
Information Technology Manager	Project Manager	Risk Advisor	
Injury Prevention and Ergonomics Lead	Project Quality Manager	Sales and Operations Strategy Consultant	
Integration & Innovation Director	Purchasing Manager	Six-Sigma Consultant	
Kaizen Promotion Officer	Quality Manager	Supply Chain Consultant	
Lean Facilitator	Supply Chain Lead	Supply Chain Management Consultant	
Lean Practitioner	Supply Chain Manager		
Lean Manufacturing Manager	Supply Chain Operations Director		
Lean/Six Sigma Projects Leader	Supply Chain Project Manager		
Logistics Coordinator	Value Stream Manager		
Manufacturing Manager	Workforce Optimization Manager		

4.4.2 Job categories based on areas of concern

As was uncovered in the Results & Analysis Chapter, there were many more Descriptor 1 words than there were Descriptor 2 words (82 vs 17 words, respectively). There was also more variety in the Descriptor 1 words than the Descriptor 2 words. Therefore, categorising the Descriptor 1 words was not as straightforward as categorising the Descriptor 2 words. Rather than using frequency as the starting point for categorisation (as was done for the Descriptor 2 words), other means of categorisation were considered for the Descriptor 1 terms.

The following sections briefly explore the different types of Descriptor 1 terms and some potential ways that were considered to categorise them. All examples were taken from the IE job titles presented in Table 10.

4.4.2.1 Area of concern: knowledge area

Many of the Descriptor 1 words represented a certain type of knowledge area. These were words such as “Business”, “Management”, “Manufacturing”, and “Ergonomics.”

By categorising job titles based on their knowledge areas, the area of concern would be a certain type of knowledge. The unifying element behind each category becomes the theoretical knowledge behind each title rather than the type of practical application it can have.

The IEBoK (or any other knowledge-based categorisation of industrial engineering) can be used to illustrate this type of categorisation. A sample of an IEBoK-based categorisation can be seen in Figure 15 of Section 4.3.3. This figure shows 14 knowledge areas (and thus categories) in which the job titles could be placed.

Another example of how the job titles could be categorised based on knowledge areas could be by using the knowledge areas presented in Figure 4 in the Literature Review. A sample of this categorisation would be as follows:

Table 15: Knowledge area categorisations

Knowledge area (Salvendy, 2001)	Examples of job titles
Operations Research	Operations Research Analyst, Operations Engineer
Human Factors Engineering	Human Factors Engineer, Ergonomics Engineer
Management Systems	Management Engineer, Business Operations Manager
Manufacturing Systems Engineering	Manufacturing Systems Engineer, Automation Engineer

4.4.2.2 Area of concern: resource

The industrial engineering definition mentions several types of resources that industrial engineers deal with, such as people, materials, information, equipment, and energy. Some other resources (derived from the Descriptor 1 words) are: money, facilities, and vehicles.

Job titles could be grouped based on which resources form an industrial engineer's area(s) of concern. This type of grouping is illustrated in Table 16.

Table 16: Job categories based on resources

Resource(s)	Examples of job titles
People	Ergonomics Engineer
	Workforce Optimization Manager
	Human Factors Engineer
Materials	Demand Planning Manager
	Supply Planner
	Inventory Deployment Analyst
Information	Big Data Engineer
	Information Technology Manager
	Technology Analyst
Facilities, energy, and equipment	Plant Manager
	Field Engineer
	Facility Planner
Money	Spend Analyst
	Purchasing Manager
	Procurement Engineer
Vehicles	Fleet Scheduler
	Transport Planner
	Transportation or Freight Analyst

4.4.2.3 Area of concern: activity

Instead of viewing job titles as being concerned with a certain knowledge area or resource, one could also view them as being concerned with a certain activity. For example, from Table 16's examples of job titles concerned with money, a Purchasing Manager and a Procurement Analyst would be concerned with the activities of purchasing and procurement, respectively. In the Materials row, a Demand Planning Manager and Inventory Deployment analyst would be concerned with the activities of demand planning and inventory deployment, respectively.

Some other examples of activity-focused job titles are:

- **Process Improvement** Engineer
- **Integration & Innovation** Director
- **Design and Development** Engineer
- **Automation** Engineer

In these examples, the activity part is bolded.

4.4.2.4 Area of concern: result/approach

Similar to activity-focused job titles, some job titles are focused on trying to achieve a certain result or apply a certain approach. In these jobs, the industrial engineer is trying to achieve a goal, reach a certain metric, maintain a certain standard, or abide by a certain philosophy/approach.

Some examples of result/approach-focused job titles are:

- **Safety** Engineer
- **Systems Integration** Engineer
- **Quality Assurance** Engineer
- **Reliability** Engineer
- **Workforce Optimization** Manager
- **Compliance** Manager
- **Kaizen Promotion** Officer
- **Continuous Improvement** Coordinator
- **Lean/Six Sigma Projects** Leader
- **Lean Manufacturing** Consultant

In the bulleted examples of job titles, the result/approach part is bolded.

4.4.2.5 Area of concern: scope

Words such as “Operation”, “Process”, and “System” were some of the most commonly occurring words in the Descriptor 1 parts of the job titles. In fact, “Operations” was the most commonly occurring one. It is common to describe industrial engineering using these words because industrial engineering is often concerned with abstract concepts. What differentiates one industrial engineer from another could be the scope of their concern.

Figure 16 illustrates how industrial engineers could be working at different scopes or levels.

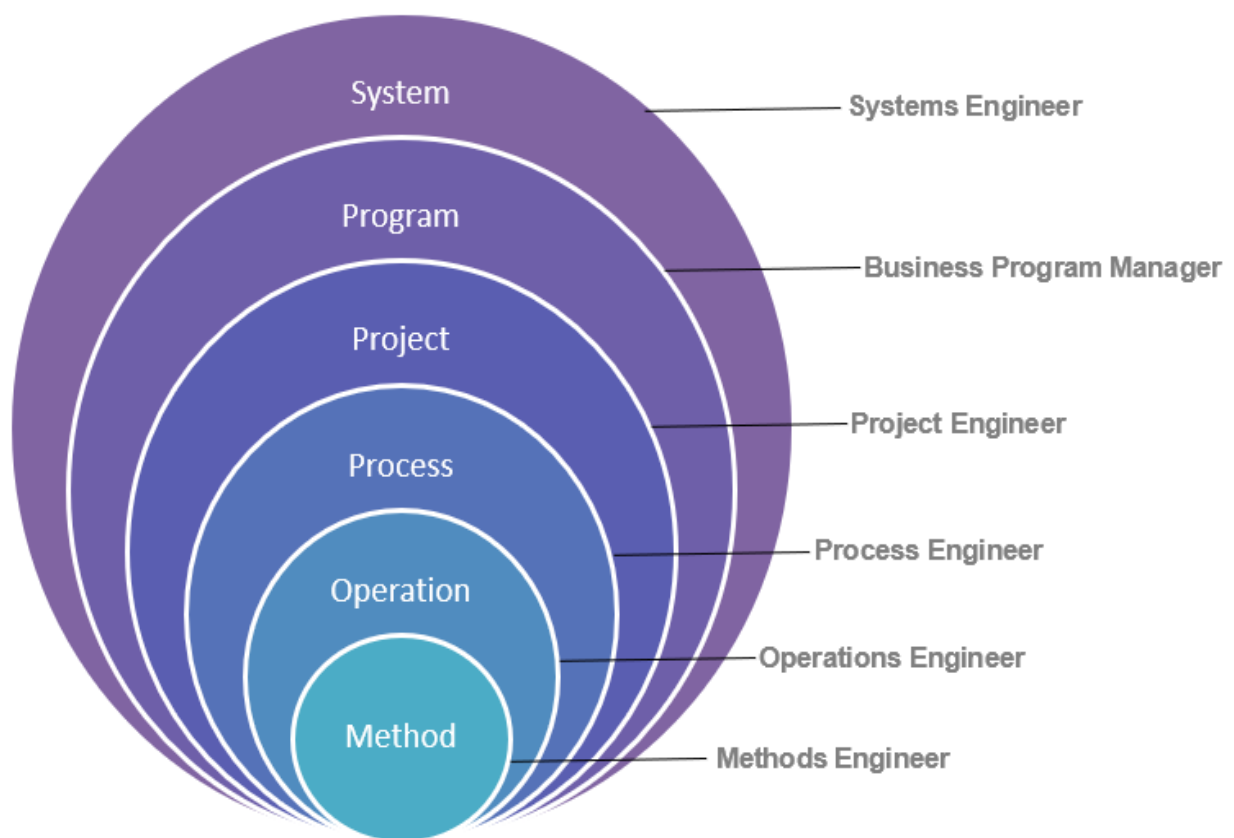


Figure 16: Scope categories and examples of job titles

The boundaries of Figure 16 should be viewed as malleable, given that each level in the hierarchy is abstract and could be defined in a different way depending on the context. Thus, the hierarchy shown is subject to variation and overlaps. An example of a variation would be that, in certain contexts, a “project” could be placed at a higher level than a “program.” Examples of overlaps would be with job titles such as “Methods Process Analyst” or “Operations Program Analyst”, where each job title is concerned with multiple scopes/levels at the same time.

4.4.2.6 Job categories based on areas of concern: revisited

Thus far in Section 4.4.2, several ways to categorise the Descriptor 1 terms have been displayed. These categories were provided to showcase possibilities of categorisations and to depict the multi-faceted nature of the IE job titles. However, each method of categorisation highlighted industrial engineering from only one angle. Furthermore, each category type could not encompass all the job titles. Thus, to categorise all of the job titles, a new way of categorisation was chosen. This way combined several of the ways suggested previously. The main basis for categorisation was similarities in the most prominent Descriptor 1 terms.

When examining the Descriptor 1 terms, many similarities could be found. These similarities could be in the meaning, type, or relationships of the words.

Some examples of Descriptor 1 words that are similar in terms of their meaning are:

- “Procurement” and “Purchasing”
- “Data” and “Information”
- “Transportation”, “Transport”, and “Freight”
- “Kaizen” and “Continuous Improvement” (Kaizen is Japanese for “continuous improvement”)

Some examples of words that are similar in type or relation are:

- “Lean”, “Six Sigma”, and “Continuous Improvement”
- “Quality”, “Reliability”, and “Safety”
- “Business” and “Management”
- “Logistics”, “Demand”, “Inventory”, “Transportation”, and “Supply Chain”

After examining the Descriptor 1 words for their similarities and relationships, ten categories were created to reflect areas of concern. These categories, along with examples of job titles in each category, are depicted in Table 17.

For most of the job titles, the area of concern was evident from the job title itself. Most of the job titles included the same words as the title of their category. For example, the “Reliability Engineer” was placed in the “Quality/Reliability/Safety” category. Other jobs were more ambiguous or flexible and required extra research to uncover their area(s) of concern. For example, an “Enterprise Resource Planning Consultant” interfaces with two categories: “Business/Management” and “Data/Information/Technology.” Job titles that evidently fit into multiple categories were placed into multiple categories. Although there may be more overlaps between the categories, the categorisation was kept as straightforward and distinct as possible.

Table 17: Job categories based on area(s) of concern (continued on the next page)

Business/Management	Data/Information/Technology
Business & Systems Integration Analyst Business Analyst Business Operations Manager Business Process Analyst Business Process Management Manager Business Program Manager Business Transformation Consultant Corporate Value Consultant Enterprise Resource Planning Consultant Management Engineer Performance Analyst Value Stream Manager Workforce Optimization Manager	Big Data Engineer Data Analyst Data Engineer Data Modeler Data Scientist Enterprise Resource Planning Consultant Functional Consultant Health Informatics Consultant Information Technology Analyst Information Technology Manager Manufacturing Technology Analyst Systems and Data Analyst Technology Analyst
Quality/Reliability/Safety	Lean/Six-Sigma/Continuous Improvement
Quality Assurance Engineer Quality Engineer Quality Manager Reliability Engineer Risk Advisor Safety Engineer Warranty Analyst Injury Prevention and Ergonomics Lead Project Quality Manager Supplier Quality Engineer Compliance Manager Health Informatics Consultant	Continuous Improvement Analyst Continuous Improvement Coordinator Continuous Improvement Engineer Kaizen Promotion Officer Lean Facilitator Lean Manufacturing Consultant Lean Manufacturing Engineer Lean Manufacturing Manager Lean Practitioner Lean/Six Sigma Projects Leader Six-Sigma Consultant
Manufacturing/Production	
Automation Engineer Core Product Engineer Manufacturing Engineer Manufacturing Manager Manufacturing Supervisor Manufacturing Systems Engineer Manufacturing Technology Analyst Product Manager Production Control Analyst Production Control Supervisor	Production Engineer Production Scheduler Robust Design Engineer Design and Development Engineer Lean Manufacturing Consultant Lean Manufacturing Engineer Lean Manufacturing Manager Product Development Program Manager Integration & Innovation Director Performance Analyst

The numbers of job titles in each category are as follows: Manufacturing/Production (20), Business/Management (13), Data/Information/Technology (13), Quality/Reliability/Safety (12), Lean/Six-Sigma/Continuous Improvements (11).

Table 17: Job categories based on area(s) of concern (started on the previous page)

Method/Process/Operation/System/Project	
Engineering Operations Manager Methods Engineer Methods Process Analyst Operations Analyst Operations Consultant Operations Engineer Operations Program Analyst Operations Research Analyst Plant Operations Supervisor Process Control Analyst Process Engineer Process Improvement Analyst Business & Systems Integration Analyst Business Operations Manager Business Process Analyst Business Process Management Manager Business Program Manager Performance Analyst	Process Improvement Engineer Process Improvement Manager Program Analyst Project Controls Engineer Project Engineer Project Manager Project Quality Manager Sales and Operations Strategy Consultant Systems Analyst Systems and Data Analyst Systems Engineer Systems Integration Engineer Manufacturing Systems Engineer Plant Operations Supervisor Supply Chain Operations Director Supply Chain Project Manager Integration & Innovation Director Value Stream Manager
Supply Chain/Logistics	Ergonomics/Human Factors
Demand Planner Demand Planning Manager Fleet Scheduler Inventory Deployment Analyst Logistics Coordinator Logistics Engineer Logistics Method Analyst Supplier Quality Engineer Supply Chain Analyst Supply Chain Consultant Value Stream Manager Supply Chain Engineer Supply Chain Lead Supply Chain Management Consultant Supply Chain Manager Supply Chain Operations Director Supply Chain Project Manager Supply Network Design Planner Supply Planner Transport Planner Transportation or Freight Analyst	Ergonomics Engineer Human Factors Engineer Injury Prevention and Ergonomics Lead
	Facility/Field/Plant
	Facilities Engineer Facility Engineer Facility Planner Field Engineer Plant Manager
	Procurement/Purchasing/Investment
	Investment Analyst Procurement Analyst Procurement Engineer Purchasing Manager Spend Analyst

The numbers of job titles in each category are as follows:

Method/Process/Operation/System/Project (36), Supply Chain/Logistics (21), Facility/Field/Plant (5), Procurement/Purchasing/Investment (5), Ergonomics/Human Factors (3).

4.4.3 Combining the categories

Research question 3 asked: “How can the job titles that are associated with industrial engineering on the internet be categorised and visualized?” Tables 14 and 17 directly answered the categorisation part of the question. They also had a visual element to them, given that the tables themselves are visual representations of the job titles. However, another way to visualize the job titles can be created by combining the categories of Tables 14 and 17.

The categorisations that were created in Tables 14 and 17 could be combined since they have overlapping elements. To combine them, the Descriptor 1 categories of Table 17 were compared against the Descriptor 2 categories of Table 14. The results of this comparison are summarised in Figure 17.

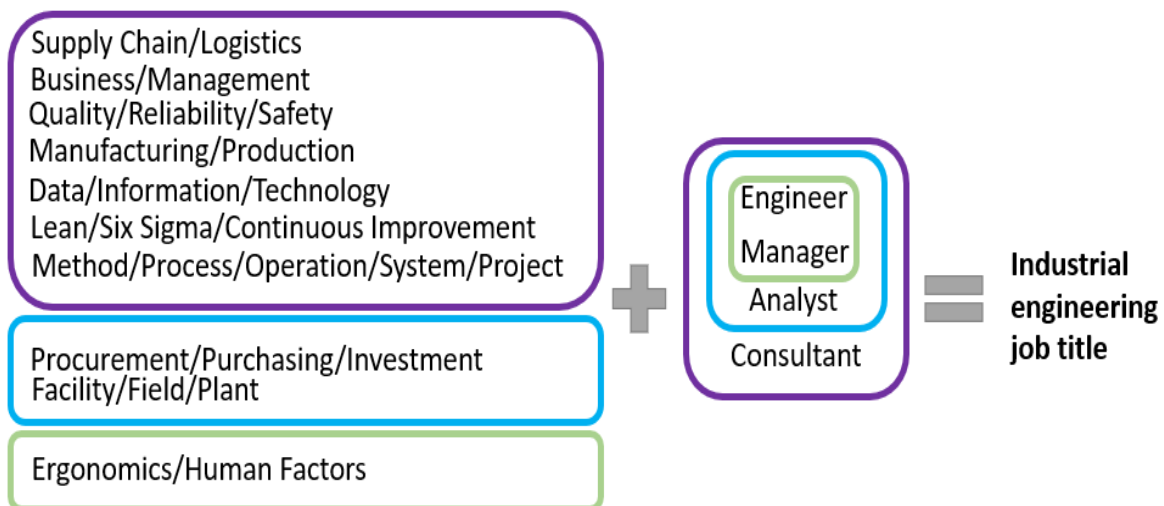


Figure 17: Summary of Descriptor 1 and Descriptor 2 categories combined

Figure 17 shows which Descriptor 1 categories appeared with which Descriptor 2 categories. Correspondences were shown by the coloured borders. For example, the purple border that encompasses seven of the Descriptor 1 categories coincided with all four of the Descriptor 2 categories. As another example, the “Ergonomics/Human Factors” category coincided only with the “Engineer” and “Manager” categories, as is indicated by their mutual green borders.

Figure 17 succinctly summarises the Results & Analysis Chapter. The chapter started by sharing a sample of 115 IE job titles. These job titles were then deconstructed into two parts: Descriptor 1 terms and Descriptor 2 words. Afterwards, the terms and words were inspected for patterns by using analytical text statistics. The patterns were then used to create job categories for the two parts of the job titles. Finally, the categories of the two parts were combined, to generate the summarizing diagram of Figure 17.

4.4.4 Reliability assessment

As was mentioned in Section 3.3.2 of the Methodology Chapter, the same methodology was repeated with the excluded data sources of Appendix A to assess reliability. The raw data of this second iteration of web-scraping can be seen in Appendix I. The filtration processes can be seen in Appendices J and K. The list of job titles after filtration can be seen in Table 18.

Table 18: Second iteration of web-scraping with repetitions

Facilities Engineer	Systems Engineer	Materials Engineer
Logistics Coordinator	Automation Engineer	Occupational Health and Safety Technician
Logistics Engineer	Compliance Engineer	Packaging Engineer
Management Engineer	Controls Engineer	Performance Engineer
Manufacturing Engineer	Cost Engineer	Plant Engineer
Operations Analyst	Cost Estimator	Process Control Engineer
Operations Engineer	Design Engineer	Process Design Engineer
Process Engineer	Efficiency Engineer	Process Engineering Manager
Production Engineer	Engineering Director	Product Engineer
Project Controls Engineer	Field Service Engineer	Production Manager
Project Engineer	Health and Safety Engineer	Proposal Engineering Coordinator
Quality Engineer	Industrial Production Manager	Quality Control Inspector
Reliability Engineer	Maintenance Engineer	Test Engineer
Supply Chain Analyst	Management Analyst	Tooling Engineer
Supply Chain Consultant	Manufacturing Engineering Manager	Validation Engineer
Key		
Blue highlight and dark blue font	Exact repetitions of job titles	
Black font	Unique words	
Orange font	Repetitions of Descriptor 1 words	
Green font	Repetitions of Descriptor 2 words	

To assess reliability, Table 18 also shows where there were repetitions between the results of the first iteration of web-scraping (shown in Table 10) and this second iteration of web-scraping (shown in Table 18). Some job titles were repeated fully, while others repeated in part.

Of the 45 job titles shown in Table 18, 17 (38%) were exact repetitions of the job titles shown in Table 10. Of the remaining 28 job titles, 27 (96%) had at least one word that was repeated in the job titles shown in Table 10. The only job title that was unique and did not share any repeated words was “Cost Estimator.” Thus, out of 45 job titles, 44 job titles (97%) shared at least one word with the words of Table 10.

Some unique words were “Validation”, “Maintenance”, and “Technician.” These words, among the other unique words and variations of job titles, add more dimensionality to the job potential of the industrial engineer. However, in terms of assessing overall reliability, there was significant similarity between Tables 10 and 18. Thus, the results of this research seem to reliably represent the job potential of the industrial engineer.

4.5 Summary of results

The results can be summarized within the context of the Research Questions:

- **Answer to Research Question 1 (What job titles are associated with the industrial engineering discipline on the internet?):** It was found that there were 115 unique job titles that were associated with the industrial engineering discipline on the internet. These job titles can be seen in Table 10. Some job titles repeated often, while others were rarer (Section 4.2.1). There were also some job titles that could be indirectly associated with the industrial engineering discipline (Section 4.2.2).
- **Answer to Research Question 2 (What patterns emerge from the job titles that are associated with industrial engineering on the internet?):** Some of the most common words/terms describing the area of concern of a job title were: Operations, Supply Chain, Process, Manufacturing, Business, Data, Systems, and Improvement. Some of the most common words describing the job role/function of a job title were: Engineer, Analyst, and Manager. There seemed to be a repetitive pattern of job titles, where most areas of concern matched with most job roles/functions. The full display of patterns can be seen in Section 4.3.
- **Answer to Research Question 3 (How can the job titles that are associated with industrial engineering on the internet be categorised and visualized?):** Job titles could be categorised and visualized in multiple ways, whether in terms of resources, knowledge areas, or activities. The most holistic and inclusive ways of categorisation were based on job role/function and areas of concern. Notable categories based on job role/function were: Engineer, Analyst, Manager, and Consultant. Notable categories based on areas of concern were: Method/Process/Operation/System/Project, Supply Chain/Logistics, Manufacturing/Production, Business/Management, Data/Information/Technology, Quality/Reliability/Safety, Lean/Six-Sigma/Continuous Improvement, Ergonomics/Human Factors, Facility/Field/Plant, and Procurement/Purchasing/Investment. These categories were derived from the patterns that were uncovered in the job titles (as evident in answering Research Question 2). Figure 17 shows a summary of the results, with the job titles visualized as an “equation” where certain areas of concern can be matched with certain job roles/functions.

The preliminary answer to Research Question 4 (What do the job titles that are associated with industrial engineering on the internet reveal about the job potential of the industrial engineer?), based on the answers to Research Questions 1-3, is that the job potential of the industrial engineer is broad and varied, with many ways of categorisation. This answer is expanded on in the next chapter, the Discussion Chapter.

CHAPTER 5: DISCUSSION

Research Questions 1-3 were answered in the Results & Analysis Chapter. In the Discussion Chapter, the answers are expanded on and discussed with more insight and nuance. Also, Research Question 4 (“What do the job titles that are associated with industrial engineering on the internet reveal about the job potential of the industrial engineer?”) is addressed. Finally, this chapter discusses interesting parts of the results, makes connections with literature, revisits the problem statement and research aim, and “maps” the job potential of the industrial engineer.

5.1 The differing perspectives of data sources

Despite the general consensus across data sources about the job potential of the industrial engineer, there was a benefit in choosing data sources from different perspectives. Each perspective provided unique insights.

5.1.1 Academic source and perspective

The academic source (University of Washington) was the only source that mentioned academic job titles as potential job titles for the industrial engineer. These job titles were in professorship or research. It may not be a coincidence that the academic job titles came from the academic website. The source document of job titles was created by the University’s Industrial and Systems Engineering Executive Advisory Board. The Board must have been aware of academic job titles since the members of the Board themselves are involved in academia. Thus, they may have wanted to share academic job paths with their students or graduates from an educational point of view.

In the introduction of the source document, the list of job titles is described as “...a handy resource as you look to secure your first job.” Since the document was created by a university, the words “you” and “your” likely refer to students and graduates. The document also acknowledged that “when job seeking, it’s important to look beyond the title “Industrial Engineer” and/or “Systems Engineer.”” Thus, the Board may have been familiar with the challenges of industrial and systems engineers on the job market, specifically those related to the job titles “Industrial Engineer” or “Systems Engineer” – both of which were discussed in the Literature Review Chapter. Also, the members of the Board may have experienced some challenges themselves with regards to their industrial engineering identity. The document of job titles may have even been created as a response to these challenges that are faced by the industrial engineering community. The university may have been trying to promote industrial engineering in its most correct and holistic form (which aligns with the aim of this dissertation), and this would explain why this source was the most populated and the most varied source when it came to job titles.

5.1.2 Career source and perspective

The career website, Zippia, was unique in that it was the only data source that showed multiple job paths for industrial engineers, with each job path beginning with an internship and then progressing into different job titles. All examples of these job paths can be seen in the screenshot of the web-page in Appendix D. An example from the web-page is:

Process Engineering Internship → Process Engineer → Manufacturing Manager → Lean Manufacturing Manager

The example of the job path links back with the examples of job paths given in the Introduction Chapter illustrating the potential job paths of a Mechatronics Engineer. The job path also links with the idea of interdisciplinarity and specialization within industrial engineering. Each job path represents an orientation of interdisciplinarity and/or a path of specialization, starting with an indication of what type of internship they would need. In the “Process Engineer” example that was provided, the industrial engineering graduate would need a “Process Engineering Internship” first to orient them into process engineering knowledge and skills. Then, they can decide to specialize in manufacturing and then into lean manufacturing. Thus, they would apply process engineering knowledge and skills in a manufacturing environment.

Continuing with the “Process Engineer” example gives more insight coming from Zippia’s perspective. Another job path with “Process Engineer” is as follows:

Process Engineering Internship → Process Engineer → Quality Manager → Project Quality Manager

This job path shows that, rather than specializing in manufacturing, a Process Engineer may specialize in quality. The Zippia website shows multiple other paths using some of the same job titles or internships, to illustrate the flexibility that an industrial engineer can have in their professional lifecycle.

5.1.3 Community source and perspective

Although the community source (an answer from Quora) was not as formal as the other sources, it shared a unique insight. This insight probably stemmed from the Quora answerer’s personal experience with industrial engineering. The answerer mentioned that “Automation and Robotics (with specialization and experience)” and “Sales and Operations Strategy Consultant (with MBA)” are part of the job prospects for an industrial engineer. The words in parentheses show that an industrial engineer may require extra specialization or experience to pursue certain types of jobs, which is a valid point.

5.2 Job titles and their categories

Many patterns emerged from the web-scraped job titles in Table 10. These patterns were noted in the Results & Analysis Chapter and are expanded on in the following sections.

5.2.1 High frequency job titles and categories

As was mentioned in Section 4.2.1 of the previous chapter, there were several repeated and similar job titles within and across the data sources. The repeated job titles are in Table 11. These job titles, along with similar job titles or words with a high frequency, indicate which types of jobs are most associated with industrial engineering on the internet.

Some of the most common and widespread associations were the job titles that repeated across all three sources: “Manufacturing Engineer”, “Quality Engineer”, “Quality Manager”, and “Supply Chain Analyst.” These repetitions imply that industrial engineering is most commonly associated with manufacturing, quality, and supply chain. Some of the remaining repetitions (Production Engineer, Reliability Engineer, Supply Chain Manager, Logistics Engineer, and Demand Planner) strengthened the association of industrial engineering with manufacturing, quality, and supply chain. For example, a Production Engineer and a Manufacturing Manager are both related to manufacturing. A Reliability Engineer is similar to a Quality Engineer. Finally, a Supply Chain Manager, Logistics Engineer, and Demand Planner all deal with supply chain concepts. Industrial engineering is also commonly associated with processes, given that “Process Engineer” and “Process Improvement Manager” each repeated twice.

The associations are strengthened when examining the frequencies of the words “Manufacturing”, “Quality”, “Supply Chain”, and “Process”:

- The word “Manufacturing” was the 4th most common word out of the 82 Descriptor 1 words. It appeared by itself and in other forms, such as “Manufacturing Systems”, “Manufacturing Technology”, and “Lean Manufacturing.”
- The term “Supply Chain” was the most common collocated term, appearing 8 times. It appeared by itself and in other forms, such as “Supply Chain Management” and “Supply Chain Operations.”
- The word “Quality” was moderately common, having the 12th most common frequency of the 82 Descriptor 1 words. It appeared by itself and in other forms, such as “Quality Assurance” and “Supplier Quality.”
- The word “Process” was the 3rd most common word of the 82 Descriptor 1 words. It appeared by itself and in other forms, such as “Process Improvement” and “Process Control.”

Another strong association was with the word “Operations”, which was the most frequently occurring word of the Descriptor 1 words.

The categories of job titles can be examined to further strengthen the associations of industrial engineering with manufacturing, supply chain, processes, and operations. The three most populated Descriptor 1 categories were: Method/Process/Operation/System/Project, Supply Chain/Logistics, and Manufacturing/Production. These were relatively high frequency categories.

The associations of industrial engineering with manufacturing, quality, supply chain, processes, and operations were supported by literature. For example, in one of the studies that was reviewed in the Literature Review about perceptions of industrial engineering, alumni/industry partners defined industrial engineering as dealing with “logistics, planning, process improvement, ergonomics, manufacturing, [and] quality control” (Specking, Kirkwood and Yang, 2015). Thus, the perceived associations with manufacturing, quality, and processes were explicitly stated. The association with supply chain was through the mention of logistics, which is connected to supply chain concepts. In this study, the association with operations could be seen through mentions of operations management, operations research, and operation of systems (Specking, Kirkwood and Yang, 2015).

Mentions of manufacturing, quality, supply chain, processes, and operations could be seen through literature capturing the industrial engineering discipline, too. For example, according to a study on trends, two of the most favourite fields of industrial engineering future research will be on subjects related to quality and supply chain management (Dastkhan and Owlia, 2009). In another study, the top 20 skills groupings for industrial engineering included supply chain management, process improvement/optimization, operations research, lean manufacturing, and manufacturing (van Dyk, 2014).

The association of industrial engineering with manufacturing is particularly notable. It may have a historic and linguistic significance. The historic significance comes from the fact that industrial engineering had its roots in manufacturing and production (Martin-Vega, 2001; Lucas, 2014). Thus, over a century after the establishment of industrial engineering as an academic discipline, the association of industrial engineering with manufacturing is still strong. The linguistic significance comes from the link of the word “industrial” with the word “manufacturing.” This link may lead people to think that industrial engineers work only in factories, that industrial engineering is limited to manufacturing, or that industrial engineering is the same as mechanical engineering (Specking, Kirkwood and Yang, 2015; Darwish, 2018). The link is so strong that “...the terms Industrial Engineering and Manufacturing Engineering are frequently confused or used interchangeably” (Stan, Tulcan and Cosma, 2010).

The evolution of the industrial engineering discipline may have weakened the association of industrial engineering with manufacturing. The association may still be strong in theory, but not as much in reality. When it comes to studying trends and censuses on industrial engineering, non-manufacturing topics (especially supply chain and processes) appeared more often than manufacturing topics (Dastkhan and Owlia, 2009; van Dyk, 2014). In fact, "...the percentage of industrial engineers working outside of the traditional manufacturing industries has exceeded the percentage of those working inside the field in the next several years, and so the types of roles and responsibilities of Industrial Engineers are subject to change" (Dastkhan and Owlia, 2009). This reality is supported by the results of this dissertation since the Manufacturing/Production category was not as populated as the Method/Process/Operation/System/Project and Supply Chain/Logistics categories. However, manufacturing remains an important part of industrial engineering, whether from literature or this study. The results of this study simply highlight the broadening of the discipline beyond traditional manufacturing industries. Also, the systems orientation of the industrial engineering discipline in the 21st century (Salvendy, 2001) was depicted through the popularity of the Method/Process/Operation/System/Project category and the moderately high frequency of the word "systems."

The popularity of the Method/Process/Operation/System/Project category is telling. In a way, this category best represents the broadness and flexibility of the industrial engineer. The same way an industrial engineer cannot be pinned down to one job role/function in one place, neither can a methods/process/operations/systems/project engineer. Industries, like processes and systems (etc...), are abstract concepts that are present everywhere. Defining their boundaries depends on a viewer's perspective. For example, the transportation industry could have its boundaries around road vehicles. Alternatively, it can expand its boundaries to incorporate the aviation industry or the supply chain industry. Similarly, a system could have its boundaries around one manufacturing process in a factory. Alternatively, it can expand its boundaries to consider the factory as a whole or even the entire manufacturing industry. Thus, even when trying to clarify the job potential of the industrial engineer using job titles, there remains some vagueness and flexibility.

To summarize, the high frequency job titles were identified as the ones including the words "manufacturing", "quality", "supply chain", "processes", and "operations." The strongest associations were with supply chain, manufacturing, and processes/operations. The strength of the association was determined by the number of times a job title repeated across different sources, how frequent its Descriptor 1 words/terms were, how populated the relevant Descriptor 1 categories were, and how often the association appeared in the reviewed literature. The resulting high frequency categories were: Method/Process/Operation/System/Project, Supply Chain/Logistics, and Manufacturing/Production.

5.2.2 Medium frequency job titles and categories

Job titles including the word “Quality” were mentioned as potent job titles in the previous section primarily because they repeated across sources. However, they had medium levels of frequency when it came to their Descriptor 1 words/terms. There were other job titles and categories that had a medium frequency but were still potent and informative of the industrial engineering job potential. The medium frequency categories were:

- Business/Management
- Data/Information/Technology
- Quality/Reliability/Safety
- Lean/Six-Sigma/Continuous Improvement

These categories were fairly even in their population, each having 11-13 job titles in them. This range of population was about half or less of the high frequency job categories, which had 20-36 job titles in them.

Like the high frequency categories, the medium frequency categories appeared often in some of the reviewed literature. For example, in the census of industrial engineers, “Business Process Analysis/Design/Mapping”, “Continuous Improvement/Kaizan/Six Sigma”, and “Data Analysis/Data Modelling/Analytics/Operations Research” were part of the top 10 skills groupings that industrial engineers attributed to themselves (van Dyk, 2014). Furthermore, in a study uncovering trends in research topics, “Business Management Approaches & Strategies” was listed as the most covered topic (Uys, Schutte and Esterhuizen, 2010).

When it comes to literature about perceptions of industrial engineering, the Business/Management category is significant. Many people are drawn to industrial engineering due to its business orientation (Trytten *et al.*, 2004; Shehab, Rhoads and Murphy, 2005; Murphy *et al.*, 2006). Students were interested in industrial engineering because they viewed it as a “mix of business and engineering” (Specking, Kirkwood and Yang, 2015). The association with business even led to the misconceptions that Industrial engineering was “business engineering”, the “business of engineering”, or a “glorified business degree” (Specking, Kirkwood and Yang, 2015).

The association of industrial engineering with business, like the association with manufacturing, has a historic significance. Henry Towne, one of the founders of industrial engineering, had expressed a need for a new type of profession that was a combination of a mechanical engineer, a business man, and an accountant (Towne, 1886). Thus, the perception of industrial engineering as a “mix of business and engineering” reflects its origins.

5.2.3 Low frequency job titles and categories

The low frequency job categories were:

- Ergonomics/Human Factors
- Facility/Field/Plant
- Procurement/Purchasing/Investment

These categories were fairly even in population and had between 3-5 job titles in them. Thus, the population of each category was about half the population of the medium frequency categories and about a quarter (or less) of the population of the high frequency categories.

The low frequency of these categories is mirrored by a low or absent frequency in some of the reviewed literature. For example, in the census and studies on trends in industrial engineering, these categories made little to no appearance. “Ergonomics and Human factors” and “Facility Layout” were identified as research subjects in industrial engineering, but they did not appear as trends (Dastkhan and Owlia, 2009). In van Dyk's (2014) census and Uys, Schutte and Esterhuizen's (2010) study on trends, there was no mention of ergonomics/human factors topics. In both of these studies, there was some mention of finance-related topics, which is connected to the Procurement/Purchasing/Investment category. In the census, “Procurement” was the 24th most common skill that industrial engineers attributed to themselves (van Dyk, 2014). “Financial Modeling/Risk /Analysis /structuring” was listed as the 35th most common skill (van Dyk, 2014). In the study on trends, “Financial Risk Analysis” was acknowledged as part of the industrial engineering research topics, and “Optimal Facility Location” was an identified trend (Uys, Schutte and Esterhuizen, 2010).

The Business/Management category was significant in the medium frequency categories when it came to the perceptions of industrial engineering. The case is similar to the Ergonomics/Human Factors category. Many people are drawn to industrial engineering due to its people orientation (Trytten *et al.*, 2004; Shehab, Rhoads and Murphy, 2005; Murphy *et al.*, 2006). The people orientation was typically described as “working with people” rather than as the science of ergonomics. However, the perceptions of industrial engineering must have been influenced by the understanding that the discipline interfaces with human factors, or that the discipline incorporates both the soft sciences and the hard sciences.

It seems that the low frequency categories are not very prominent job options for industrial engineers or that they do not represent the core of industrial engineering. However, it is still important to acknowledge these categories as potential, yet niche, job options. Also, elements of these categories (such as humans, money, and facilities) may still be present in other categories. For example, industrial engineers are often trying to reduce costs (and this relates to money).

5.2.4 Overview of job titles

Web-scraping job titles gave a quantifiable indication of the broadness and variability of the industrial engineer's job potential. The job titles in Table 10 are a comprehensive representation of the industrial engineer's job potential, according to the online community. It can be observed that an industrial engineer does indeed have broad and varied job potential (as descriptors of industrial engineering often claimed in Section 2.6 of the Literature Review). Many of the job titles represent a unique path of specialization and interdisciplinarity within industrial engineering.

Consider the job title "Human Factors Engineer" as an example. Of all the knowledge areas in the IEBoK, a Human Factors Engineer would have chosen to specialize in Ergonomics and Human Factors (knowledge area 6 in the IEBoK), either during their university studies or after. As such, a Human Factors Engineer would represent the interdisciplinary domain of psychology and engineering. However, they would still be knowledgeable of other knowledge areas.

Some job titles give an indication of the type of job being done regardless of speciality, interdisciplinarity, or context. Examples of these job titles are "Data Analyst", "Process Engineer", and "Project Manager" since they do not necessarily represent specialization, interdisciplinarity, or a certain context. Interestingly, these job titles are similar to the "Industrial Engineer" job title since they are broad and flexible in and of themselves. Any industry, company, or organization could have data or processes that need to be analysed and projects that need to be managed.

Some job titles did give an indication of the types of industries they work in. The most notable of these job titles were the ones including the word "manufacturing" since these job titles must be applied in the manufacturing industry. The specific type of product being manufactured or the type of manufacturing process being applied was not typically indicated.

Most of the job titles in Table 10 were similar in that one does not necessarily need an industrial engineering qualification to pursue them. Thus, they are not characteristic of, or unique to, an industrial engineering qualification. However, the distinctness of industrial engineering is that it encompasses all those job titles. Another qualification may not necessarily be flexible enough to provide such a broad career potential. Also, industrial engineers have a unique "way" of approaching jobs by using discrete variable mathematics and other techniques (Savory, 2005).

When further examining Table 10, it is important to keep in mind that the job titles represent industrial engineering in the most holistic and generic sense. The representation was built off the IISE's view of industrial engineering, which tried to capture industrial engineering fully in its IEBoK. Also, these job titles are a representation of how different people from different websites perceive industrial engineering's job potential to be, rather than what it actually is for a certain individual in their real-world job market.

5.3 Other job titles

Thus far in the Discussion Chapter, the job titles of Table 10 and their patterns were discussed. Some of these job titles are generic or strongly associated with industrial engineering, while others were more infrequent or unconventional. In this section, the job titles that were web-scraped but excluded from Table 10, among others, are discussed as other potential job options.

5.3.1 The job title of “Industrial Engineer”

Both industrial engineers and their employers may choose to use the title “Industrial Engineer.” Despite the broadness of the title, it is still informative about a general type of work, especially for those already familiar with industrial engineering. In fact, some individuals might choose to maintain the “Industrial Engineer” job title because its broadness is desirable; the title inherently implies that the individual is flexible and is capable of doing multiple types of jobs (Greene, 2001). The “Industrial Engineer” job title is powerful in that it encompasses the entire set of job titles that are associated with it.

Another reason one may choose to use the “Industrial Engineer” job title relates to identity. By choosing to use this job title, the industrial engineering identity may be preserved, highlighted, and distinguished. Otherwise, the industrial engineering identity may be muted or fragmented, especially since many of the job titles that are associated with industrial engineering are associated with other disciplines too.

5.3.2 Personal/entrepreneurial job titles

The lack of entrepreneurial job titles in the web-scraped data might indicate that industrial engineering is not typically associated with entrepreneurial endeavours. However, it is more likely that entrepreneurial job titles are not mentioned often because they are not specific to or descriptive of industrial engineering. They also tend to be associated with business more than with engineering. Given that industrial engineering does interface with business, an industrial engineer might be in a suitable place to start an entrepreneurial venture if they choose to. Also, the broadness and flexibility of industrial engineering competencies could aid in the development of an entrepreneurial venture.

More personalized job titles are also an option. An industrial engineer might decide to use their creativity and individuality to create a unique job title for themselves. They could consider adopting other “IE” job titles such as Integration Engineer or Innovation Engineer, or “...other words that begin with / and may better describe the future of the industrial engineering profession” (Greene, 2001). Alternatively, an industrial engineering graduate could always diverge from industrial engineering and choose to follow a more unconventional career path.

5.3.3 Indications of seniority, speciality, or rank

Several job titles were excluded based on their displays of speciality, seniority, or rank (exclusion criterion 2 of Table 8). Typically, these job titles were also excluded on the basis that they did not meet the preferred job title format (exclusion criterion 8 of Table 8), which needed to show some indication of job role/function. Whenever applicable, the indicators of seniority, speciality, or rank were removed (alteration criterion 2 of Table 7).

Indicators of seniority, speciality, or rank were removed since the purpose of this research was to explore the generic job potential of the industrial engineer. Indicators of seniority, speciality, and rank do not necessarily serve this purpose. Also, these indicators imply that an industrial engineer would require further training or job promotion. Naturally, an industrial engineer is expected to develop a degree of seniority, speciality, or rank as they progress in their professional journey. Mentioning the range of this seniority, speciality, or rank was not particularly beneficial in the case of this research. However, there were a few job titles that were excluded on the basis of their speciality, but still represented the industrial engineering discipline well. These were:

- Optimization Expert
- Process Integration Specialist
- Productivity Improvement Specialist

The industrial engineering discipline, by its nature, gives some level of expertise when it comes to optimization, process integration, and productivity improvement. Thus, these job titles were worth mentioning as part of the IE job titles.

5.3.4 Real-word job titles and other variations

The job potential of the industrial engineer is by no means limited to the job titles shown in Table 10 or the other job titles discussed in this section. The excluded job titles in Appendix H may also be potential job prospects for some. Furthermore, real-life job titles may be even more specific or varied than those shown in Table 10.

In reality, industrial engineering graduates will have many differences in their competencies, career preferences, and contexts. Their competencies may largely be influenced by their university's curriculum or previous work experiences, as different curricula and work programs will produce different types and levels of competencies. Their career preferences will be personal and may abide by or diverge from the typical industrial engineering job potential. The overarching context of their lives – such as the job market in the country or city they are living in – may influence what job potential they actually have. Finally, any job title may require extra training post-graduation to gear the industrial engineering graduate in the direction closer to a job title.

5.4 Categorisations

In the industrial engineering context, categorising jobs based on their area(s) of concern may have been more informative than categorising them based on their job role/function. The job role/function of engineering (and its related job functions, such as design and analysis) is already implied in the job title of “Industrial Engineer.” It is the “Industrial” part that is ambiguous and misleading (Greene, 2001; Stan, Tulcan and Cosma, 2010). Thus, the Descriptor 1 terms provided clarity on what is meant by the “Industrial” part; they provided examples of the area(s) of concern that an industrial engineer may have within industry. These terms represent the broadness, adaptability, and flexibility of industrial engineering in terms of its content rather than its functionality. Also, since there were more Descriptor 1 terms/words than there were Descriptor 2 words, there were many more options for categorisation based on areas of concern rather than job roles/functions.

5.4.1 Descriptor 1 categorisations

The Descriptor 1 categories that were identified in the Results & Analysis Chapter were similar and related to the categories identified in the IEBoK. The relations can be seen in Table 19.

Table 19: Relations between Descriptor 1 and IEBoK categories

Descriptor 1 category	Related IEBoK categories
Method/Process/Operation/System/Project	Work Design & Measurement Operations Research & Analysis Operations Engineering & Management Systems Design & Engineering
Supply Chain/Logistics	Supply Chain Management
Manufacturing/Production	Design & Manufacturing Engineering Product Design & Development
Business/Management	Operations Engineering & Management Engineering Management
Data/Information/Technology	Information Engineering
Quality/Reliability/Safety	Quality & Reliability Engineering Safety
Ergonomics/Human Factors	Ergonomics & Human Factors
Facility/Field/Plant	Facilities Engineering & Energy Management
Procurement/Purchasing/Investment	Engineering Economic Analysis

Other similar categorisations are present in Section 2.6.3 of the Literature Review Chapter. Some of these similarities are shown in Table 20.

Table 20: Relations between Descriptor 1 categories and the literature review

Descriptor 1 category	Related categories from literature
Method/Process/Operation/System/Project	<p>Process Analysis and Modelling (IE Solutions, cited in Zandin and Maynard 2001)</p> <p>Work Measurements/Methods Engineering (IE Solutions, cited in Zandin and Maynard 2001)</p> <p>Manufacturing Processes and Systems (Savory, 2005)</p> <p>Operations Research (Savory, 2005)</p>
Supply Chain/Logistics	Supply Chain Management (Lima <i>et al.</i> , 2017)
Manufacturing/Production	<p>Production Management (Lima <i>et al.</i>, 2017)</p> <p>Production (Savory, 2005)</p> <p>Manufacturing Processes and Systems (Savory, 2005)</p>
Business/Management	<p>Management Support Systems (IE Solutions, cited in Zandin and Maynard 2001)</p> <p>Management (Savory, 2005)</p>
Quality/Reliability/Safety	<p>Quality Management (IE Solutions, cited in Zandin and Maynard 2001)</p> <p>Quality (Lima <i>et al.</i>, 2017)</p>
Ergonomics/Human Factors	<p>Human Factors Engineering (IE Solutions, cited in Zandin and Maynard 2001)</p> <p>Ergonomics and Human Factors (Lima <i>et al.</i>, 2017)</p> <p>Ergonomics (Savory, 2005)</p>
Procurement/Purchasing/Investment	Economics Engineering (Lima <i>et al.</i> , 2017)

Table 19 and Table 20 show that there was much overlap between the Descriptor 1 categories and categories from industrial engineering literature. Thus, it seems that there is a general consensus over some prominent industrial engineering categories.

In the Results & Analysis Chapter, several other ways were considered to categorise IE job titles based on their area(s) of concern. These ways were according to the job title's knowledge areas, resources, activities, results/approach, and scope. Although none of these ways was ultimately used to create the final categorisation, the fact that the industrial engineer's job potential could be categorised in so many ways is significant. It conveys different levels of broadness, adaptability, and interconnectedness between areas of concern. From the exploration of these categories, the following insights can be made about the industrial engineer's job potential:

- The industrial engineer can be utilising one or more knowledge areas in their work.
- The industrial engineer can be concerned with various types of resources, such as money, people, and materials. They may be focused on one resource or on integrating them all in a system. Also, they may be focused on reducing resource wastage.
- The industrial engineer may be focused on completing a certain type of activity in their work, such as procurement or process improvement.
- The industrial engineer may need to achieve a certain type of result (such as quality assurance) or use a certain approach (such as lean/six sigma) in their work.
- Some industrial engineers might be concerned with the high, systematic level of an industry or organization, while others might be concerned with the detailed, methodical level.

Thus, the industrial engineer has vast dimensionality in their job potential. Knowing the different types of dimensions may help an industrial engineer to decide on their own area(s) of concern.

5.4.2 Descriptor 2 categorisations

Many insights can be drawn when examining the Descriptor 2 categories (Engineer, Analyst, Manager, and Consultant). The "Engineer" category is perhaps the broadest. When looking back at the industrial engineering definition, some job roles/functions that are mentioned in it are: design, improvement, installation, analysis, prediction, and evaluation. All of these roles/functions may be encompassed within the "Engineer" category. "Engineer" may even encompass the category of "Analyst" since analysis is part of the industrial engineering definition. Thus, "Analyst" may have had the 2nd highest frequency because it is closely related to engineering.

The roles of the industrial engineer as a "Manager" or a "Consultant" are perhaps less traditional than the role of an "Engineer" or "Analyst." However, they may emerge naturally for an industrial engineer once he/she advances enough in their career to oversee and orient the work of others (as a manager would), or to give advice on how to do work better (as a consultant would). Also, the industrial engineering knowledge areas tend to include management. The consultancy role, however, may be the only category that is not directly related to competencies/knowledge areas.

5.4.3 Combined categorisation

Figure 17 combined the Descriptor 1 and Descriptor 2 categories. This combination resulted in an “equation” for the IE job titles that were gathered.

In Figure 17, most of the Descriptor 1 categories corresponded with all of the Descriptor 2 categories. For these Descriptor 1 categories, it can be expected that an industrial engineer’s job potential will be quite expansive and flexible in terms of job role/function.

The only Descriptor 1 categories that did not correspond with all of the Descriptor 2 categories were the Procurement/Purchasing/Investment, Facility/Field/Plant, and Ergonomics/Human Factors categories. Interestingly, these three categories were the same categories that were defined as low frequency categories. Hence, it is not surprising that these categories did not appear with all of the Descriptor 2 categories.

The three low frequency categories both never corresponded with the “Consultant” category. This may be because industrial engineers may not typically have consultant-level proficiency in these categories. After all, consultancy jobs tend to require extensive experience; the consultant should be thoroughly knowledgeable about the topic he/she will consult on. According to the results of this dissertation, it is more probable that industrial engineers would develop consultant-level proficiency in the categories they are more traditionally associated with, such as supply chain.

When examining Figure 17, it is important to note that the figure is not an absolute representation of the job potential of the industrial engineer. Rather, it was a summary of the results and depended on the data that was gathered, the way it was filtered, and the way it was categorised. Differences in the data gathering, filtration, and categorisations may have produced a different diagram. Regardless of any differences or variations, the most important part of Figure 17 is that it represents the broadness, variability, and flexibility of the industrial engineering discipline. The figure depicts all of the different options for areas of concern and job roles/functions in a way that they can be “mixed and matched.” Since the industrial engineering discipline is broadening even more with time (Billings *et al.*, 2001), it may eventually look like it does in Figure 18.

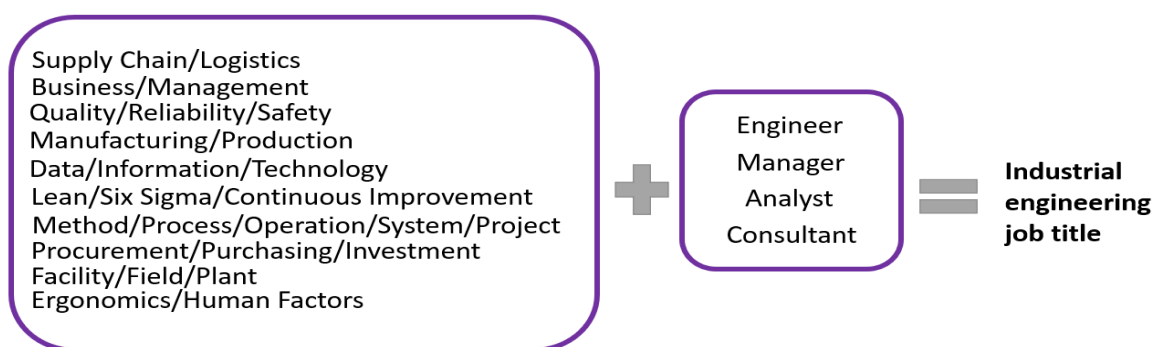


Figure 18: A potential future of industrial engineering job titles

5.5 Variations and overlaps in categorisations

In this dissertation, job categories were created mainly based on 2 premises:

1. High frequencies of words
2. Similarities or close relationships between words

The job categories were essentially representative of the data sample since the titles and content of the categories emerged from the data itself. However, the ways to categorise the industrial engineering discipline are variable. Furthermore, the content of each category is variable and may overlap with other categories.

One way to examine variations is through comparing categorisations across literature. This was done in Tables 19 and 20. Other categorisations were mentioned in Section 2.6.3. Another way to examine variations and overlaps is by experimenting with different decisions for data analysis.

To give an example of a variation in a data analysis decision, one may choose to combine categories such as “Engineer” and “Analyst” on the premise that engineers are bound to do some form of analysis in their work. Alternatively, one may choose to ignore job role/function categories and only focus on categories highlighting areas of concern. Because industrial engineering has so many potential areas of concern, there is much room for variation in categorisations. There is also much overlap between the categories. For example, some might argue that a job title with procurement and purchasing should be part of the “Supply Chain/Logistics” category. In this dissertation, procurement and purchasing were both associated with money/finances, so they were placed with other money/finance job titles such as “Investment Analyst” and “Spend Analyst” – hence the job category titled “Procurement/Purchasing/Investment.”

Some overlaps were shown throughout Table 17. A job title such as “Systems and Data Analyst”, for example, was placed into both the Method/Process/Operation/System/Project category and the Data/Information/Technology category. Displays of overlaps were kept to a minimum, to keep each category distinct and to keep the prominent area(s) of concern evident. However, there remain many job titles that could theoretically be placed in almost any category due to their broadness and flexibility.

As was mentioned in Section 3.4, the main limitation of this research is that it is subject to interpretation and change based on human opinions or biases. However, these limitations are not necessarily disadvantageous. They may even be advantageous. Opinions and biases provide insights about how industrial engineering is perceived. Variations in the gathering, filtration, analysis, and categorisation of data simply add more dimensionality to the results. Also, the nature of the research topic is malleable, which allows room for interpretation and exploration.

5.6 Revisiting the problem and aim statements

The problem statement was that the job title of “industrial engineer” is **misleading**, **vague**, and **variable**. The job title is misleading because industrial engineering has evolved from its roots in the industrial revolution to encompass industries in the broader sense (Stan, Tulcan and Cosma, 2010); this makes it **difficult to explain**. The job title is vague because industrial engineering has broad and flexible applications (Greene, 2001); this makes it **difficult to navigate**. The job title is variable because the industrial engineer can adopt many other job titles that still reflect industrial engineering competencies (Greene, 2001); this makes it **difficult to capture**.

Through conducting a literature review on the topic, as well as gathering/categorising IE job titles, each of the bolded words in the problem statement was addressed in the following ways:

- **Misleading and difficult to explain:** The misleading aspect of the job title of “industrial engineer” was explained from its historic and linguistic angles, as well as how it relates to the nature of the industrial engineering discipline itself. The list and categorisation of job titles provided clear and specific examples of the job potential of the industrial engineer. That way, the discipline became easier to explain.
- **Vague and difficult to navigate:** The vagueness of the job title of “industrial engineer” was addressed by exploring what industrial engineering is, what it is not, and which types of areas of concern and job roles/functions are most associated with it. The list and categorisations of job titles removed the vagueness since the job potential of the industrial engineer became defined and clear. Thus, the job potential became easier to navigate.
- **Variable and difficult to capture:** The variability of the job title of “industrial engineer” was illustrated by an entire list of other job titles that an industrial engineer could potentially adopt. Also, the categories of job titles were visualized in a way where the potential options for job titles were related to each other. That way, the variability was explicitly captured.

As was mentioned in the Introduction Chapter, this research aims to investigate the job potential of industrial engineers based on web-scraped job titles. The intention of this investigation is to provide guidance and clarity on how to navigate the industrial engineering profession. The investigation part of the aim statement was completed by the web-gathering and categorisation of job titles. Each job title or category represents a potential “destination” for an industrial engineer on their job search, and the entire study represents a “landscape” of job potential. Thus, the job potential of the industrial engineer could be “mapped” to provide guidance and clarity on how to navigate the industrial engineering profession. To sum up this dissertation with the concept of a “map”, an infographic combining several key elements of the dissertation thus far has been created (Figure 19). This infographic is a visual attempt at “mapping” the very broad and flexible job potential of the industrial engineer. It is introduced and presented in the next section.

5.7 Summarizing the job potential of the industrial engineer

This dissertation used job titles to reveal the job potential of the industrial engineer. These job titles showed the broadness and variability of the roles/functions and areas of concern of industrial engineering jobs. However, most of the job titles did not give an indication of the type of industry they could be present in. It is important not to overlook the industry part of the job potential of the industrial engineer. It is also important to note that the industry part includes the service sector.

As was mentioned previously, industrial engineers can be found in virtually any industry (Greene, 2001). They are even present in “non-industry” environments such as in healthcare, sports, public policy, security, and humanitarian relief (Mackenzie, 2016). Although IE job titles were most associated with manufacturing/production and supply chain/logistics, there are a plethora of other contexts where industrial engineering can be applied. Ostensibly, industrial engineering knowledge and methods can be applied in any context, provided there is room for improvement. The types of knowledge and methods utilised are context-dependent.

An infographic (Figure 19 on the next page) was created to capture the job potential of the industrial engineer. In this infographic, the following elements of the job potential are depicted:

- **Job roles/functions:** The typical types of job roles/functions are depicted by the people icons on top of the text box. These job roles/functions were extracted directly from the four main Descriptor 2 categories that were identified in the Results & Analysis Chapter.
- **Areas of concern:** Areas of concern are depicted by the words spread across the sky of the infographic. Most of these words were directly extracted from the Descriptor 1 words/terms in the Results & Analysis Chapter. Some other words associated with industrial engineering, such as “efficiency” and “productivity”, were also added.
- **Industries:** Some of the different industries that industrial engineers can be present in are represented by the ground area with the road and buildings. These examples of industries were extracted from industrial engineering literature.

“Mapping” the job potential of the industrial engineer in an infographic does not necessarily need to provide a conclusive career path for industrial engineers to follow. It may even be unreasonable to limit the industrial engineering job potential. Rather, the “map” is metaphoric, and it intends to show that industrial engineering can be present almost anywhere in a combination of different ways. These combinations are depicted through the infographic and each individual industrial engineer is responsible for choosing their own path. An industrial engineer may end up choosing one or more job roles/functions, along with one or more areas of concern, to be applied in one or more industries – whether that is quality analysis in the manufacturing industry, facility management in the retail industry, or human factors engineering in the healthcare industry.



Figure 19: Infographic summarizing the job potential of the industrial engineer

5.8 Saturation, validity, and reliability

Most of the indicators of saturation were discussed in the Results & Analysis Chapter. The last of the saturation criterion (“It can be reasonably and logically deduced that adding more data would be redundant for the purposes of the study”) is discussed in this section.

Since the research questions were addressed in the Results & Analysis Chapter and the Discussion Chapter, it can be deduced that the data was saturated and sufficient. Adding more data may have strengthened certain patterns and findings, but it may have also overcrowded the dataset without producing any significant or novel insights. Other indicators of saturation were based on the assessments of validity and reliability. The reliability assessment (conducted in Section 4.4.4) showed that there was a high degree of reliability. Validity was shown throughout the Discussion Chapter by illustrating that the results were generally compatible with the findings of pre-existing literature.

5.9 Significance and novelty of the study

This dissertation was completed in pursuit of the Master of Engineering with Development and Management Engineering degree. Although the research topic was not built around a typical industrial engineering research problem, it was built around a problem facing the industrial engineering discipline itself. The research was conducted to develop, enhance, and refine the understanding of the industrial engineering profession.

When searching for literature, there were multiple studies concerned with the challenges faced by industrial engineers with regards to their identity and recognition. These studies usually explored perceptions of industrial engineering and the implications of these perceptions. Other studies gathered online data on industrial engineering to capture its trends and application areas.

This study combined the search for perceptions, trends, and application areas. The job titles that were gathered essentially came from the perceptions of the types of jobs that industrial engineers can do. There were evident patterns and trends that emerged from these job titles, making them categorizable into multiple application areas. By the end of the study, the job title of “industrial engineer” was supplemented with 115 other potential job titles. For anyone interested in industrial engineering, these job titles offer concrete examples of what an industrial engineer can do.

The methodology that was applied for this research was customized to the research’s needs. The same methodology was not found in any of the reviewed literature. Thus, the methodology is a contribution to the research. The generic outline of the methodology was provided in Figure 9. It can be used by other researchers conducting similar studies for any discipline. Finally, the infographic mapping the job potential of the industrial engineer was a contribution to the research.

5.10 Reflection on methodology

Since the methodology for this research was original and customized to the research's needs, it is worth reflecting on as part of the discussion. The methodology of this research was inspired by the large amount of data on industrial engineering on the internet. Web-scraping this data allowed for the capturing, filtration, organization, and analysis of the data. Consequently, the methodology was effective in answering the research questions. However, the methodology is subject to limitations, as was discussed in Section 3.4. Also, the job potential of the industrial engineer can never be fully captured or codified, as it will always vary based on real-life contexts.

5.11 Summary of discussion

The Discussion Chapter explored various interesting parts of the research process. The discussion started with a comparison of the differing perspectives of data sources – that is, the academic, career, and community sources. The content of the sources was similar overall, but each source provided a slightly different perspective, making a richer dataset.

There was ample discussion on the job titles themselves, as well as their categorisations. The job title categories were split into three types: high frequency, medium frequency, and low frequency categories. These categories gave insight into which job titles are most commonly associated with industrial engineering on the internet. Other job titles that did not fit into these categories were also noted. Finally, variations and overlaps in categorisations were explored.

Throughout the Discussion Chapter, several links and references were made back to the Literature Review Chapter. The new knowledge from this research was compared against pre-existing knowledge to enhance the validity of the study, as well as to provide more dimensionality.

To contextualize the Discussion Chapter back to the research topic, the problem and aim statements were revisited. Then, the job potential of the industrial engineer was summarized and “mapped.” To close off the Discussion Chapter, the saturation, validity, reliability, significance, and novelty of the study were discussed.

In terms of the Research Questions, the answers to Research Questions 1-3 were already addressed in the previous chapters. The Discussion Chapter added more nuance and complexity to these answers. Most notably, the Discussion Chapter addressed Research Question 4 (“What do the job titles that are associated with industrial engineering on the internet reveal about the job potential of the industrial engineer?”). The summarized answer to this question is that the job potential of the industrial engineer is broad, flexible, and variable in terms of its job role/function, area(s) of concern, and context/industry. Each industrial engineer will have to choose for himself/herself which combination of aspects he/she wants to work in, and in what context.

CHAPTER 6: CONCLUSION & RECOMMENDATIONS

In this dissertation, job titles associated with the industrial engineering discipline were gathered, analysed, and categorised. Then, the job potential was summarized in an infographic. Thus, this dissertation provided clarity and guidance in navigating the job potential of the industrial engineer. However, there remains a certain predicament surrounding the job title “industrial engineer.”

6.1 Revisiting the job title of “industrial engineer”

When examining each of the gathered job titles in isolation, the industrial engineer’s job potential is fragmented. However, when examining the job titles as a whole, industrial engineering can be viewed in a new light. Each job title provides a unique avenue for an industrial engineer, but there is something that they all have in common: being applied in industry (or in the service sector). When this commonality is observed between job titles that may otherwise have little in common, the job title “industrial engineer” suddenly gains more value. The misleading, vague, and variable aspects of it can be viewed as benefits rather than problems.

There is a timeless element that comes with the industrial engineering qualification and identity, precisely because it is so vague and variable. The misleading aspect seems to fade when one gains a correct understanding of what industrial engineering is. Ostensibly, no change of term suggested in literature or to-be invented in the future will be able to capture the full breadth and flexibility of the discipline and profession. Regardless of nomenclature, there will always be abstract concepts that can be improved – whether these concepts be processes, systems, productivity, or industries. The industrial engineering qualification provides the tools and techniques to address those concepts in a scientific, engineered way. Perhaps it is best to view industrial engineering as a way of life or a way of thought, a philosophy, that can be transferred across contexts.

To sum up the situation of the industrial engineer, Greene (2001) writes:

“What is clear is that there is little in any area that is even remotely related to industrial engineering that is not industrial engineering or can be done by an [industrial engineer]. One thing is true about industrial engineering: if you define it as industrial engineering, it is industrial engineering. If it is not industrial engineering today, it will probably be industrial engineering tomorrow. An industrial engineer, now long since passed away, once said that industrial engineers find problems, find tools to solve the problems, and solve the problems. That part of industrial engineering will not change. How [industrial engineers] solve the problem, what tools [they] use to solve the problem, and the problems [they] address will change – but [they] will always solve the problem.”

6.2 Recommendations

It seems that many of the societal and professional problems that face industrial engineers result from the misperceptions and misunderstandings surrounding them. Otherwise, industrial engineering is a powerful qualification with promising career prospects. Thus, one of the main recommendations for this research is to increase awareness of industrial engineering. The results of this research can be used to increase awareness about the job potential of industrial engineers, specifically through the potential job titles they can adopt.

The concepts of job titles/potential can be transferred to other research projects. Recommendations for future research are:

- Comparing generic job titles for industrial engineers to the job titles that real-life industrial engineers hold
- Comparing the job titles for industrial engineers across time, whether in the past or the future
- Comparing the job potential of industrial engineers with the job potential of other related disciplines, whether they be engineering disciplines or not
- Investigating whether job advertisements target/recognize individuals with industrial engineering qualifications (for the job titles associated with industrial engineers), and if not, which other qualifications they target
- Suggesting new job titles for individuals with an industrial engineering qualification
- Uncovering perceptions of the industrial engineer's job potential from individuals within the industrial engineering community
- Uncovering perceptions of the industrial engineer's job potential from human resource departments in industry
- Comparing which job titles are common among both industrial engineers and non-industrial engineers and examining how industrial engineering competencies are unique for these job titles
- Interviewing industrial engineering graduates and their potential employers to assess the recognition of industrial engineering
- Comparing general labour statistics/requirements to industrial engineering labour statistics/job potential to make better use of industrial engineers in industry

Any research done on industrial engineering will promote more awareness and understanding of the discipline. However, more hands-on initiatives are also recommended, especially for prospective students and potential employers of industrial engineers. That way, industrial engineering can be fully embraced, rather than constantly being caught in misperceptions and misunderstandings.

6.3 An analogy with medicine

In the Introduction Chapter, an analogy comparing industrial engineering and medicine was presented. In this analogy, Greene (2001) stated that a medical doctor's role is "fairly crisp and well defined", making it easy for the typical person to understand what a medical doctor does. However, this is not the case for the industrial engineer, who struggles with their professional and societal recognition due to their multiplicity in roles (Greene, 2001). The analogy with medicine can be expanded on to summarize and conclude this dissertation.

The industrial engineering degree is comparable to the general medicine degree in many ways. Typically, industrial engineering students and medical students start their professional journeys by obtaining a degree covering their respective disciplines in the broadest sense. While medical students will learn about general human physiology, industrial engineering students will learn about general engineering subjects. Industrial engineers will also get exposure to various specific industrial engineering knowledge areas but will not necessarily specialize in any particular one at an undergraduate level.

Both the medical degree and the industrial engineering degree will be loaded with knowledge from different subjects. These subjects, when consolidated and combined, formulate a whole – whether that is the human body or an entire industry. However, it is unreasonable to expect an individual medical or industrial engineering graduate to master all of the areas in their discipline. Therefore, often, graduates will specialize post-graduation. This specialization turns the medical doctor into a specialist doctor who has a focused area of concern. Similarly, specialization turns the industrial engineer into a specialized industrial engineer who has a focused area of concern. Each specialization will be built off of the broad knowledge base presented at the undergraduate level. There can also be cases of interdisciplinarity, where multiple knowledge areas intertwine.

Medical doctors, for example, can converge in medicine through specialization. Medical doctors can also diverge by using knowledge from non-medical disciplines to aid them in solving medical problems. For instance, one specialization of medicine is neurology. Neurologists converge in medicine by concentrating on the knowledge relating to the nervous system. Neurologists diverge from medicine by interacting with non-medical disciplines, such as statistics and technology. This interdisciplinarity allows neurologists to use medical machines and analyse data. Furthermore, neurology has inherent (or medicine-bound) interdisciplinarity since it interfaces heavily with psychiatry, which is another standalone specialization in medicine.

Industrial engineers, like medical doctors, can also converge and diverge in industrial engineering. They can specialize and interface with the soft sciences, the hard sciences, or somewhere in-between. An example of a specialist industrial engineer could be a manufacturing

engineer, who specialized in production/manufacturing. However, an industrial engineer could adopt a more general role the same way a medical doctor can remain a general practitioner physician. An example of a more general role would be a process improvement engineer, which can be applied in any environment requiring process improvement (whether that be a hospital, an amusement park, a bank, or a factory).

Regardless of any specialization or interdisciplinarity, there will always be a certain philosophy guiding a discipline. In the case of medicine, this philosophy might be “improving health.” In the case of industrial engineering, perhaps this philosophy is “improving processes and systems in industry.” The application of this philosophy will depend on the knowledge and technologies available at the time. Even in times where medicine and industrial engineering were not officially established as academic disciplines and professions, they may have still been applied in principle.

Medicine can best meet its function if we assign the correct patient (who has symptoms) to the correct specialist doctor (who can give diagnoses and treatments). Industrial engineering can best meet its function if we assign the correct problem (which has features) to the correct specialist industrial engineer (who can explore and apply solutions to the problems). It is crucial to comprehensively understand the knowledge base of medicine to be able to facilitate the patient-doctor coordination process and, in turn, improve health. Similarly, it is crucial to understand the different types of industrial engineers, so that problems in industry are solved in expert ways.

The discrepancy in the analogy for medicine and industrial engineering becomes present when it comes to societal perceptions. There is something that can be intuitively understood and appreciated about medicine. For example, it is intuitive that cardiologists are mostly concerned with the cardiovascular system of the medical sciences. It would thus be logical to assign a patient exhibiting cardiology-associated symptoms to a cardiologist. Another discrepancy is that, in medicine, there are rules and regulations preventing specialists from meddling in each other’s works. However, there is something more general about the industrial engineer, where they are flexible enough to move around specialities. After all, they are considered as “masters of change” (Billings *et al.*, 2001) and as “being connected to all fields of knowledge but masters of some” (Darwish, 2016). Furthermore, their most desired characteristic is having “adaptable problem solving skills” (Eskandari *et al.*, 2005; Rabelo *et al.*, 2006).

To close off this analogy, it may be appropriate to view industrial engineers as the doctors of industry. Industrial engineers identify symptoms in industries that need to be managed or fixed. Then, they apply their expertise to manage or cure those symptoms. With industrial engineers at work worldwide, industry comes closer to having “integrated systems of people, materials, information, equipment and energy” – as the definition of industrial engineering calls for.

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APPENDIX A: LIST OF SOURCES FOR WEB-SCRAPING

Source	Type of website	URL	Num of data entries
University of Washington	Academic	https://ise.washington.edu/sites/ise/files/ISE-Job-Titles_0.pdf	100
Zipia	Career	https://www.zipia.com/industrial-engineering-major/	55
The Ladders	Career	https://www.theladders.com/job-titles/industrial-engineering	29
The Balance Careers	Career	https://www.thebalancecareers.com/engineering-job-titles-2061493	25
Quora	Community	https://www.quora.com/What-are-the-job-prospects-for-an-industrial-engineer	20
BestColleges	Academic	https://www.bestcolleges.com/careers/science-and-engineering/industrial-engineering/	8
CollegeGrad	Academic/Career	https://collegegrad.com/careers/industrial-engineers	9
WorldWideLearn	Academic	https://www.worldwidelearn.com/online-education-guide/engineering/industrial-engineering-major.htm	4
RaiseMe	Career	https://www.raise.me/careers/architecture-and-engineering/industrial-engineers	4
Indeed	Career	https://www.indeed.com/recruitment/job-description/industrial-engineer	3

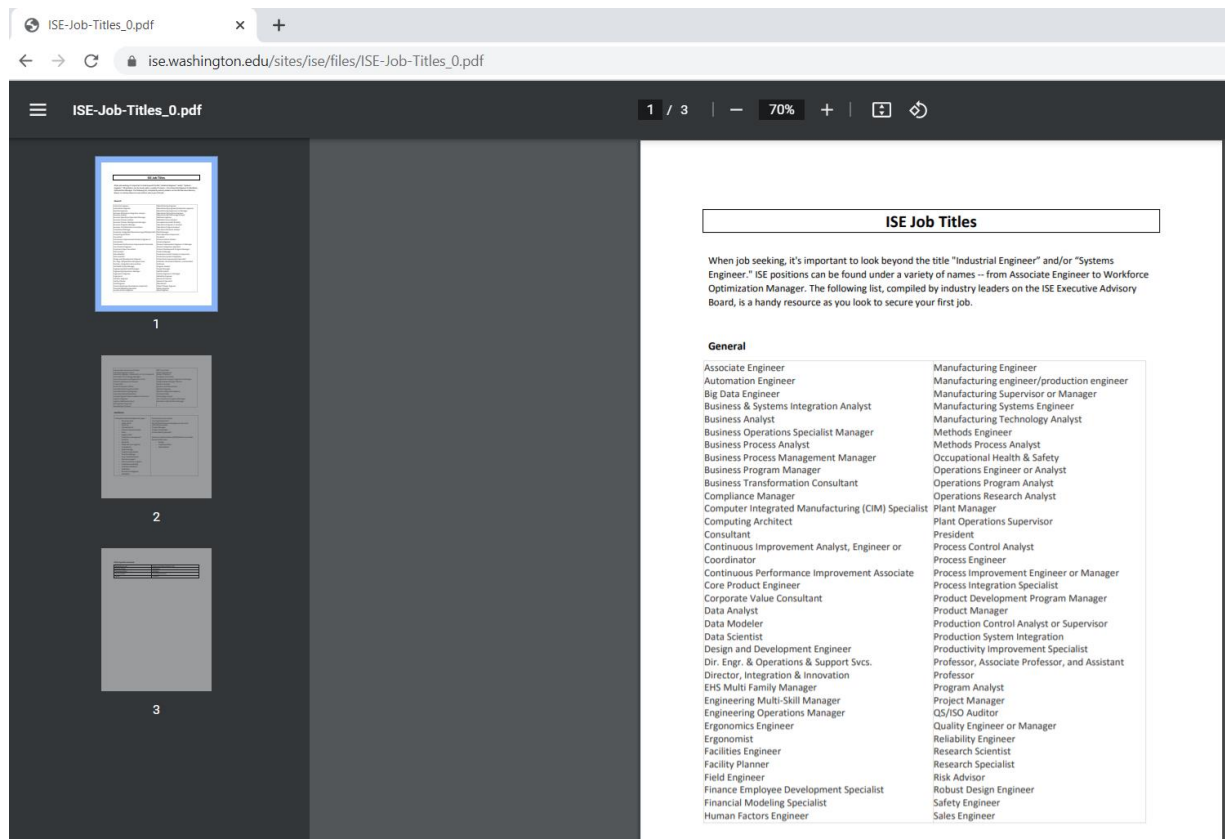
The highlighted rows were the ones included to create the dataset of job titles. The ones that were included had the highest number of data entries per their source type. The different colours represent the different types of sources: Academic, Career, and Community sources.

APPENDIX B: BORDERLINE CASES OF JOB TITLES

Job Title	Incl./Excl.	Reason for borderline status	Reason for Inclusion/Exclusion
Kaizen Promotion Officer	Incl.	Kaizen is a Japanese word meaning "continuous improvement." Neither the term "Kaizen" nor "continuous improvement" appear in the IEBoK. However, multiple other concepts relating to continuous improvement appear (such as process and productivity improvement).	Even though the term "Kaizen" was not used in the IEBoK, there are enough similar concepts to justify the inclusion of this data entry. Kaizen is an important concept in industrial engineering, whether it is referred to as Kaizen or its translation/synonyms.
Optimization Expert	Excl.	These job titles do reflect industrial engineering well, since they revolve around integration/productivity/optimization. Industrial engineers inherently do have some degree of mastery over these areas. However, terms indicating speciality/seniority/rank are not very descriptive when it comes to job function/role.	These data entries were excluded on the basis that they are specialist/expert positions. These types of positions would not add value when analyzing the Descriptor 2 parts of the job titles, since they do not give an indication of the job function/role. Also, multiple other similar job titles were included instead.
Process Integration Specialist	Excl.		
Productivity Improvement Specialist	Excl.		
Health Informatics Consultant	Incl.	A Health Informatics Consultant does not necessarily need to be a health professional. However, a Health Informatics Consultant would need to have knowledge of health concepts. The term "Health Informatics" is not specifically referred to in the IEBoK. However, the IEBoK does mention health movement, health management, health practices, and health regulations - all of which could include health informatics.	An industrial engineer should be able to analyze informatics in any environment, even health environment. Thus, this data entry was included. Also, since this was the only job title with the word "Health" in it, including it added variety to the final dataset of job titles.
Information Technology Manager	Incl.	The term "Information Technology" is not specifically referred to in the IEBoK. However, the IEBoK does mention technology management and information systems (which Information Technology Managers and Analysts work with).	These data entries were included since much of the industrial engineering competencies interface with information and technology.
Information Technology Analyst	Incl.		
Supply Chain Lead	Incl.	The terms "Lead" and "Leader" indicate rank/seniority. However, they also imply a job function/role similar to that of a manager.	These data entries were included on the basis of "Lead" and "Leader" being taken as a descriptor of job function/role and not necessarily as indicators of seniority/rank.
Injury Prevention and Ergonomics Lead	Incl.		
Lean/Six Sigma Projects Leader	Incl.		
Ergonomist	Excl.	This data entry is one of the only entries that is only 1 word. Thus, it is not in the preferred 2-part job title format. However, it is a potential industrial engineering job title.	The reason for excluding this job title was that it is not in the preferred 2-part job title format. Thus, it would have been the only included data entry that could not be split up and analyzed based on its two parts. Similar, more descriptive alternatives (such as Ergonomics Engineer) were included instead to show that an industrial engineer could work in ergonomics.
Sales and Operations Strategy Consultant	Incl.	Neither the term "Sales" nor the term "Operations Strategy" appear in the IEBoK. However, the IEBoK does mention the terms "operations" and "strategy" often. Also, the IEBoK mentions many concepts related to sales, such as forecasting and demand. This data entry, before alteration, mentioned that an MBA is required to pursue this job title. However, that is the opinion of the Quora answerer who wrote the answer. An industrial engineer could still pursue this type of job if they have a strong business background.	A Sales and Operations Strategy Consultant essentially deals with improving the processes behind sales and does not handle the sales themselves. Industrial engineers can improve processes in almost any context, so this data entry was included. Also, an industrial engineering graduate may have enough business knowledge to pursue this role without an MBA.

APPENDIX C: SCREENSHOTS OF THE ACADEMIC SOURCE

Screenshot of the URL with the pdf document of job titles:



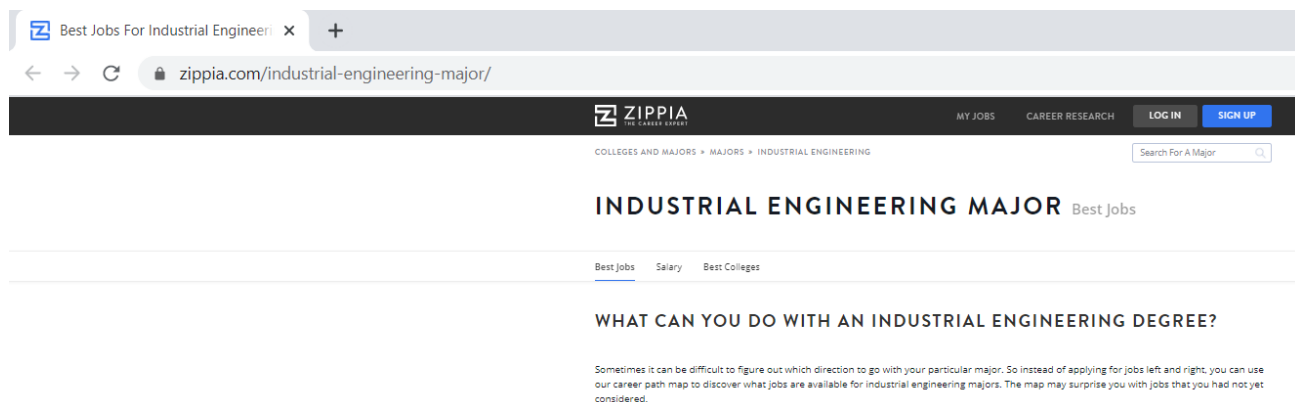
The zoomed-in screenshots of the job titles can be seen in the next two pages.

Associate Engineer	Manufacturing Engineer
Automation Engineer	Manufacturing engineer/production engineer
Big Data Engineer	Manufacturing Supervisor or Manager
Business & Systems Integration Analyst	Manufacturing Systems Engineer
Business Analyst	Manufacturing Technology Analyst
Business Operations Specialist Manager	Methods Engineer
Business Process Analyst	Methods Process Analyst
Business Process Management Manager	Occupational Health & Safety
Business Program Manager	Operations Engineer or Analyst
Business Transformation Consultant	Operations Program Analyst
Compliance Manager	Operations Research Analyst
Computer Integrated Manufacturing (CIM) Specialist	Plant Manager
Computing Architect	Plant Operations Supervisor
Consultant	President
Continuous Improvement Analyst, Engineer or Coordinator	Process Control Analyst
Continuous Performance Improvement Associate	Process Engineer
Core Product Engineer	Process Improvement Engineer or Manager
Corporate Value Consultant	Process Integration Specialist
Data Analyst	Product Development Program Manager
Data Modeler	Product Manager
Data Scientist	Production Control Analyst or Supervisor
Design and Development Engineer	Production System Integration
Dir. Engr. & Operations & Support Svcs.	Productivity Improvement Specialist
Director, Integration & Innovation	Professor, Associate Professor, and Assistant Professor
EHS Multi Family Manager	Program Analyst
Engineering Multi-Skill Manager	Project Manager
Engineering Operations Manager	QS/ISO Auditor
Ergonomics Engineer	Quality Engineer or Manager
Ergonomist	Reliability Engineer
Facilities Engineer	Research Scientist
Facility Planner	Research Specialist
Field Engineer	Risk Advisor
Finance Employee Development Specialist	Robust Design Engineer
Financial Modeling Specialist	Safety Engineer
Human Factors Engineer	Sales Engineer

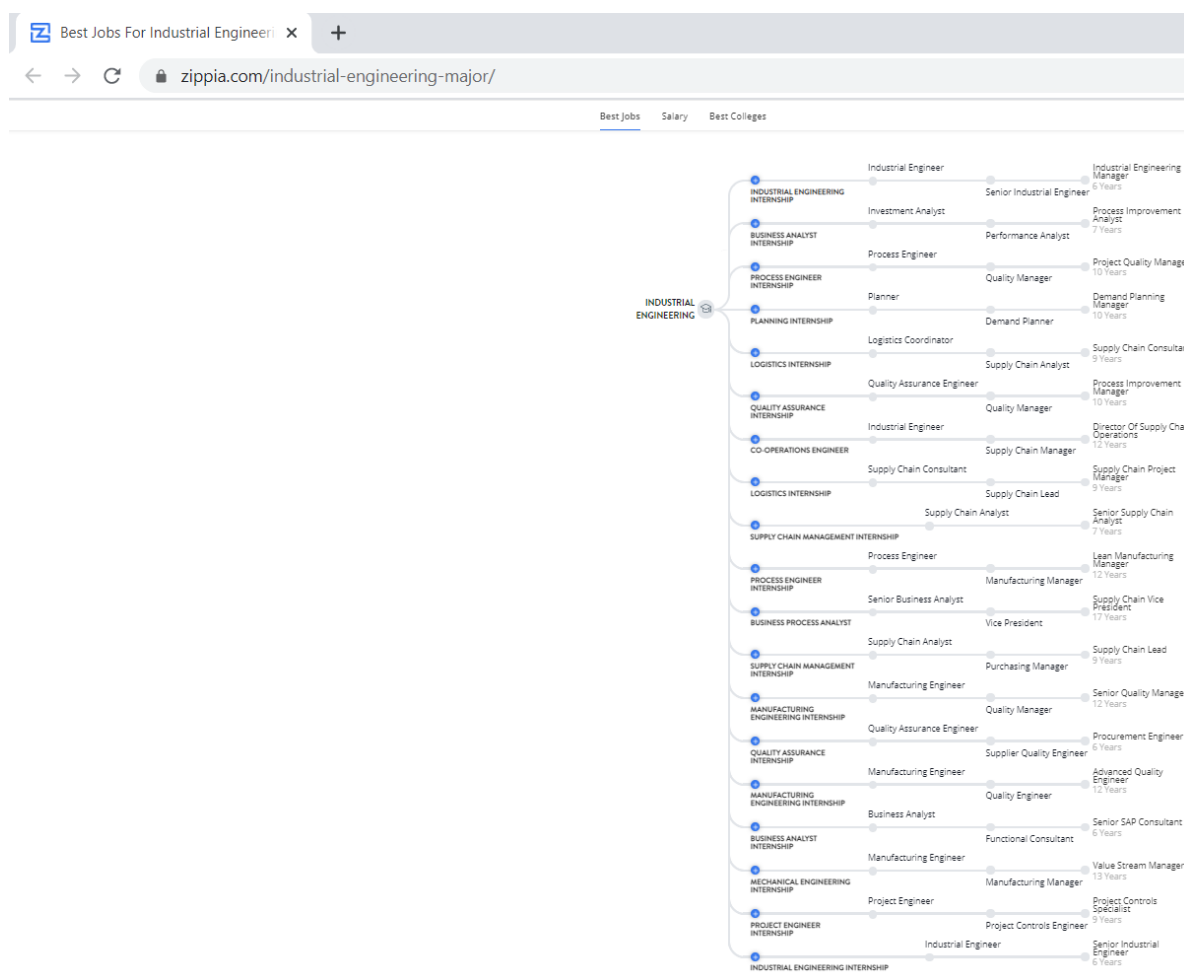
Independent Researcher/Author	ERP Consultant
Industrial Engineer Intern	Senior Ergonomist
Industrial Engineer, Associate IE, Sr. IE, Principal IE	Senior IT Analyst
Information Technology Manager	Six-Sigma Consultant
Injury Prevention and Ergonomics Lead	Supply Chain Analyst, Engineer or Manager
Inventory Deployment Analyst	Supply Network Design Planner
IT Specialist	Systems Analyst
Kaizen Promotion Officer	Systems and Data Analyst
Lean Manufacturing Consultant	Systems Engineer
Lean Manufacturing Engineer	Systems Integration Engineer
Lean Practitioner/Facilitator	Technical Sales
Lean/Six Sigma Projects Leader or Instructor	Technology Analyst
Logistics Engineer	User Experience Engineer/Manager
Logistics Methods Analyst	Workforce Optimization Manager
Management Engineer	
Management Trainee	

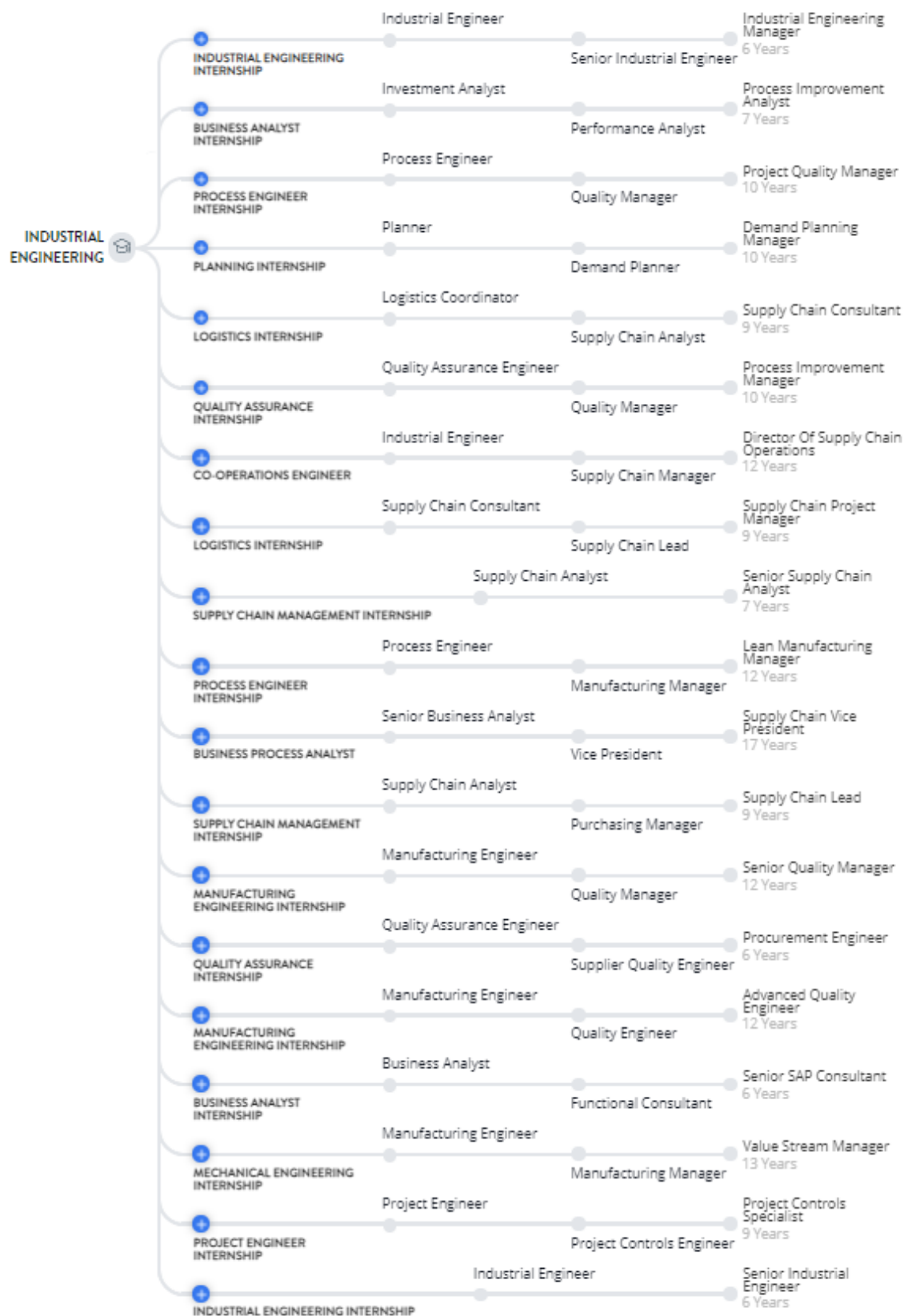
APPENDIX D: SCREENSHOTS OF THE CAREER SOURCE

Screenshot of the URL at the top of the web-page:



Screenshot of the URL and web-page with the job titles and career paths (the zoomed-in version can be found on the next page):





APPENDIX E: SCREENSHOT OF THE COMMUNITY SOURCE

Screenshot of the URL with the chosen Quora answer for the question “What are the job prospects for an industrial engineer?”:

The screenshot shows a web browser window with the Quora website. The address bar displays the URL: quora.com/What-are-the-job-prospects-for-an-industrial-engineer. The Quora logo and navigation icons are visible at the top. The main content area shows an answer by Anil, BS Chemistry, Pune, Maharashtra, India, dated July 24, 2018. The answer lists 20 job prospects for industrial engineers, followed by a concluding statement and engagement metrics.

Q (1) What are the job prospects for an industrial engineer?

Quora Home Write Ask Log In Search Quora

Anil, BS Chemistry, Pune, Maharashtra, India
Answered July 24, 2018

1. Quality Engineer
2. Production or Manufacturing Engineer
3. Operations Consultant
4. SCM consultant
5. Automation and Robotics (with specialization and experience)
6. Data Scientist
7. Data Engineer
8. Reliability Engineer
9. Logistics Engineer , Transportation or Freight Analyst or Supply Chain analyst
10. Facility Engineer
11. Demand Planner
12. Optimization Expert
13. Sales and Operations Strategy Consultant (with MBA)
14. Procurement or Spend Analyst
15. Warranty Analyst
16. Insurance or Actuarial Analyst
17. Health Informatics Consultant
18. Six Sigma Black Belt, Green Belt or Master Black Belt with experience
19. Supply Planning
20. Production Scheduler, Master Scheduler, Fleet Scheduler or Transport Planner

Above title jobs are available for industrial engineers. I would say prospects depend on your skills and application of the skills

1.7K views · View 7 upvotes · Answer requested by Deepu S Nair

7 upvotes · 0 downvotes · 0 comments

APPENDIX F: RAW DATA OF WEB-SCRAPED JOB TITLES (MAIN DATA)

Job Titles		
Associate Engineer	Product Manager	Project Quality Manager
Automation Engineer	Production Control Analyst or Supervisor	Planner
Big Data Engineer	Production System Integration	Demand Planner
Business & Systems Integration Analyst	Productivity Improvement Specialist	Demand Planning Manager
Business Analyst	Professor, Associate Professor, and Assistant Professor	Logistics Coordinator
Business Operations Specialist Manager	Program Analyst	Supply Chain Analyst
Business Process Analyst	Project Manager	Supply Chain Consultant
Business Process Management Manager	QS/ISO Auditor	Quality Assurance Engineer
Business Program Manager	Quality Engineer or Manager	Process Improvement Manager
Business Transformation Consultant	Reliability Engineer	Supply Chain Manager
Compliance Manager	Research Scientist	Director of Supply Chain Operations
Computer Integrated Manufacturing (CIM) Specialist	Research Specialist	Supply Chain Lead
Computing Architect	Risk Advisor	Supply Chain Project Manager
Consultant	Robust Design Engineer	Senior Supply Chain Analyst
Continuous Improvement Analyst, Engineer or Coordinator	Safety Engineer	Manufacturing Manager
Continuous Performance Improvement Associate	Sales Engineer	Lean Manufacturing Manager
Core Product Engineer	Independent Researcher/Author	Senior Business Analyst
Corporate Value Consultant	Industrial Engineer Intern	Vice President
Data Analyst	Industrial Engineer, Associate IE, Sr. IE, Principal IE	Supply Chain Vice President
Data Modeler	Information Technology Manager	Purchasing Manager
Data Scientist	Injury Prevention and Ergonomics Lead	Manufacturing Engineer
Design and Development Engineer	Inventory Deployment Analyst	Senior Quality Manager
Dir. Engr. & Operations & Support Svcs.	IT Specialist	Supplier Quality Engineer
Director, Integration & Innovation	Kaizen Promotion Officer	Procurement Engineer
EHS Multi Family Manager	Lean Manufacturing Consultant	Quality Engineer
Engineering Multi-Skill Manager	Lean Manufacturing Engineer	Advanced Quality Engineer
Engineering Operations Manager	Lean Practitioner/Facilitator	Business Analyst
Ergonomics Engineer	Lean/Six Sigma Projects Leader or Instructor	Functional Consultant
Ergonomist	Logistics Engineer	Senior SAP Consultant
Facilities Engineer	Logistics Method Analyst	Value Stream Manager
Facility Planner	Management Engineer	Project Engineer
Field Engineer	Management Trainee	Project Controls Engineer
Finance Employee Development Specialist	ERP Consultant	Project Controls Specialist
Financial Modeling Specialist	Senior Ergonomist	Quality Engineer
Human Factors Engineer	Senior IT Analyst	Production or Manufacturing Engineer
Manufacturing Engineer	Six-Sigma Consultant	Operations Consultant
Manufacturing engineer/production engineer	Supply Chain Analyst, Engineer, or Manager	SCM consultant
Manufacturing Supervisor or Manager	Supply Network Design Planner	Automation and Robotics (with specialization and experience)
Manufacturing Systems Engineer	Systems Analyst	Data Scientist
Manufacturing Technology Analyst	Systems and Data Analyst	Data Engineer
Methods Engineer	Systems Engineer	Reliability Engineer
Methods Process Analyst	Systems Integration Engineer	Logistics Engineer , Transportation or Freight Analyst or Supply Chain analyst
Occupational Health & Safety	Technical Sales	Facility Engineer
Operations Engineer or Analyst	Technology Analyst	Demand Planner
Operations Program Analyst	User Experience Engineer/Manager	Optimization Expert
Operations Research Analyst	Workforce Optimization Manager	Sales and Operations Strategy Consultant (with MBA)
Plant Manager	Industrial Engineer	Procurement or Spend Analyst
Plant Operations Supervisor	Senior Industrial Engineer	Warranty Analyst
President	Industrial Engineering Manager	Insurance or Actuarial Analyst
Process Control Analyst	Investment Analyst	Health Informatics Consultant
Process Engineer	Performance Analyst	Six Sigma Black Belt, Green Belt or Master Belt with experience
Process Improvement Engineer or Manager	Process Improvement Analyst	Supply Planning
Process Integration Specialist	Process Engineer	Production Scheduler, Master Scheduler, Fleet Scheduler or Transport Planner
Product Development Program Manager	Quality Manager	

Key	Source
Purple Font	University of Washington
Blue Font	Zippia
Orange Font	Quora

APPENDIX G: ALTERATION PROCESS (MAIN DATA)

Appendix G shows which data entries were altered and how they were altered. The dark green cells represent the original data entries that needed alteration. To the right of each dark green data entry is an abbreviation of the type of alteration it had, corresponding with the alteration criteria in Table 7. Some data entries had multiple forms of alteration. Underneath each dark green cell is the altered form of the data entry. Each altered data entry, which was transformed into the preferred job title format, is in light green.

Key	
Purple Font	University of Washington
Blue Font	Zippia
Orange Font	Quora
Green Highlight	Data entry in need of alteration
Light Green Highlight	Altered data entry

Job Title	Type of Alteration
Advanced Quality Engineer	Removed speciality/seniority/rank (2)
Quality Engineer	
Professor, Associate Professor, and Assistant Professor	Split (4)
Professor	
Associate Professor	
Assistant Professor	
Senior Business Analyst	Removed speciality/seniority/rank (2)
Business Analyst	
Business Operations Specialist Manager	Removed speciality/seniority/rank (2)
Business Operations Manager	
Continuous Improvement Analyst, Engineer or Coordinator	Split (4)
Continuous Improvement Analyst	
Continuous Improvement Engineer	
Continuous Improvement Coordinator	
Director of Supply Chain Operations	Turned into preferred job title format (5)
Supply Chain Operations Director	
ERP Consultant	Expanded abbreviation (3)
Enterprise Resource Planning Consultant	
Industrial Engineer, Associate IE, Sr. IE, Principal IE	Split (4), Expanded Abbreviation (3)
Industrial Engineer	
Associate Industrial Engineer	
Senior Industrial Engineer	
Principal Industrial Engineer	
Insurance or Actuarial Analyst	Split (4)
Insurance Analyst	
Actuarial Analyst	
Director, Integration & Innovation	Turned into preferred job title format (5)
Integration & Innovation Director	
Lean Practitioner/Facilitator	Split (4)
Lean Practitioner	
Lean Facilitator	

Job Title	Type of Alteration
Lean/Six Sigma Projects Leader or Instructor	Split (4)
Lean/Six Sigma Projects Leader	
Lean/Six Sigma Projects Instructor	
Logistics Engineer , Transportation or Freight Analyst or Supply Chain Analyst	Split (4)
Logistics Engineer	
Transportation or Freight Analyst	
Supply Chain Analyst	Split (4), Capitalized (1)
Manufacturing engineer/production engineer	
Manufacturing Engineer	
Production Engineer	Split (4)
Manufacturing Supervisor or Manager	
Manufacturing Supervisor	
Manufacturing Manager	Split (4)
Operations Engineer or Analyst	
Operations Engineer	
Operations Analyst	Split (4)
Process Improvement Engineer or Manager	
Process Improvement Engineer	
Process Improvement Manager	Split (4)
Procurement or Spend Analyst	
Procurement Analyst	
Spend Analyst	Split (4)
Production Control Analyst or Supervisor	
Production Control Analyst	
Production Control Supervisor	Split (4)
Production or Manufacturing Engineer	
Production Engineer	
Manufacturing Engineer	Split (4)
Production Scheduler, Master Scheduler, Fleet Scheduler or Transport Planner	
Production Scheduler	
Master Scheduler	Split (4)
Fleet Scheduler	
Transport Planner	
Quality Engineer or Manager	Split (4)
Quality Engineer	
Quality Manager	
SCM Consultant	Expanded abbreviation (3)
Supply Chain Management Consultant	
Senior Quality Manager	Removed speciality/seniority/rank (2)
Quality Manager	
Senior Supply Chain Analyst	Removed speciality/seniority/rank (2)
Supply Chain Analyst	
Supply Chain Analyst, Engineer, or Manager	Split (4)
Supply Chain Analyst	
Supply Chain Engineer	
Supply Chain Manager	Turned into preferred job title format (5)
Supply Planning	
Supply Planner	Split (4)
User Experience Engineer/Manager	
User Experience Engineer	
User Experience Manager	Removed speciality/seniority/rank (2), Expanded abbreviation (3)
Senior IT Analyst	
Information Technology Analyst	
Senior SAP Consultant	Removed speciality/seniority/rank (2)
SAP Consultant	
IT Specialist	Expanded abbreviation (3)
Information Technology Specialist	
Sales and Operations Strategy Consultant (with MBA)	Removed speciality/seniority/rank (2)
Sales and Operations Strategy Consultant	

APPENDIX H: EXCLUSION PROCESS (MAIN DATA)

Appendix H shows which data entries were excluded and why. These data entries are in red cells. The reason(s) for exclusion is/are to the right of each data entry, corresponding with the exclusion criteria in Table 8.

Key	
Purple Font	University of Washington
Blue Font	Zippia
Orange Font	Quora
Red Highlight	Excluded Data Entry

Job Title	Reason for Exclusion
Assistant Professor	Academic position (3), Speciality/seniority/rank (2)
Associate Engineer	Ambiguous (6), Speciality/seniority/rank (2)
Associate Industrial Engineer	Speciality/seniority/rank (2), Includes "industrial engineer" (1)
Associate Professor	Academic position (3), Speciality/seniority/rank (2)
Automation and Robotics (with specialization and experience)	Not in preferred job title format (8), Speciality/seniority/rank (2)
Business Analyst	Repetition (9)
Business Analyst	Repetition (9)
Optimization Expert	Speciality/seniority/rank (2)
Computer Integrated Manufacturing (CIM) Specialist	Not in IEBoK (7), Speciality/seniority/rank (2)
Computing Architect	Not in IEBoK (7), Speciality/seniority/rank (2)
Consultant	Ambiguous (6), Not in preferred job title (8)
Continuous Performance Improvement Associate	Speciality/seniority/rank (2)
Data Scientist	Repetition (9)
Demand Planner	Repetition (9)
Dir. Engr. & Operations & Support Svcs.	Unclear abbreviation (5), Not in preferred job title format (8)
EHS Multi Family Manager	Not in IEBoK (7), Unclear abbreviation (5)
Engineering Multi-Skill Manager	Ambiguous (6)
Finance Employee Development Specialist	Not in IEBoK (7), Seniority/Specialty/Rank (2)
Financial Modeling Specialist	Not in IEBoK (7), Seniority/Specialty/Rank (2)
Independent Researcher/Author	Personal/entrepreneurial endeavour (4)
Industrial Engineer	Includes "industrial engineer" (1), Repetition (9)
Industrial Engineer	Includes "industrial engineer" (1), Repetition (9)
Industrial Engineer Intern	Includes "industrial engineer" (1), Speciality/seniority/rank (2)
Industrial Engineering Manager	Includes "industrial engineer" (1)
Insurance Analyst	Not in IEBoK (7)
Actuarial Analyst	Not in IEBoK (7)
Information Technology Specialist	Not in IEBoK (7), Speciality/seniority/rank (2)
Lean/Six Sigma Projects Instructor	Academic position (3)
Logistics Engineer	Repetition (9)
Management Trainee	Ambiguous (6), Speciality/seniority/rank (2)

Job Title	Reason for Exclusion
Manufacturing Engineer	Repetition (9)
Manufacturing Engineer	Repetition (9)
Manufacturing Engineer	Repetition (9)
Manufacturing Manager	Repetition (9)
Master Scheduler	Speciality/seniority/rank (2), Not in preferred job title format (8)
Occupational Health & Safety	Not in preferred job title format (8)
Ergonomist	Not in preferred job title format (8)
Planner	Ambiguous (6), Not in preferred job title (8)
President	Ambiguous (6), Not in IEBoK (7), Not in preferred job title format (8)
Principal Industrial Engineer	Speciality/seniority/rank (2), Includes "industrial engineer" (1)
Process Engineer	Repetition (9)
Process Improvement Manager	Repetition (9)
Process Integration Specialist	Speciality/seniority/rank (2)
Production Engineer	Repetition (9)
Production System Integration	Not in preferred job title format (8)
Productivity Improvement Specialist	Speciality/seniority/rank (2)
Professor	Academic position (3)
Project Controls Specialist	Speciality/seniority/rank (2)
QS/ISO Auditor	Unclear abbreviation (5)
Quality Engineer	Repetition (9)
Quality Engineer	Repetition (9)
Quality Engineer	Repetition (9)
Quality Manager	Repetition (9)
Quality Manager	Repetition (9)
Reliability Engineer	Repetition (9)
Research Scientist	Academic position (3)
Research Specialist	Academic position (3), Speciality/seniority/rank (2)
Sales Engineer	Not in IEBoK (7)
Senior Ergonomist	Speciality/seniority/rank (2), Not in preferred job title format (8)
Senior Industrial Engineer	Speciality/seniority/rank (2), Includes "industrial engineer" (1), Repetition (9)
Senior Industrial Engineer	Speciality/seniority/rank (2), Includes "industrial engineer" (1), Repetition (9)
SAP Consultant	Not in IEBoK (7), Unclear abbreviation (5)
Six Sigma Black Belt, Green Belt or Master Belt with experience	Speciality/seniority/rank (2), Not in preferred job title format (8)
Supply Chain Analyst	Repetition (9)
Supply Chain Analyst	Repetition (9)
Supply Chain Analyst	Repetition (9)
Supply Chain Manager	Repetition (9)
Supply Chain Vice President	Speciality/seniority/rank (2)
Technical Sales	Not in preferred job title format (8), Not in IEBoK (7)
User Experience Engineer	Not in IEBoK (7)
User Experience Manager	Not in IEBoK (7)
Vice President	Speciality/seniority/rank (2), Ambiguous (6), Not in preferred job title format (8)

APPENDIX I: RAW DATA OF WEB-SCRAPED JOB TITLES (ITERATION 2)

	Job Titles
Applications Engineer	Packaging Engineer
Automation Engineer	Performance Engineer
Chief Engineer	Plant Engineer
Controls Engineer	Process Control Engineer
Design Engineer	Process Design Engineer
Engineering Director	Process Engineer
Field Service Engineer	Production Engineer
Industrial Designer	Project Controls Engineer
Industrial Engineer	Project Engineer
Industrial Engineering Manager	Proposal Engineering Coordinator
Industrial Specialist	Sales Engineer
Maintenance Engineer	Senior Manufacturing Engineer
Manufacturing Engineer	Senior Process Engineer
Manufacturing Engineering Manager	Industrial Engineer
Materials Engineer	Process Engineer
Mining Engineer	Supply Chain Analyst
Operations Engineer	Logistics Coordinator
Packaging Engineer	Industrial Engineering Manager
Process Engineer	Process Engineering Manager
Product Engineer	College Professor
Production Engineer	Supply Chain Consultant
Production Manager	Architectural and Engineering Managers
Project Engineer	Cost Estimators
Quality Engineer	Health and Safety Engineers
Reliability Engineer	Industrial Engineering Technicians
Systems Engineer	Industrial Production Managers
Test Engineer	Logisticians
Tooling Engineer	Management Analysts
Validation Engineer	Occupational Health and Safety Specialists and Technicians
Compliance Engineer	Quality Control Inspectors
Component Engineer	Management Engineer
Controls Engineer	Ergonomist
Cost Engineer	Operations Analyst
Design Engineer	Quality Engineer
Facilities Engineer	Efficiency engineers
Industrial Engineer	Manufacturing engineers
Logistics Engineer	Packaging engineers
Maintenance Engineer	Production engineers
Manufacturing Engineer	Engineer
Nuclear Engineer	Manufacturing Engineer
Operations Engineer	Mechanical Engineer

Key	Source URL
Grey font	https://www.theladders.com/job-titles/industrial-engineering
Blue font	https://www.thebalancecareers.com/engineering-job-titles-2061493
Orange font	https://www.bestcolleges.com/careers/science-and-engineering/industrial-engineering/
Yellow font	https://collegegrad.com/careers/industrial-engineers
Green font	https://www.worldwidelearn.com/online-education-guide/engineering/industrial-engineering-major.htm
Light blue font	https://www.raise.me/careers/architecture-and-engineering/industrial-engineers
Purple font	https://www.indeed.com/recruitment/job-description/industrial-engineer

APPENDIX J: ALTERATION PROCESS (ITERATION 2)

Appendix J shows which data entries (from the second iteration of web-scraping) were altered and how they were altered. The dark green cells represent the original data entries that needed alteration. To the right of each dark green data entry is an abbreviation of the type of alteration it had, corresponding with the alteration criteria in Table 7. Some data entries had multiple forms of alteration. Underneath each dark green cell is the altered form of the data entry. Each altered data entry, which was transformed into the preferred job title format, is in light green.

Job title	Type of Alteration
Senior Manufacturing Engineer	Removed speciality/seniority/rank (2)
Manufacturing Engineer	
Senior Process Engineer	Removed speciality/seniority/rank (2)
Process Engineer	
Cost Estimators	Turned into preferred job title format (5) by removing plurality
Cost Estimator	
Health and Safety Engineers	Turned into preferred job title format (5) by removing plurality
Health and Safety Engineer	
Industrial Production Managers	Turned into preferred job title format (5) by removing plurality
Industrial Production Manager	
Management Analysts	Turned into preferred job title format (5) by removing plurality
Management Analyst	
Occupational Health and Safety Specialists and Technicians	Turned into preferred job title format (5) by removing plurality, Removed speciality/seniority/rank (2)
Occupational Health and Safety Technician	
Quality Control Inspectors	Turned into preferred job title format (5) by removing plurality
Quality Control Inspector	
Efficiency engineers	Turned into preferred job title format (5) by removing plurality, Capitalized (1)
Efficiency Engineer	
Manufacturing engineers	Turned into preferred job title format (5) by removing plurality, Capitalized (1)
Manufacturing Engineer	
Packaging engineers	Turned into preferred job title format (5) by removing plurality, Capitalized (1)
Packaging Engineer	
Production engineers	Turned into preferred job title format (5) by removing plurality, Capitalized (1)
Production Engineer	

APPENDIX K: EXCLUSION PROCESS (ITERATION 2)

Appendix K shows which data entries (from the second iteration of web-scraping) were excluded and why. These data entries are in red cells. The reason(s) for exclusion is/are to the right of each data entry, corresponding with the exclusion criteria in Table 8.

Job title	Reason for Exclusion
Controls Engineer	Repetition (9)
Applications Engineer	Not in IEBoK (7)
Chief Engineer	Ambiguous (6), Seniority/Specialty/Rank (2)
Industrial Designer	Not in IEBoK (7)
Industrial Engineer	Includes "industrial engineer" (1)
Industrial Engineering Manager	Includes "industrial engineer" (1)
Industrial Specialist	Seniority/Specialty/Rank (2)
Mining Engineer	Not in IEBoK (7)
Component Engineer	Not in IEBoK (7)
Industrial Engineer	Includes "industrial engineer" (1)
Nuclear Engineer	Not in IEBoK (7)
Sales Engineer	Not in IEBoK (7)
Industrial Engineer	Includes "industrial engineer" (1)
Industrial Engineering Manager	Includes "industrial engineer" (1)
College Professor	Academic position (3)
Architectural and Engineering Managers	Not in IEBoK (7)
Industrial Engineering Technicians	Includes "industrial engineer" (1)
Logisticians	Not in preferred job title format (8)
Ergonomist	Not in preferred job title format (8)
Engineer	Ambiguous (6), Not in preferred job title format (8)
Mechanical Engineer	Not in IEBoK (7)
Design Engineer	Repetition (9)
Maintenance Engineer	Repetition (9)
Manufacturing Engineer	Repetition (9)
Manufacturing Engineer	Repetition (9)
Manufacturing Engineer	Repetition (9)
Manufacturing Engineer	Repetition (9)
Manufacturing Engineer	Repetition (9)
Operations Engineer	Repetition (9)
Packaging Engineer	Repetition (9)
Packaging Engineer	Repetition (9)
Process Engineer	Repetition (9)
Process Engineer	Repetition (9)
Process Engineer	Repetition (9)
Production Engineer	Repetition (9)
Production Engineer	Repetition (9)
Project Engineer	Repetition (9)
Quality Engineer	Repetition (9)