Complexity factors affecting the duration of research and development projects

MAGISTER PHILOSOPHIAE

In

ENGINEERING MANAGEMENT

At the

FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

Of the

UNIVERSITY of JOHANNESBURG

Student: PM Molepo 200807345

Supervisor: Prof A. Marnewick

Co-supervisor: Mr. N Joseph

November 2018

Declaration

I **Pheladi Morufa Molepo**, hereby declare that the content of this report represents my own work, unless otherwise indicated by appropriate references. I declare that I have written my own sentences and paragraphs throughout my essay and I have credited all ideas I have gained from other people's work.

Abstract

Research and development (R&D) plays an important role in the development of the economy. Organisations are encouraged to strive for innovative ways to survive due to worldwide competition, constant changes of customer needs and technological advancements. Today R&D projects are fast becoming the core business of many organisations and are used to increase profitability and growth. These projects have a time based competition and fast technological development. Therefore, the time it takes to get an innovation into the market becomes a very significant and critical index of global competition.

Despite being the core business of many organisations, R&D projects are beset with time and cost overrun and thus are terminated before achieving the objectives. These projects are characterised by high uncertainties and complex properties. As a result, organisations are faced with the challenges of effectively managing these projects. The core objective of this study is to identify the complexities of the R&D project management process and their impact on project duration.

This research study is executed through literature review and a single case study conducted on the R&D team in an engineering organisation. The case study was conducted using questionnaires and interviews. The questionnaires were sent to the R&D technical specialists whereas the interviews were conducted with the managers. Literature review identified eight sources of R&D project complexity as technological, organisational, intraorganisational, technical, development, marketing, dynamic and uncertainty. Under each complexity, there are different factors contributing to the source of project complexity.

In terms of the impact the complexity has on project duration; the results show that lack of competent resources is the main reason why projects end up delayed. Again, the change in project scope involves addition of project activities to the project, requiring more time to complete the project.

The main findings of the research show that the R&D technical specialists and the managers have different perspectives regarding the factors that contribute to R&D project complexity. According to the technical specialists, changes in process management and scope variation are the highest complexity contributors. However, the results from interviews with the managers indicate that lack of top management support is the cause of complexities in projects.

Although the identified list of R&D complexity factors might differ depending on the project type and industry, the results of this research will benefit the project managers of R&D

projects across industries. This research contributes to the existing knowledge on the complexities of R&D projects.

Acknowledgements

Let me first start by thanking God, without whom none of this will be possible. Thank you Lord for the gift of Life. "For I know the plans I have for you..." Jerimiah 29:11

I want to extend my sincere gratitude to my family for their love, support, motivation and understanding throughout my studies. You guys are my source of strength. I love you all so much.

A special dedication to my beloved parents, thank you for always believing in me and supporting my dreams in all ways possible. Ke a leboga Moloto le Mosebjadi. God will continue to bless you through your descendants.

I would also like to thank my partner Kgabane for his endless love and motivation. I love you babe.

Last but not least, a very special thank you to my beautiful daughter Rethabile T, my angel, my purpose, my inspiration, my force. You are the reason I kept on pushing even when it was not easy. Those kicks kept me awake and motivated, and they reminded me that I have to do this. Thank you for allowing us to finish what we have started. I dedicate this Masters to you my sweet little angel, may you value education as much as mommy does. I love you.

Lastly, many thanks to my supervisors, Prof Annlizé and Nazeer for all the sessions, discussions, reviews and comments. They were fruitful.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ICT	Information communication technology
ISO	International Standard Organisation
IT	Information Technology
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
R&D	Research and Development
RQ	Research question

1 Chapter 1 Introduction

In this chapter, the background of the study is introduced from which the problem statement is formulated. The research questions are derived from the problem statement and the objective of the study is detailed. Lastly, the layout of the research is explained.

1.1 Introduction and Background

A project is defined by PMI (2017) as a temporary endeavour undertaken to create a unique product or service. Projects play an important role in many modern industries and organisations for new product development, construction, product improvement and system development (Soderlund, 2005; Shenhar and Dvir, 2008). Many organisations organise their activities in projects as part of their strategic and operational management to achieve their goals or objectives (Soderlund, 2002; Chroneer and Bergquist, 2012).

In order to achieve the end goal of the project, different project activities are broken down into subtasks and project management is applied to plan, schedule and control these activities (Radujković and Sjekavica, 2017). According to Wang *et al.* (2017), project management plays a significant role in the sustainable growth of organisations. Not only does it focus on achieving the objectives of the projects but also on integrating different resources and stakeholders at different phases of the project. The interest in project management has grown over the years, since projects are now the main activities of many organisations. The implementation of project management in organisations has proven to be beneficial in that amongst others, it increases customer satisfaction and gives a return on investment (Badewi, 2016).

One type of project undertaken by many technology-based organisations is the research and development project. R&D projects are important for bringing competitive advantage to the organisation by developing new and enhanced products (Naveh, 2007). These projects play an important role in developing the economy and therefore their management becomes a key factor in the organisation (Salguero *et al.*, 2015; Khoshnevis and Teirlinck, 2018). However, since these projects have a time-based competition and a fast technological development, it becomes a challenge managing them (Soderlund, 2002). R&D management processes, different tools and techniques are put in place to ensure efficient management of these projects. However, just like any other process, R&D management processes have their weaknesses.

1.2 Problem statement

R&D projects present high uncertainty which leads to high risks that could result in project failure (Wang and Yang, 2012). These uncertainties can be due to different reasons such as management processes, technical or financial conditions. The authors, Kerzner (1981), Burder (2002), Daim (2014), Mikulskienė (2014) and Salguero *et al.*(2015) all agree that many organisations are faced with the challenges of managing R&D activities. In many cases, R&D facilities comprise of technical minded people such as engineers and scientists and often these people are expected to lead the projects as project managers (Kerzner, 1981).

In the research conducted by Kiyota and Kubo (2016), it is stated that due to high uncertainty and unclear objectives of R&D projects, there was no project management process suitable for these projects. However with the increasing degree of competition and accelerated pace of technological changes, effective project management of R&D projects has become important but remains challenging (Park and Kim, 2005).

Although different project management tools and techniques are utilised in managing many R&D projects, these projects still exceed planned project times and costs and end up terminated without achieving the objective (Chroneer and Bergquist, 2012). There are several different types of R&D organisations each with a distinct purpose and objective and R&D management process differs from industry to industry due to the nature of the work and size of the organisation (Cavone, Chiesa and Manzini, 2000). However Mikulskienė (2014) argues that due to their complexity and uncertainty, all R&D projects require a flexible management approach.

R&D projects are further described by Mikulskienė (2014) as being complex and interdependent. Project complexities can be due to controllable and uncontrollable factors such as resource requirements, change in scope and under budgeting. R&D complexities have raised a serious concern as they influence project management processes such as modelling, evaluation, and control (Cristóbal, 2017). Other factors of project management impacted by project complexities include time, cost and quality.

The success and duration of the project is somewhat influenced by the way in which complexity and uncertainty are managed in the project (Izmailov, Korneva and Kozhemiakin, 2016). It is therefore vital that R&D project managers understand the complexities of R&D projects, their impact on project delivery, and how to effectively manage them in order to achieve the project objectives, particularly delivering the project within the planned period.

According to Soderlund (2002), the importance and role of milestones and deadlines is not given adequate attention in project management. R&D projects tend to run for a longer time than planned and the project managers overlook the effect of the late delivery on the overall outcome of the project. **Therefore, the objective of this research study is to identify R&D project complexities and their impact on project duration.**

1.3 Research objectives

Innovation is considered one of the most vital factors in growing the country's economy that can be improved through research and development. According to the South African National Survey of Research and Experimental Development CeSTII (2014); South Africa's investment in R&D is growing rapidly. However, despite this sudden interest in R&D there is very limited literature study conducted on the management of R&D projects (Salguero *et al.*, 2015). Therefore, it is crucial that more focus should be spun on the management of these projects.

This research aims to identify the complexities of managing projects in R&D and the impact these complexities have on the overall outcome of the projects. The research will be conducted through theoretical literature review and a case study.

1.4 Research questions

This research will focus on the effective management of R&D projects to ensure that these projects are delivered on time by focusing on the following questions relating to the complexities experienced in R&D projects:

1. What are the complexities of R&D project management processes?
2. What is the impact of the complexities on project duration?

Although each project is different, the research will establish how different R&D projects are from other projects and whether the complexities encountered in these projects are the same or different from those in other projects.

1.5 Research Design

The literature review on this research study will be conducted on different R&D projects, however; the case study will focus on R&D complexities in an engineering organisation.

1.5.1 Literature review

The research is executed by conducting literature review from reputable scholarly articles, books, standards and surveys on existing research pertaining to the complexities of R&D

management processes. There exists different types of literature review; however, this research will focus more on the theoretical review type that will include studying existing theories and determining the extent to which the theories were scrutinised. Through literature review, a clear understating of the context of the research problem will be formulated. Any gaps that are present in the literature will be identified and the execution of this research intends to close those gaps.

1.5.2 Case study

In addition to the literature, a case study will be conducted using questionnaires and interviews. The questionnaires will be derived based on the theory from the literature review and driven by the existing research questions in section 1.4. The case study will be conducted on an R&D team in an engineering organisation. The questionnaires will be sent to R&D technical specialists and the interviews will be conducted with the managers.

The results of the case studies will be analysed and compared with the theory from the literature review to establish the relationship between theory and practical experience with regard to the complexities of project management in R&D and the impact they have on the deadline of the project.

1.6 Research layout

This research report consists of five chapters structured as follows:

Chapter 1: Introduction and background

Chapter 1 introduces the background of projects, R&D and project management in general. The problem statement is formulated in this chapter based on the background of R&D projects and the problem that the research aims to solve. The main objective of conducting this research is stated in the chapter from which the research hypotheses are derived. Lastly, the chapter describes the research design followed for conducting this research study.

Chapter 2: Literature study

A literature study will be conducted to establish the role of project management processes in R&D projects. In this chapter, the processes of R&D management will be studied to make sense of the two research questions formulated in section 1.4. The complexities experienced in R&D management processes and how they affect the project delivery will be identified.

Chapter 3: Research methods

Chapter 3 will present the most appropriate research method that will be used in this study to address the research problems. The details of how data will be collected, analysed and

presented from the case study to ensure accurate presentation of information will be detailed in this chapter.

Chapter 4: Data analysis

Chapter 4 will present an analysis of the data collected through questionnaires and interviews. The method of data analysis will be detailed in this chapter as well as the findings of the results.

Chapter 5: Conclusions and recommendations

Although each chapter will have a summary of important facts discussed, the research will include a final chapter that will summarise what was discussed in the report. In this section, conclusions on the findings of the research will be drawn. The appropriate recommendations will also be included in this chapter. Any limitations encountered throughout the research study will also be stated in this chapter.

1.7 Conclusion

R&D projects are complex, challenging and present high uncertainties. The ways in which these projects are managed affect the project outcomes. Project managers are faced with the challenge of effectively managing and achieving project outcomes due to the complexities of these projects. This study was initiated to identify why R&D projects are delivered late to the market. This is going to be achieved by answering the two research questions generated in this chapter. The research questions are; what are the complexities of R&D project management process and what is their impact on project duration.

The objectives of the research will be achieved through literature review and a case study where questionnaires will be completed and interviews will be conducted with an R&D team. Data from the case study will be analysed and compared with the findings of the literature review.

2 Chapter 2 Literature review

This chapter presents the literature review to answer the research questions formulated in chapter 1. The properties of R&D projects are presented to understand these projects. The sources of R&D project complexities and the factors that contribute to each complexity source are identified through this literature study. The impacts of each complexity factor on project duration are discussed. Lastly, effective ways of managing R&D project complexities to ensure on-time delivery are discussed in this chapter.

2.1 R&D projects

Many organisations are encouraged to identify innovative ways to survive due to worldwide competition, constant changes of customer needs and technological advancements. Organisations improve their innovation aptitudes in order to increase profitability and growth through R&D (Daim, 2014). R&D is defined by Mikulskienė (2014), *as activities of intellectual work for creating new knowledge through research and the development of new products.* R&D projects are becoming the core business of many organisations in this era of technology and innovation. More and more organisations are investing in these forms of projects, because besides being key to development, innovation and technology, R&D projects play an important role in the development and sustaining of the national economy Khoshnevis and Teirlinck (2018) bringing a competitive advantage to the organisation's market.

R&D activities, just like any other project have defined start and finish points and are carried out to meet specified objectives within defined aspects of project management (Mikulskienė, 2014). The activities of R&D projects differ from industry to industry, according to the organisation size, structure and objectives (White, 1980; Cavone, Chiesa and Manzini, 2000). There exists three types of R&D activities namely; basic, applied and development research (Krause and Liu, 1993; Lalienė and Sakalas, 2014). Public institutions expand on existing knowledge or acquire new knowledge mainly through basic research. Applied research is conducted to find practical solutions to problems in industries by applying the findings of the basic research. Development research is mainly conducted by business organisations in an attempt to upgrade their products or to develop new products (Kuchta *et al.*, 2015).

R&D projects and purpose further differ in private and public entities. In public sectors like academic and government entities, research is conducted to discover new and advanced knowledge; whereas in most private sectors the core function of R&D is to apply knowledge to develop new products and gain profit (Basu, 2016).

In their nature R&D projects have unique attributes; they present high uncertainties, they are flexible and therefore require flexible management. Although perceived to be unique, R&D projects should not be isolated from the rest of the business. In order for organisations to create an optimal value from the investments of R&D projects, these projects should be aligned with the business strategy (Krause and Liu, 1993; Too and Weaver, 2014). Management should support R&D as a business activity because lack of support and conflicting corporate issues from executives can have a negative influence on the progress and outcome of the project (Too and Weaver, 2014).

2.1.1 Properties of R&D projects

Many R&D projects are executed for several years and require large amount of financial investment. R&D projects are subjected to unpredictable technological, time, goal and cost uncertainties (Kuchta *et al.*, 2015). Presented in Figure 1 as derived by the author are the properties that make R&D projects complex. R&D projects are multidisciplinary, interconnected with several departments or companies and the development of the new products introduces uncertainty and therefore requires flexible management (Kerzner and Belack, 2010). Although all projects present risks, R&D projects are at a higher risk of being completed successfully and on time due to their high uncertainties, spontaneity and flexible process (Laliene and Liepe, 2015).

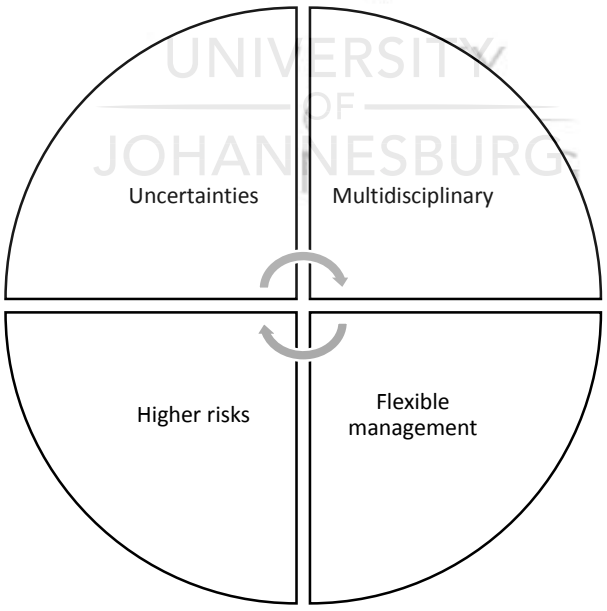

Figure 1: Properties of R&D projects

2.2 Project management in R&D

R&D is not considered a project until it is evaluated, planned, scheduled, budgeted, controlled, monitored and managed by a project manager applying project management methodologies (Basu, 2016). Project management is essential in ensuring that project aspects are planned, organised, monitored and controlled to accomplish the objectives within agreed time, cost and performance by applying the project management knowledge, skills, techniques and tools (Association for Project Management, 2006; PMI, 2017). Due to their unique attributes, R&D projects are expected to be managed differently not using traditional project management methods (shenhar, 2001; larsen, 2004; kuchta and skowron, 2015).

By applying project management techniques and principles, organisations enhances the technical, cost and schedule performance of the project. Well-developed standards such as the Project Management Institute's Project Management Body of Knowledge (PMI's PMBOK) and ISO 21500 standards are available for providing knowledge, guidelines and framework on how to apply project management to projects (Zandhuis and Stellingwerf, 2012). The use of these standards provides a common understanding of how the project should be managed from start to finish. In R&D projects, the application of project management techniques assists in dealing with the uncertainties of the project (Mikulskienė, 2014).

2.2.1 Project management process

Managing projects is a process; a process that ensures that there is an effective flow of the project throughout its life cycle (PMI, 2017). The project management process is a defined continuous methodology used to manage projects to ensure that all aspects of the project are considered so that the project achieves its objectives (Tonchia, 2008). The project management process, like any other process requires to be managed for improvement purposes and to ensure that it is compliant. The effective management of the project management process enhances the success rate of projects. Without these processes in place, project management will be conducted in an unpredictable way, which will lead to inefficiencies. In R&D, the project management process differs according to the type of R&D and its activities and unlike other projects, R&D processes are continuous and iterative (Cavone, Chiesa and Manzini, 2000; Lalienė and Sakalas, 2014).

According to the Association for Project Management (2006), the project management process is the only point of integration between project inputs and outputs as illustrated in Figure 2. It is considered a standard operating procedure to deal with project issues encountered during execution (Mossalam, 2017). To achieve the objectives of the project,

the activities of the project management process transform inputs into outputs, by applying project management mechanisms and taking into consideration project constraints (Tonchia, 2008). Project input in this case is considered as the need for initiating the project, mechanisms refer to project management tools, techniques and resources that will be used to perform the process and constraints are the variables that project achievement is based on (Mossalam, 2017). The output is the achieved project deliverable.

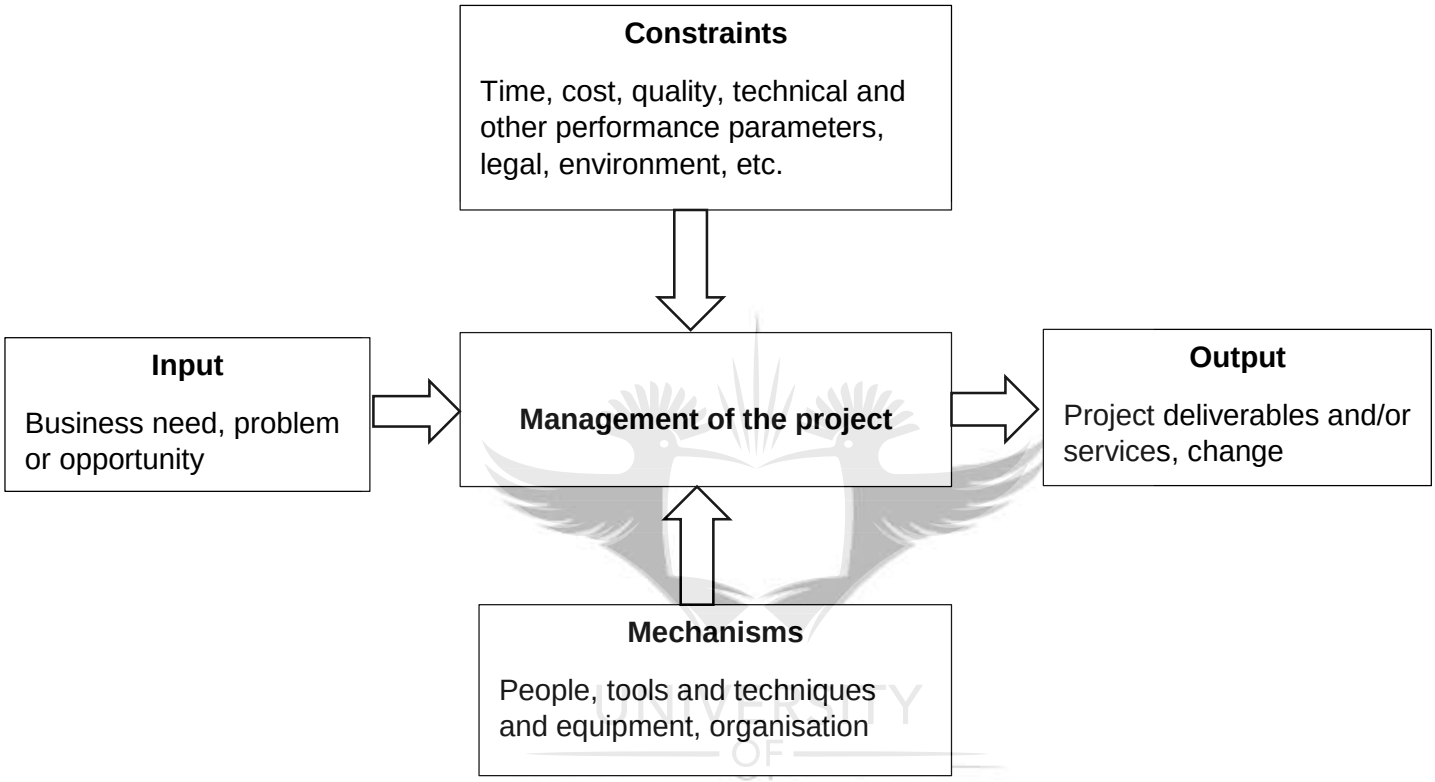

Figure 2: The project management process

The R&D project management process supports project managers to thoroughly control and monitor the activities of R&D (Lee, Jeong and Byungun, 2017). Without this process organisations are risking the progress of achieving R&D deliverables.

2.2.2 R&D project life cycle

All projects go through a life cycle and the life cycle differs according to the type of project, industry or organisation (Association for Project Management, 2006). A project life cycle is tailored to suit each individual project based on project requirements and application (Labuschagne and Brent, 2005; Basu, 2016). Based on their flexibility, the author Mikulskienė (2014), proposed that R&D projects can be managed through a six stage project life cycle as shown in Figure 3, derived by the author. The project life cycle should not be confused with the project management process. A project life cycle is defined by the

Association for Project Management (2006) as a series of phases that all projects pass through; while the project management process is the application of the processes to each project phase to ensure that the project deliverables are reached.

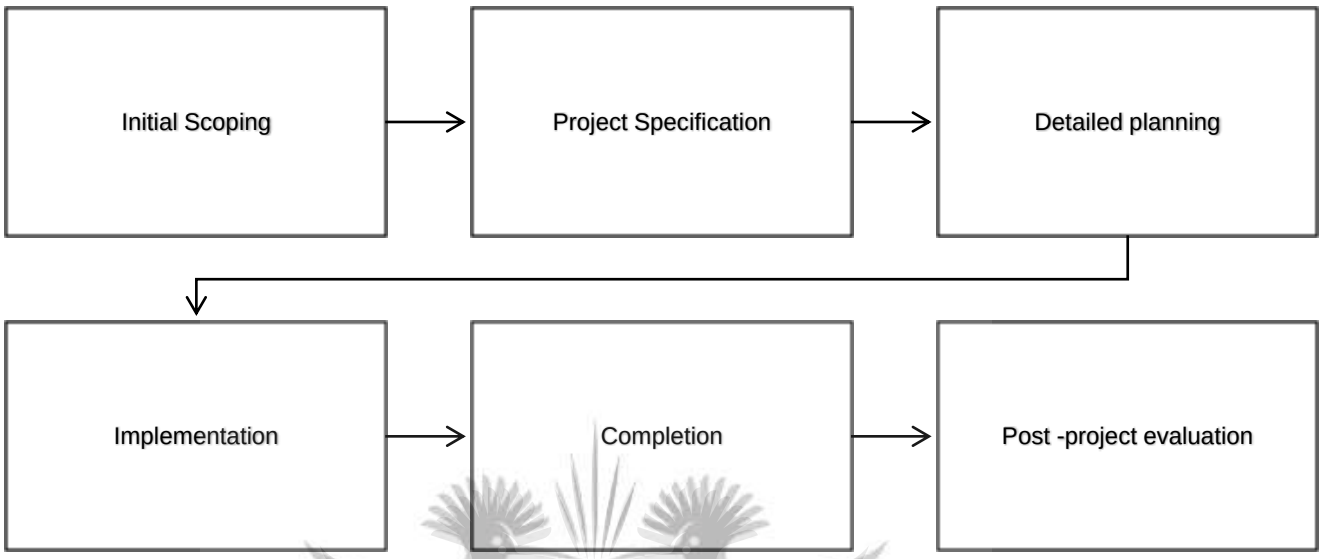

Figure 3: Six phases of R&D project lifecycle

In each project phase, project management processes are applied as follows:

Initial scoping

Initiation is the first phase of the project life cycle, where the problem or the need to initiate the project is identified (Association for Project Management, 2006). In this phase, feasibility studies are conducted and the project goal is defined and aligned with the business strategy (Mikulskienė, 2014). The output of this phase is usually a project charter which describes key information of the project such as the project scope, resource impacts and deliverables (Loudon, 2012). When setting the goals of R&D projects, it is essential to permit flexibility to accommodate project improvement due to the complexity and uncertainty of these projects.

Project specification

In this phase, a clear project specification is drafted and agreed upon between the client and the service provider. The availability of the required resources, tools and skills is arranged in this phase before project planning starts (Mikulskienė, 2014). Project specification in R&D projects is done based on the project needs accommodating for flexibility based on project complexity.

Detailed planning

At this phase, the project deliverables are planned and the deadlines are scheduled (Association for Project Management, 2006). The main output of the planning phase is a project plan. The project plan describes the complete methodology on how the project will be undertaken to reach the objectives (Loudon, 2012). Planning in R&D projects is somewhat challenging because of the projects' high uncertainty and complexity. These uncertainties make it difficult to set the time and deliverables of R&D projects.

Implementation

Also known as the project execution phase; the project plan is executed, monitored and controlled during this phase. The project manager monitors the implementation to ensure that the objectives of scope, time, cost and quality are achieved (Kuchta *et al.*, 2015). The output of the project implementation is a completed project. This is a crucial phase in R&D projects; new possibilities can be observed and implemented in this stage, changing or increasing the initial scope of the project and therefore increasing the project complexity.

Completion

During the project completion stage, the activities of the project are completed and the project is handed over to the client. The deliverables are evaluated against the acceptance criteria. However in R&D, more often the goals set during the initiation stage can be changed during implementation, therefore in this phase flexibility of the acceptance criteria should be taken into consideration when accepting project deliverables (Association for Project Management, 2006).

Post project evaluation

During this phase, the project is in service and it receives the required maintenance and support from the team that was part of the project. Lessons learned during the period of the project are reviewed and documented for referral in improving future projects (Loudon, 2012). In R&D, since the technology is evolving, the project gets advanced to meet the latest technology.

The life cycle attributes of R&D projects are more dynamic and flexible unlike those of traditional projects such as those in the manufacturing and construction industries (Basu, 2016). Variations exist in the stages of the project life cycle and failure to take them into consideration lead to difficulties in R&D performance (Daniel Sherman and Olsen, 1996).

2.2.3 R&D Project management success

The success of project management is assessed based on many components. Some of which include the deliverables provided at the end of the project whereas others are measured during the execution of the project. The famous project constraints of time, cost and quality are used to assess many projects in the industry including R&D projects (Sebestyen, 2017). These constraints do not directly measure the overall project success. The scope of time, cost and quality is used to measure the short term goals of the project and it should not be confused with project success which measures the general long term goals of the project (Munns and Bjeirmi, 1996; Radujković and Sjekavica, 2017). There exists a relationship between these three constraints or factors as shown in Figure 4, such that if any one of the factors are changed, the others are likely to be impacted (PMI, 2017).

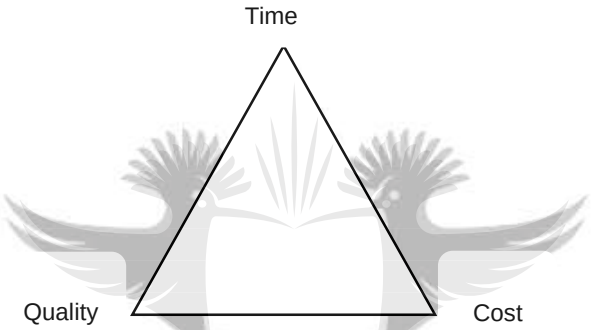

Figure 4: Traditional cost-time-quality triangle

According to Sebestyen (2017) project delay, poor quality and overrun costs do not necessarily cause the project to be a failure; however, they are an indication of an ineffective project management process. For the purpose of this research, the focus will be on the factors that influence the constraint of time in R&D projects and how they affect the project delivery date.

2.3 R&D complexities

R&D projects are highly complex with specific needs and intrinsic risks that can delay the project or jeopardise its success (Löhr *et al.*, 2018). Complexity in projects is vague because different elements contribute to the project complications. The articles by Chroneer and Bergquist (2012) and Cristóbal (2017) define complexity by the number of different elements interacting in a project and how they interconnect. The more elements involved in the project, the more complex the project becomes. R&D projects are considered complex, because of their multidisciplinary properties.

R&D complexities can either be due to internal or external factors (Jalali *et al.*, 2016). Internal factors are those factors that can be controllable such as technical or management

challenges. External factors are mostly uncontrollable and may involve change in business, market trends and technological breakthroughs (Lee, Jeong and Byungun, 2017).

In R&D projects, the complexities are caused by uncertainties, risks and challenges presented by these projects. Complexities have a major influence on R&D project management processes. They can hinder the clear identification of project objectives and affect project outcomes such as time, cost and quality. Organisations are faced with the challenge of effectively managing R&D projects because of their complex characteristics (Nobelius, 2004; Löhr *et al.*, 2018). Project managers are required to understand the complexities of these projects to enable them to better manage the projects (Cristóbal, 2017).

2.3.1 Properties of complex projects

Almost all large, high technology and many small projects experience complexity in their projects (Remington and Pollack, 2007). An analysis of three projects is done to identify their complex properties. The aim is to establish whether R&D project complexities are common in other complex projects. Presented in Table 1 is the comparison of the different components contributing to project complexity between Information Communication and Technology (ICT), R&D and construction projects derived from the authors (Kim and Wilemon, 2003; Remington and Pollack, 2007; Eriksson, Larsson and Pesämaa, 2017; Luo *et al.*, 2017; Marnewick, Erasmus and Joseph, 2017). A tick (✓) indicates that according to literature, the specific project experiences the complexity indicated in the first column. The reason for selecting a construction project is because according to Luo *et al.*, (2017), these projects are beset with cost overruns and delayed schedules due to their increasing complexities. ICT projects were selected because according to Joseph (2017), these projects do not perform well and the level of complexity in the projects is underestimated.

Table 1: Components of complexity in ICT, R&D and construction projects

Source of complexity	ICT projects	R&D projects	Construction projects	Source
Organisational complexity Organisational structure, organisational size, project team, Trust, Risk	✓	✓	✓	(Kim and Wilemon, 2003; Luo *et al.*, 2017; Marnewick and Nel, 2017)
Technical complexity Project scope, goals, technical challenges, technology, technical risk	✓	✓	✓	(Kim and Wilemon, 2003; Luo *et al.*, 2017; Marnewick, Erasmus and Joseph, 2017)
Environmental complexity				(Remington and Pollack,

Stakeholders, location, environmental risk	✓		✓	2007; Luo *et al.*, 2017; Marnewick, Erasmus and Joseph, 2017)
Uncertainty Scope, goal, project activities, technological, stakeholder, cost	✓	✓	✓	(Kim and Wilemon, 2003; Remington and Pollack, 2007; Marnewick, Erasmus and Joseph, 2017)
Dynamic complexity Change management	✓	✓		(Kim and Wilemon, 2003; Marnewick, Erasmus and Joseph, 2017)
Intraorganisational complexity Collaboration, resource sharing	✓	✓		(Kim and Wilemon, 2003; Marnewick, Erasmus and Joseph, 2017)
Technological complexity Component integration, new technology	✓	✓	✓	(Kim and Wilemon, 2003; Eriksson, Larsson and Pesämaa, 2017; Marnewick, Erasmus and Joseph, 2017)
Marketing complexity Competition, customer needs, new technology	✓	✓		(Kim and Wilemon, 2003; Marnewick, Erasmus and Joseph, 2017)
Temporal complexity Environmental impacts, future constraints, change in government leadership, change in company ownership			✓	(Remington and Pollack, 2007)
Development complexity R&D process management, information integration, project time and cost	✓	✓		(Kim and Wilemon, 2003; Marnewick, Erasmus and Joseph, 2017)
Structural complexity Top management support, component interactions, user support, Project manager's control over resources			✓	(Remington and Pollack, 2007)

From the analysis in Table 1, it can be revealed that some of the R&D complexity components are common in ICT and construction projects. However the difference lies in the fact that each component of complexity consists of several underlying factors contributing to the complexity and these factors are different in these projects (Kim and Wilemon, 2003).

2.3.2 Sources of R&D project complexity

The two research questions stated in chapter 1, that is; what are the complexities in R&D project management processes as well as their impact on the project duration, are answered through literature review in this chapter. Complexity is influenced by a number of different factors some of which are predictable and others that are not (Rolstadås and Schiefloe, 2017). Sometimes one source of project complexity can be derived from the other complexity source. According to Joseph (2017), complexity differs for different projects, organisations and goals. Complexity in R&D is due to different sources arising from its numerous activities and technologies and its impact on R&D processes differs (Kim and Wilemon, 2003). The main sources of complexities in R&D projects as mapped in Figure 5 are technological, marketing, organisational, intraorganisational, technical, development, uncertainty and dynamic (Kim and Wilemon, 2003; Joseph, 2017). Some of these sources of complexity in most cases are interrelated, some have common origins and causes, and therefore the effect of each source is considered in relation to other influences (Kim and Wilemon, 2003).

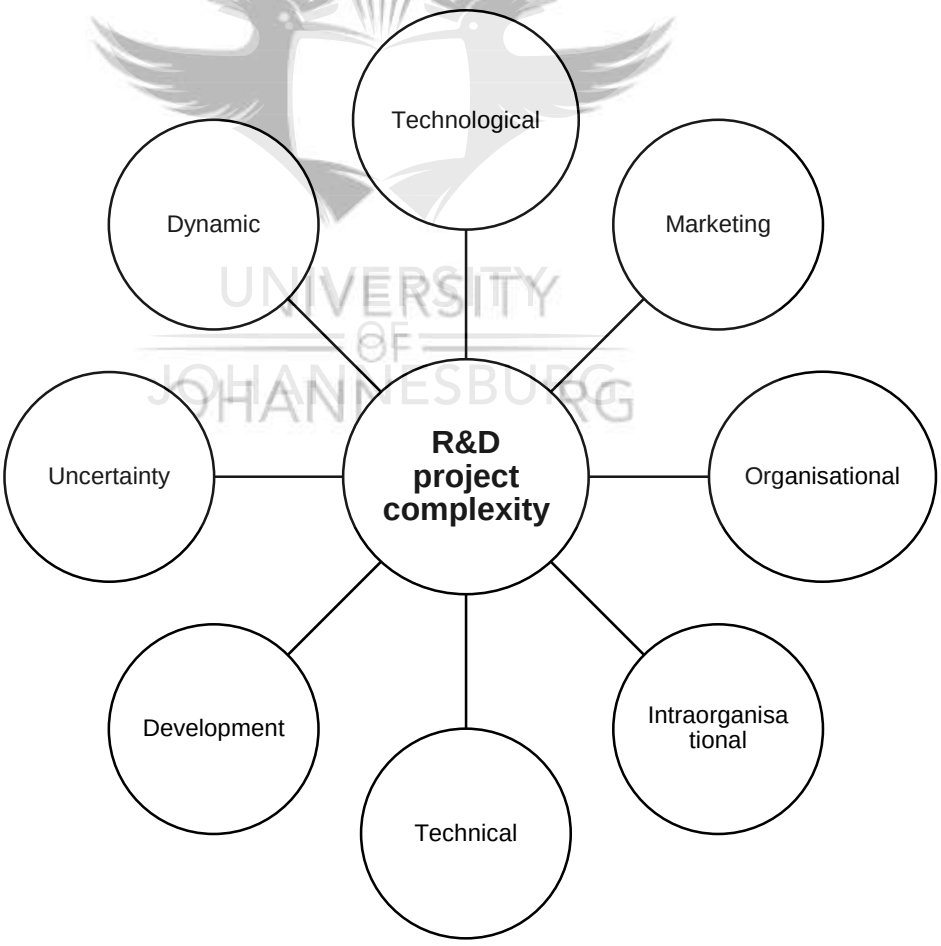

Figure 5: Sources of R&D project complexity

Each source of complexity has one or more factors that contribute to complexity as follows:

2.3.2.1 Technological complexity

Technological complexity is one of the most frequently encountered sources of complexity in R&D projects and this is due to the difficulties surrounding technological approaches and project activities (Kim and Wilemon, 2003). The factors that are associated with technological complexity in R&D include the level of component integration required and the use of new and improved technology.

Component integration

Depending on the type of product development an R&D organisation is working on, product development is an interdisciplinary system consisting of different parts, components and subsystems that are interrelated. Different components may be developed independently however; the final project requires a complete integration of the components to function effectively. A delay in the development of one of the components results in a delay of the whole product development; thus delaying the overall project. According to Kim and Wilemon (2003), complexity arises when a high number of component integration is required.

New technology

New and advanced technology is crucial in R&D projects for new product development. The migration from one form of technology to another poses complexity as it requires a new skill set, knowledge and understanding. In other cases, the technological complexity is due to the incompatibility arising when integrating the new technology into the existing processes (Kim and Wilemon, 2003). Technological complexity has an impact on the project processes and thus the project scope.

2.3.2.2 Marketing complexity

R&D projects are faced with an increased and unpredictable market change incited by competition, emergence of new technology and customer needs (Kim and Wilemon, 2003; Lee, Jeong and Byungun, 2017). These changes contribute to market complexities. R&D projects aim to break into the market with new products. A new product requires different skills and new distribution channels. According to Kim and Wilemon (2003), the creation of new marketing and distribution channels could extend the time required to develop and bring new products to market. R&D projects delivered late to the market end up being non-competitive because of the change in technology and market (Wang and Yang, 2012).

2.3.2.3 Organisational complexity

R&D projects play an important role in the development of the organisation and are influenced by the aspects of the organisation under which they operate such as the organisational size, structure and human resources (Marnewick, Erasmus and Joseph, 2017). Organisational complexity is associated with the people involved in the project and their relationship.

R&D organisational size

The size of the project team has a direct impact on project complexity. A large team with different skills and competencies executes R&D projects because of its multidisciplinary characteristics. Project managers are faced with a challenge of managing a large team of expertise with different knowledge and backgrounds. There exists high possibilities of collaboration and communication breakdown in these teams Marnewick, Erasmus and Joseph (2017) and the assignment of project tasks becomes complex. Poor communication results in some of the project tasks being erroneously executed by more than one team member and other tasks not executed at all, and thus leading to the delay of the project.

R&D organisational structure

Different types of R&D activities are executed under different organisational structures. The type of organisational structure under which R&D projects are executed has an influence on the outcome of the project (Chen, Qiao and Lee, 2014). In organisational structures where decision making is slow because of a high hierarchy of reporting structure, R&D projects are delayed because of the time it takes for information to reach the stakeholders and make decisions (Chen, Qiao and Lee, 2014).

Resources/ Project team

According to Kim and Wilemon (2003), a project team is important in achieving complex R&D activities, however the formation and management of a team involving several specialists can be challenging and complicated. It is well understood that due to their complex, multidisciplinary characteristics; R&D projects require highly skilful resources and specialists. Often organisations outsource scarce resources which add more complexity to the project in terms of diversity, geographical distance in case of dispersed teams, contractual agreements communication and collaboration (Kim and Wilemon, 2003; Marnewick, Erasmus and Joseph, 2017). A team of individuals with different knowledge, cultural differences and backgrounds becomes complex to manage. In addition, complexity arises because of the interaction between these individuals resulting in conflict and poor communication. Organisational complexity due to conflict and poor communication can result in project delays (Kim and Wilemon, 2003).

In organisations where multiple R&D projects are executed concurrently, resources are shared amongst different projects thus increasing the level of complexity in terms of resource allocation. Due to the unavailability or scarcity of skilful resources to run all R&D projects, some projects are compromised and not delivered on scheduled time (Verma, Mishra and Sinha, 2011).

In cases where the project scope has been modified, it is likely that more resources are needed to complete the project on time (Wei, 2010). However, due to the scarcity of specialists required in R&D projects, resources are often not reallocated and project deadlines are not met.

2.3.2.4 Intraorganisational complexity

Many R&D organisations collaborate with one another in order to acquire new knowledge for the research and development of new products. Collaboration between two or more organisations is beneficial in terms of cost advantages, skilled resources and sharing risks (Scandura, 2016). Even though the joint venture can assist both organisations in dealing with project complexity, the relationship between the organisations also contributes to intraorganisational complexity (Kim and Wilemon, 2003). Intraorganisational complexity arises due to geographic distance between the two organisations, communication problems and varying management styles between the joint organisations (Kim and Wilemon, 2003; Marnewick, Erasmus and Joseph, 2017). Poor communication can result in conflict. Conflict resolution requires time to be implemented therefore taking time away from executing project activities resulting in delays in the project.

2.3.2.5 Technical complexity

R&D projects present high technical complexity because of the number and variety of inputs and outputs of the project management process, different specialities involved in the project and how they interact (Marnewick, Erasmus and Joseph, 2017; Rolstadås and Schiefloe, 2017). The two major causes of technical complexity in R&D are change in project scope and the technical requirements of the project.

Project scope change

Almost all projects experience a change in project requirements throughout their lifecycle. Owing to their complexities, R&D projects are famous for their changing goals and requirements during their life cycle which can extend their duration to several years (Verma, Mishra and Sinha, 2011). The change in project scope increases the complexity of the R&D project; and it can be due to several factors such as the change in the competitive strategy of the organisation, change in technology, addition of project goals or project priorities (Verma, Mishra and Sinha, 2011). Since the R&D project scope is expressed in terms of the

project specification, cost and schedule it is clear that a change in project scope will affect the overall project output/objective, project cost and the time to delivery (Larsen *et al.*, 2014). Any scope creep in the project will result in more deliverables added to the project output, high costs, and longer duration of the project resulting in project delays.

Technical requirements

R&D projects are famous for their high degree of technical and research inputs, which contribute to their high uncertainty (Larsen *et al.*, 2014). The incorporation of technical requirements with the client's needs is often the cause of complexity in R&D projects and leads to design errors. Design errors stall project execution, since the design needs to be reviewed, corrected and accepted. Therefore, design errors cause project delays and consequently cost overruns.

2.3.2.6 Development complexity

Development complexity refers to the difficulties involved in the R&D process (Kim and Wilemon, 2003). R&D projects are run for several years and their process is quite lengthy. The integration of research decisions, the challenge of predicting the time and cost needed for the project, securing suppliers and managing supply chain, assessing the development process and performance measurements all contribute to development complexity (Kim and Wilemon, 2003). Poorly defined R&D management process becomes difficult to understand, integrate and execute and therefore stalls the project activities resulting in an overextended duration of the project.

2.3.2.7 Uncertainty

Uncertainty is one of the major sources of project complexity, it affects project performance resulting in additional costs if not managed properly during the planning phase (Floricel, Michela and Piperca, 2016). R&D projects have a high level of uncertainty and unpredictability of goals and financial costs.

Goals

A change of project scope has a direct influence on the project goals and objectives. Addition of goals to the project will increase the complexity of the projects such that the goals may contradict one another, leaving the team confused as to what the project must achieve (Marnewick, Erasmus and Joseph, 2017). R&D projects are characterised by having uncertain requirements that change throughout the execution of the project execution, requiring more time to complete the project.

Finances

The cost and project value of many R&D project investments are uncertain and this increases the level of complexity in the project (Chang, Li and Gao, 2016). The way in which

a project is financed can have a direct influence on the design of the project and the pace at which the project is delivered as well as whether the project will be able to accomplish the set requirements. Many R&D projects require substantial funds to execute and it takes time before the organisation can benefit from these projects. Organisations are faced with the challenge of financing R&D initiatives internally and therefore resort to external funding (Sasidharan, Jijo Lukose and Komera, 2015). The challenge with external funding is that it takes time for payments to reach the organisation resulting in some parts of the project phases delayed and thus delaying the overall project delivery date (Wei, 2010).

2.3.2.8 Dynamic complexity

Change is inevitable in almost all projects. Dynamic complexity can be due to a change in project specification, management team or supplier (Geraldi, Maylor and Williams, 2011). R&D project requirements bring radical and unpredictable change in the organisations (Floricel, Michela and Piperca, 2016). These changes are also regarded as the contributors of dynamic complexity in the project and force the organisation to implement change management.

R&D projects are famous for their multiple and frequent change of scope and goals throughout project execution and thus require change management for project implementation (Manoliadis and Vasilakis, 2016; Joseph, 2017). If not communicated properly, these changes can result in project inefficiencies (Geraldi, Maylor and Williams, 2011). Projects with multiple changes lead to complexity. The change management process becomes difficult to manage, resulting in the project not meeting deadlines.

2.3.3 Impact of R&D project complexities on project delivery

Project complexity has a negative influence on the project management process, activities and techniques, which in turn affects the project performance (Lebcir and Choudrie, 2011). However, for the purpose of this research, the focus is on the impact of R&D project complexity on the duration of the project. According to the article by Kim and Wilemon (2003), the increasing number of project activities caused by change in project scope is the main cause of project delay.

The simulation model built by Lebcir and Choudrie (2011) indicates that the sources of project complexity affect the project cycle time. The duration of the project increases as the degree of project complexity and uncertainty increases. The summary of the impact of each R&D project complexity source on project duration is derived by the author and presented in Table 2.

Table 2: Impact of R&D project complexity source on project duration

Source of R&D project complexity	Impact on project duration
Technological	- Adapting and integration of new technology requires more time, the project activities are paused to learn the new technology and the project duration is extended (Kim and Wilemon, 2003).
Marketing	- Creation of new marketing and distribution channels could extend the time it takes to bring new products to the market (Kim and Wilemon, 2003).
Organisational	- Impractical resource allocation is insufficient to complete the project on time (Kim and Wilemon, 2003; Marnewick, Erasmus and Joseph, 2017). - Slow decision making due to high level of hierarchy slows down project activities (Chen, Qiao and Lee, 2014).
Intraorganisational	- Conflict due to poor communication between organisations, requires time for resolution thus suspending project execution (Kim and Wilemon, 2003)
Technical	- The more the project scope increases the more the time taken to execute the tasks increases (Larsen *et al.*, 2014). - The review and correction of the design errors add more time to the project phases (Larsen *et al.*, 2014).
Development	- Difficulty to integrate poor R&D project management processes result in delayed project milestones, eventually extending project duration (Kim and Wilemon, 2003).
Uncertainty	- Late release of project funds delays project execution (Wei, 2010). - Change in project goals add more time to the execution of project activities (Marnewick, Erasmus and Joseph, 2017).
Dynamic	- Frequent change management process delay the project activities and therefore extending the time required to complete the project (Geraldi, Maylor and Williams, 2011).

Delays in R&D project are due to different reasons, some of which are beyond the project manager's control (Wei, 2010). Project delays happen at any phase of the project throughout the project life cycle. In most cases, a change in one project management factor affects one or more other factors, thus increasing the risks of not delivering the project on time.

These delays are a critical challenge for R&D projects because they result in cost overruns and benefit shortfalls (Eriksson, Larsson and Pesämaa, 2017). R&D projects which are not delivered on time, incur excessive costs due to prolonged human resources and equipment allocation (Eriksson, Larsson and Pesämaa, 2017). R&D projects delivered late become obsolete because of the change in market and evolving technology. Many organisations end up terminating the projects because of the depletion of the funding (Lee, Jeong and Byungun, 2017). Failure to deliver the project on time has several consequences such as dissatisfaction of client, team and stakeholders.

2.4 R&D effective management

Several studies performed for the traditional project management methods, reveal that only 44% of the projects finish in time, 70% reduce the amount of planned work and 30% simply die unrealised (Izmailov, Korneva and Kozhemiakin, 2016). R&D projects are no exception, many of them are not completed within the defined time and budget and do not deliver the expected benefits to the organisation (Too and Weaver, 2014).

In spite of R&D management specificity, no one can argue that it is essential to apply project management as an instrument to make activities more effective (Mikulskienė, 2014). Although, there is no formula to successfully manage R&D projects, studies agree that focusing on the R&D management process will improve the effectiveness of these projects (Gunasekaran, 1992). R&D organisations and management are affected by R&D processes (Cavone, Chiesa and Manzini, 2000).

2.4.1 Evolution of R&D management

The perception of R&D management has transformed over the years, because of the change in technological innovation, market and economy (Evo, Wang and Kleiner, 2005). In order to ensure an effective management of R&D activities, management processes and principles are required to adjust to these changes. So far, literature has categorized R&D management into five sequences of time series called generations to explain how to manage the project activities based on these technological and economic changes. The sixth R&D management generation is still to be concluded, however; literature has already identified its management characteristics. Table 3 summarises the characteristics of the six generations.

Table 3: Six generations of R&D management

Generation	Characteristics
First generation (1950-mid-1960)	R&D was seen as an overhead cost and its management process was direct. The objective of R&D management was to deliver the

	technology towards the market place (Nobelius, 2004; Mikulskienė, 2014).
Second generation (Mid1960-1970)	R&D was incorporated into the business division (Nobelius, 2004; Mikulskienė, 2014).
Third generation (Mid1970-1980)	R&D management became incorporated into business strategies. The concept of project management was introduced as a means to direct and control R&D activities (Nobelius, 2004).
Fourth generation (Mid1980-1990)	A new product development process was introduced. R&D activities were integrated and paralleled to ensure swiftness (Nobelius, 2004; Evo, Wang and Kleiner, 2005).
Fifth generation (Mid1990 - onwards)	Management of R&D activities became wide, popular and understandable (Mikulskienė, 2014). The collaboration between customers, competitors, suppliers, etc. was introduced in this generation (Evo, Wang and Kleiner, 2005).
Sixth generation	The sixth generation R&D management is expected to re-focus on the research part. The possibility of connecting and developing the innovation by involving all industry divisions is expected (Nobelius, 2004).

From Table 3, it is evident that R&D management has changed throughout the years from being remote to being connected and complex to handle (Nobelius, 2004). R&D processes are also changing with the evolution of R&D management, to adapt to these complexities. The applicability of the R&D generations differs according to the industry, R&D activities and organisation age. Some organisations' R&D management constitutes a combination of these generations.

2.4.2 Effective management of R&D projects

The previous sections have discussed R&D complexities, their impact on the project duration as well as the importance of having R&D processes in place to manage these projects. Cost overruns and project delays have been identified from literature as the most important project management challenges faced by R&D projects (Jalali *et al.*, 2016). One of the causes of these delays and cost overruns emerged to be project complexity.

Effective assessment and management of project complexity in R&D projects are essential for successful project performance (Kim and Wilemon, 2003). Effective management of project complexity is related to the organisation's capability and competency (Rolstadås and Schiefloe, 2017). An organisation can adopt a number of approaches, techniques, and

activities to improve the effectiveness of project management (Suomala, Kanniainen and Lönnqvist, 2012). The methods applicable for managing the consequences of the R&D project complexity are derived by the author and summarised in Table 4. Kim and Wilemon (2009) state that the methods for managing project complexity sources are often related to the factors or conditions causing it. The implementation of one method can solve one or more complexity sources concurrently or consecutively.

Table 4: Methods of managing R&D project complexity sources

Source of complexity	Managing methods
Organisational	- Open communication (Kim and Wilemon, 2009) - Appointing a competent project manager (Czuchry and Yasin, 2003)
Intraorganisational	- Commitment of resources (Marnewick, Erasmus and Joseph, 2017) - Improving communication (Kim and Wilemon, 2009)
Technological	- Collaboration (Kim and Wilemon, 2009)
Market	- Frequent interactions with customer (Kim and Wilemon, 2009) - Adapting to new market requirements (Kim and Wilemon, 2009)
Technical	- Collaboration (Kim and Wilemon, 2009) - Employing advanced techniques/tools (Maylor, Turner and Murray-webster, 2013)
Development	- Enhance the R&D project processes (De Mera Sánchez, Gaya and Peréz, 2013; Lee, Jeong and Byungun, 2017)
Dynamic	- Having a robust change management process (Marnewick, Erasmus and Joseph, 2017)
Uncertainty	- Having a flexible project management process(Wang and Yang, 2012)

2.4.2.1 Managing organisational complexity

Competent project managers

The project manager is regarded as the most important person responsible for project success (Radujković and Sjekavica, 2017). Not only is the project manager responsible for managing the project objectives such as time, cost and quality but also for managing the

technical part of the project including scope, integration, resources and risk. It is essential that R&D project managers possess the necessary skills, be detail-oriented, possess great leadership skills and have the relevant knowledge of management processes (Czuchry and Yasin, 2003). This individual must be professionally trained to utilize R&D project management processes effectively (Czuchry and Yasin, 2003). By understanding the source and level of project complexity, project managers are able to plan and develop management techniques suitable for managing these complexities.

2.4.2.2 Managing intraorganisational complexity

Communication

Intraorganisational complexity is difficult to manage because of the varying managerial styles between the joint organisations. However, in their article Marnewick, Erasmus and Joseph (2017) state that in order to minimise the complexity caused by the collaboration of the organisations, a well-defined list of roles and responsibilities should be documented during planning. The document should be communicated with all parties to ensure a common understanding. Apart from setting a list of responsibilities, there should be active open communication and interaction between the joint organisations and this could be achieved through face to face meetings or the use of efficient communication methods i.e. email or conference calls (Kim and Wilemon, 2009).

2.4.2.3 Managing technological complexity

Collaboration

Although it has already been discussed in the previous section, that collaboration in R&D contributes to organisational complexity (Marnewick, Erasmus and Joseph, 2017). This form of partnership can also alleviate the complexity due to technological factors (Kim and Wilemon, 2009). Collaboration itself is complex and requires effective management (Marnewick, Erasmus and Joseph, 2017). However, if done properly, collaboration can also solve a technological complexity (Kim and Wilemon, 2009). In order to minimise or eliminate the complexity associated with the new technology and its integration, an organisation should get the right people involved (Kim and Wilemon, 2009). This includes collaborating with organisations that possess the skilful resources. For an effective collaboration, commitment is required from both teams (Kim and Wilemon, 2009).

2.4.2.4 Managing market complexity

Adapting

Marketing requirements are always evolving to accommodate the latest technology (Kim and Wilemon, 2009). This source of complexity is not always solved. According to Kim and Wilemon (2009), the best way to deal with this complexity is to adapt to the market changes in order to meet the new market requirements. This includes having frequent interactions

with the customers to understand their requirements and incorporate any changes into the project.

2.4.2.5 Managing technical complexity

Application of complexity assessment tools

The application of tools and techniques developed for traditional projects have been found unsuitable for R&D projects because of their complex nature (Cristóbal, 2017). Several advanced project management tools have been developed for effective management of R&D projects. One such tool is the complexity assessment tool; which has been developed to identify and assess the sources of project complexities from project inception and throughout project execution (Kim and Wilemon, 2009; Maylor, Turner and Murray-webster, 2013). Complexity is also assessed periodically to check if any new source of complexity has emerged, if the existing complexity is being managed effectively or if there are any additional resources required (Kim and Wilemon, 2009).

Understanding the sources of complexities, the factors that contribute to the complexity as well as the impact of the complexity on the project is crucial for planning for complexity management (Rolstadås and Schiefloe, 2017). By identifying the sources of complexity early in the project, R&D project managers are able to develop risk management techniques to manage or minimise the negative impact of the complexity on the project. Application of risk management techniques to R&D projects is essential in improving their effectiveness and assisting in accomplishing project objectives (Wang and Yang, 2012).

2.4.2.6 Managing development complexity

Application of R&D project management process

Proper implementation and application of the R&D management process is one of the important methods for improving the management of project activities not only for R&D projects De Mera Sánchez, Gaya and Peréz (2013), but other projects of similar complexity. To ensure an effective management of R&D projects, project managers must implement a suitable R&D process to enable them to thoroughly control and monitor the R&D activities (Lee, Jeong and Byungun, 2017). The process should be capable of handling project complexity. Without this process in place, the project is at a risk of not meeting the final project objectives. Therefore to eliminate or minimise project delays, overpaying costs and to gain more effective output it is vital to use a suitable R&D process that defines the activities to be performed and expected outputs at each stage of the process (Lee, Jeong and Byungun, 2017). Most importantly, an efficient and judiciously consistent management of the R&D process will ensure successful accomplishment of project objectives.

2.4.2.7 Managing dynamic complexity

Change management process

In order to ensure that changes in the R&D projects are managed effectively, a robust and flexible change management process should be implemented (Marnewick, Erasmus and Joseph, 2017). Change management process should be planned to control and monitor the changes as they occur in the project. To ensure efficiency and effectiveness, when planning the change management process the project manager should ensure that the process of change management does not occur frequently. The project manager should analyse and understand the impact that each change will have on the project before implementing the change management.

2.4.2.8 Managing uncertainty

Allowing flexibility in R&D management

The presence of high uncertainties in R&D projects leads to high project risks which can lead to project failure (Wang and Yang, 2012). Incorporating managerial flexibility in the planning for R&D projects becomes important in decreasing the uncertainty associated with either technical, organisational or market risks (Wang and Yang, 2012). An effective R&D project management should adopt a balance between discretion and formality formats; where discretion refers to spontaneity and change and formality refers to stability and the following of rules (Naveh, 2007). The R&D project team is required to be creative and also conform to the standards and instructions and work efficiently to meet the constraints of time and cost (Naveh, 2007).

2.5 Conclusion

The time it takes to get an innovation to market has become critical key of global competition. To ensure competitiveness in the global market, R&D projects must constantly develop innovative products of high quality and deliver them on time and at a lower cost than the competitors. However, this is not always possible because of their uncertainties, complex characteristics and high risks.

Eight sources of complexity in R&D projects have been identified as organisational, intraorganisational, technological, market, technical, development, dynamic complexity and uncertainties. Each source of complexity has one or more factors that contribute to complexity such as organisational size, collaboration, new technology, marketing, scope change, R&D management process, change management and costs.

Complexities cause challenges in the R&D project management process and they have an impact on project duration. Many R&D projects are beset with delays due to the ineffective

management of the complexities. Delays in R&D projects are considered a common challenge and it have undesirable consequences such as cost overruns and client dissatisfaction.

The project duration and success is highly dependent on the way in which the complexity is managed. For effective management of R&D projects to meet the required constraint of time, it is important for organisations and project managers to understand the causes of project complexities. By incorporating flexibility in R&D project planning and management, organisations are able to manage risks and uncertainties arising from the complexities of R&D projects. R&D projects require a flexible management approach to take into consideration the uncertainty regarding project specification. To achieve an effective and efficient management of R&D projects, it is important to acknowledge change as an essential part of the process and then integrate change management to the benefit of the project.

3 Research design and methodology

The purpose of this chapter is to detail the research methodology used to gather primary data for this study. In this chapter, the research approach, research method and data collection instruments used in gathering data to answer the research questions posed in chapter 1 and validate the theory presented in chapter 2, are outlined.

3.1 Research objective

Research is described by Kothari (2004) and Nicholas (2010) as an art of scientific investigation to systematically and ethically search for new information or knowledge on a particular subject. There exist different types of research with different objectives (Kothari, 2004). The purpose of conducting this research is to explain effective management of R&D project complexities to ensure on-time delivery by describing, explaining and understanding R&D project complexities and their impact on project duration.

3.2 Research approach

3.2.1 Exploratory research study

The main objective of exploratory research is to provide an in depth understanding of the researched topic by analysing the problem and discovering new ideas (Kothari, 2004; Sreejesh, Mohapatra and Anusree, 2014). This is achieved by answering a set of questions in order to solve the problem. For the purpose of this research, an exploratory research is conducted to identify ways in which R&D project complexities can be effectively managed to optimise project duration. This is achieved by answering the formulated research questions on what are the R&D project complexities and what is their impact on project duration? An exploratory research calls for a flexible research design to take into consideration the different aspects of the research problem (Kothari, 2004).

3.3 Research method and methodology

3.3.1 Research method

Research methods are explained by Kothari (2004) as methods or techniques used for conducting the research. The choice of the appropriate research method is driven by the research questions (Tashakkori and Teddlie, 2009; Morgan, 2017). There are many research methods in exploratory research such as a survey, case study, interview, experiment; each with its own purpose and application (Gaus, 2017). This research study makes use of the case study method to explore in depth, R&D project complexity management in an engineering organisation. According to Kothari (2004) and Yin (2014), the

case study method is a popular form of exploratory and qualitative analysis applicable in many situations including organisational and management studies.

3.3.2 Data collection method

A data collection method is a process by which information is gathered and measured to answer the research question. The researcher has the flexibility to use one or more methods of collecting data under the case study method (Kothari, 2004). For the purpose of this research, primary data is gathered using questionnaires and interviews as the data collection methods. According to Noor (2008), the case study method has been criticised for its lack of robustness and rigour; therefore this research utilises multiple sources of data collection to improve the quality of the case study. At the end, data from the questionnaires and the interviews will be triangulated.

3.3.2.1 Questionnaire

A questionnaire is a set of questions designed to collect data from respondents (Sreejesh, Mohapatra and Anusree, 2014). This study uses a semi- structured form of questionnaire that includes a mix of closed and open questions, that will be emailed to the respondents. A questionnaire was selected because it is an effective way of collecting qualitative data to provide in-depth understanding on the research subject (Kothari, 2004). The questionnaires will be directed to engineers, technologists, technicians and developers who worked or are working on R&D projects. The questionnaire will collect data to validate the complexities of R&D projects as well as the impact of the complexities on project duration in this environment.

3.3.2.2 Questionnaire design

The questions in the questionnaire are derived from the research questions and literature review in chapter 2. The first RQ is "*what are the complexities of the R&D project management process*?" The second RQ is "*what is the impact of the complexities on project duration*?" From the literature review, eleven sources of project complexity were identified; eight of which were identified as being specific to R&D projects. However, the questionnaire is designed such that it includes all the eleven complexity sources and their factors. This is done to understand whether people working in the R&D projects have experienced the other complexity sources not listed for R&D in literature.

The questionnaire is divided into three sections namely; profile background, R&D project complexities and impact of R&D complexities on project duration. A summary of where each question was derived is tabulated in Table 5. A complete questionnaire for the study is in Appendix A.

Table 5: Source and purpose of the questions

Section	Question origin	Purpose
Section A	Profile background	To profile the knowledge perspective of the respondents
Section B	Derived from chapter 2, literature review Table 1	To identify R&D project complexities (RQ 1)
Section C	Derived from chapter 2,literature review Table 2	To identify the impact of R&D project complexities on project duration (RQ 2)

3.3.2.3 Interview

The interview method is regarded by Sreejesh, Mohapatra and Anusree (2014) as the most popular and frequently used method of gathering data from people. For the purpose of this research study, a personal semi-structured form of interview is conducted with the group manager, section managers and project managers of the R&D projects. The interview is included in this study to obtain an in-depth understanding of the R&D complexities and their impact on project duration from the managers' perspective.

3.3.2.4 Interview design

An interview is conducted as an additional method to collect in-depth information. The interview is structured such that it allows the respondent to give reasons for their answers. The sources of the questions were derived in the same manner as the questionnaires in Table 5. The questions derived for the interview are in Appendix B.

3.4 Sampling

Sampling is a process in which the researcher selects a small portion of the population to conduct a study and draw conclusions regarding the whole population (Sreejesh, Mohapatra and Anusree, 2014). For the purpose of this research study, sampling refers to the selection of a case study to conduct the research. This study adopts a holistic single-case design and is conducted on R&D team members in an engineering organisation. According to an article by Baxter and Jack (2008), a holistic case study is undertaken when the researcher is interested in a specific case and seeks to understand it better. A convenience, non-probability sampling is further done by selecting the size of the respondents to whom the questionnaires will be sent to; and these will be the team members who have three or more years of working experience in R&D. The reason for using convenience non-probability sampling is that the resources are available and easy to access. An interview will further be conducted with the managers and the project managers to understand the management of

the projects. The target number of respondents are twenty-five and five for the questionnaires and interviews, respectively. The summary of the respondents is listed in Table 6.

Table 6: Respondents sampling

Respondents	Questionnaire	Interview
Managers	-	5
Engineers	12	-
Technologists	5	-
Technicians	3	-
Developers	5	-
Total	**25**	**5**

3.5 Data evaluation

3.5.1 Data validation

To validate that actual interviews were conducted to collect the data, the information of the interviewee such as the position, level of qualification, and years of experience will be recorded on the questionnaires (Sreejesh, Mohapatra and Anusree, 2014).

3.5.2 Data analysis

Data analysis is a process in which the collected qualitative data is transformed into clear and understandable findings (Sreejesh, Mohapatra and Anusree, 2014). Data obtained from the interviews and questionnaires will be interpreted and compared with the literature generated in chapter 2.

3.5.3 Data presentation

Data from the interview will be recorded by taking notes during the interview and the questionnaires will be completed and sent back electronically via email. Data collected from the questionnaires and interviews will be reported in the form of a case report. The report will explain in detail the findings of the research study and draw conclusions.

3.6 Conclusion

The research design and methodology followed in achieving the objective of this research study was discussed in this chapter. This research is an exploratory study. The research is conducted using a single case study method. Data is collected in the form of questionnaires and personal interviews with the R&D team to gain an in-depth understanding of sources of

R&D project complexity and their impact on project duration. The respondents for the interviews and questionnaires were selected based on the availability of the team members. This includes 5 managers and 25 technical R&D specialists comprising of technicians, technologist, engineers and developers.

4 Data Analysis

The previous chapter detailed the methodology and techniques used to collect primary data for answering the two research questions. After collection, data needs to be processed and analysed to allow for effective comparison and analysis (Kothari, 2004). In this chapter, the collected data is systematically organised and summarised to answer the research questions. A descriptive analysis of the data will be done on the questionnaires and data from the interviews will be analysed using the grounded theory methodology. Lastly, the findings will be examined by triangulating data from the questionnaires and interviews, and then a comparison of the findings with the theory from literature review will be done.

4.1 Case description

The case study is conducted in an engineering organisation on the R&D team. The R&D team is responsible for all R&D projects as well as providing technical support to company operations. The main objective of the team is to research and develop a design system that will be used by the organisation's electrical and mechanical design departments to design the equipment manufactured by the organisation. The R&D team consists of electrical, mechanical, project management and Information Technology (IT) divisions. The IT division comprises of outsourced team. In addition, the team has collaborated with external service providers that render IT and technical consulting services. The reporting structure of the team is depicted in Figure 6 .

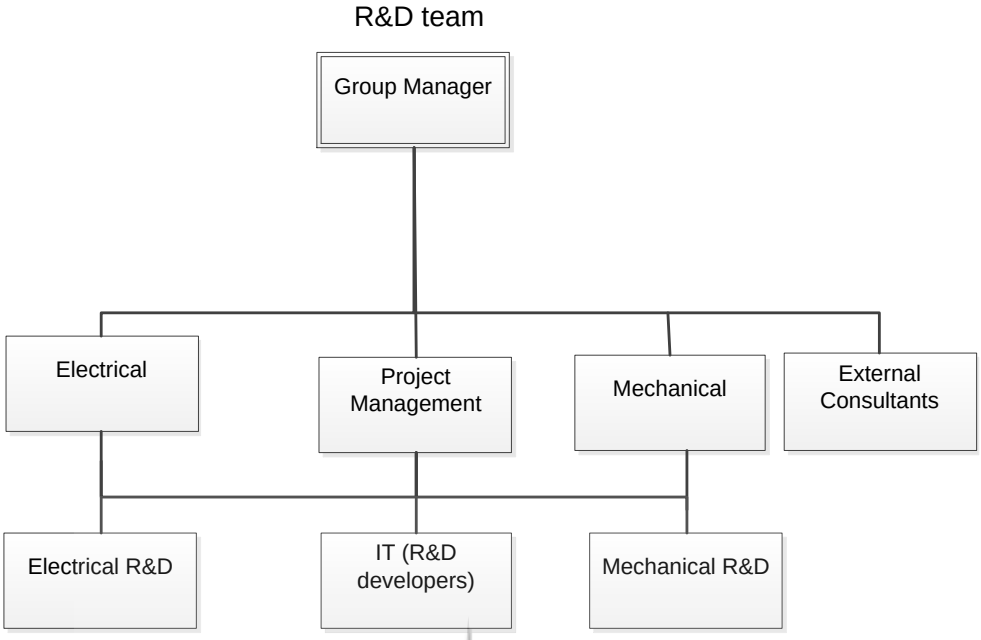

Figure 6: R&D group reporting structure

4.2 Questionnaire analysis

4.2.1 Profile of respondents

The questionnaires were sent out to 25 R&D specialists. Out of the 25, there are 12 engineers, 5 developers, 5 technologists and 3 technicians. Twelve responses were received back. This is a 48% response rate, and this is acceptable because according to Saunders, Lewis and Thornhill (2015), for most academic researches involving organisation representatives, a 35% response rate is acceptable. The profile response is categorised in terms of the level of qualifications, position and years of working experience.

4.2.1.1 Level of qualification

The percentage of the respondents with different levels of qualifications is shown in Figure 7. It can be seen that most team members are in possession of National Diplomas at 33%, whereas the number of participants with B.sc/B.Eng. and BTech degrees are the same at 25%. This is an indication that the team comprises of educated people, who will have an understanding of the concept of complexity.

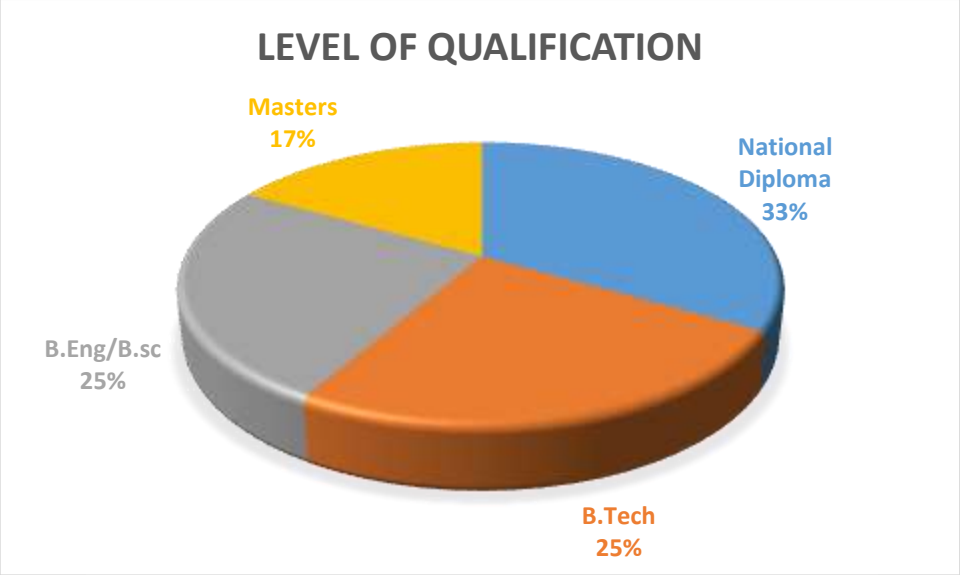

Figure 7: Respondents' level of qualification

4.2.1.2 Position

Displayed in Figure 8, is the representation of the different positions held by the R&D team members. Most of the team members are engineers and technologists at 33%. This shows that the team is made up of members with different backgrounds. This is an indication that different team members will have different views on complexity in the context of the project.

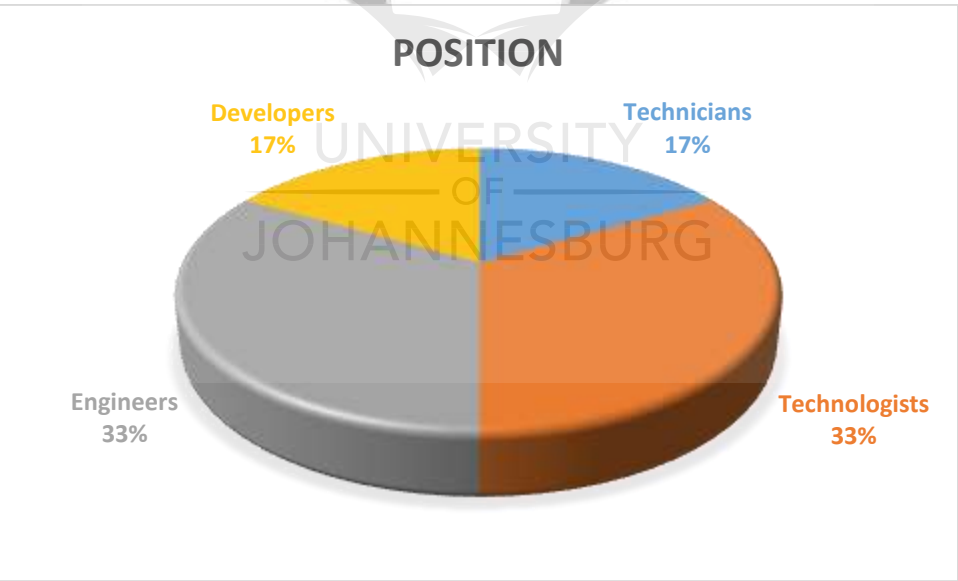

Figure 8: Respondents' position

4.2.1.3 Years of experience

The presentation of R&D team's years of working experience is shown in Figure 9. Most team members have between 5 and 10 years of working experience. This gives an indication that most members in the team have been exposed to R&D projects for a longer time and thus will have experienced different complexities in the projects and how they have affected the project duration.

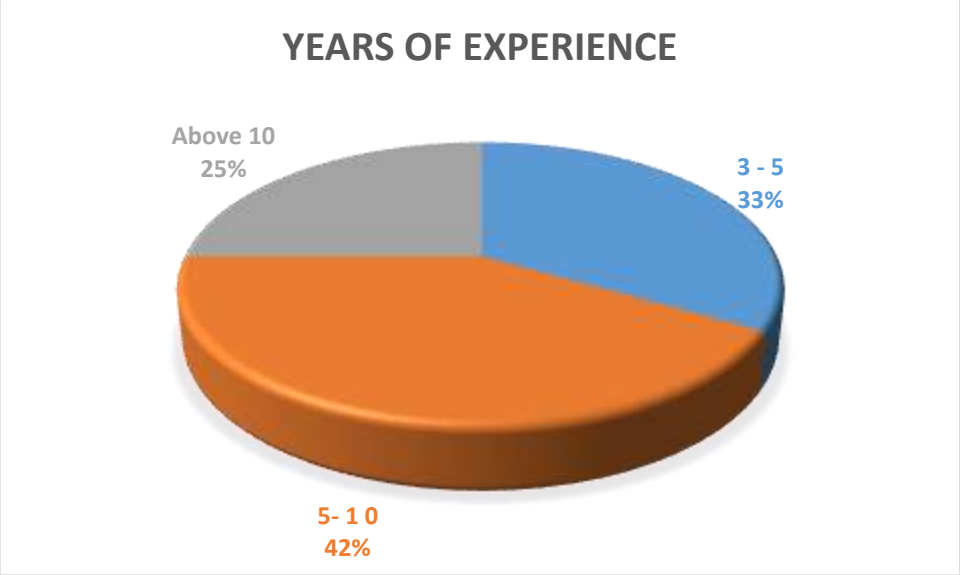

Figure 9: Respondents' years of working experience

4.2.2 Complexity factors

Questionnaires were sent to R&D specialists to identify sources of complexity encountered in R&D projects and their impact on project duration. Data from the questionnaires is analysed using a descriptive analysis. A descriptive analysis summarises data in numbers with the purpose of describing the sample (Thompson, 2009).

4.2.2.1 R&D project complexity from case study

Five questions were asked to the respondents at the beginning of the questionnaire to understand their level of understanding in terms of the definition of complexity in the context of the project as well as to obtain information about the R&D projects they worked on.

Out of the 12 responses received, the respondents undertook 71 R&D projects. From the 71 projects, 56% were completed on time and 42% were not completed on time. This implies that R&D projects are actually more on time than believed. This is contradictory but still relevant to the study because the respondents have experienced delays in their projects and will be able to relate to the factors that have affected the duration of their projects.

Another question that was posed to the respondents was "Are R&D projects complex?" This question was asked after the definition of a complex project was given as "A project is considered complex if it has several interconnected systems and it is characterised by high uncertainties." From the responses, 67% of the respondents answered "yes" and the remaining 33% answered "no." Table 7 summarises the responses with the statements supporting the answer to the question.

Table 7: Responses to R&D project complexity

Response	Yes/No	Elaborate
1.	No	It solely depends on the specific R&D project, there are other R&D projects which are relatively simple and straight forward
2.	No	A project can be complex and have high uncertainties with a single system
3.	No	A single system can be more complex than several interconnected systems. It depends on the type of the system
4.	No	R&D projects are not always complex e.g. one project I worked on recently had neither several interconnected systems nor high uncertainties
5.	Yes	The amount of work required in R&D such as data gathering, case studies and analysis of information or data makes it complex
6.	Yes	R&D involves a lot of unknowns, as the research progresses the scope of work increases and affects timelines
7.	Yes	R&D projects entail aspects from various disciplines which at times can lead to complexity and difficulty to predict the impact of one system on the other systems
8.	Yes	R&D projects have a lot of moving parts such as changing management, time, scope, and emerging technologies as such it is hard to keep to a defined track of progress
9.	Yes	R&D projects aim to produce products, which did not exist before; hence, they are uncertain in terms of behaviour, performance and from a planning point of view.
10.	Yes	R&D projects must consist of a clear problem definition. It is therefore expected that at proposal stage the nature of the outcomes and a problem to be solved will be sufficiently defined. Often, the defined projects should consist of an element of uniqueness, and sometimes novelty. These inherently introduce complexity in R&D projects.
11.	Yes	R&D projects are usually not as critical as production projects. Funding for the projects is often uncertain especially when business declines. R&D projects are often placed on hold and indefinitely postponed to deal with more critical production work.
12.	Yes	R&D projects generally have more software and technology requirements, which means more license issues. Consequently,

		R&D teams are continually challenged to learn and comprehend these technologies, which require ample time. Additionally integration and interaction of various departments/groups working on the same project requires effective management

From the responses in Table 7, 33% disagree that not all R&D projects are complex because they have worked on R&D projects that were relatively simple, straightforward, and did not have high uncertainties. According to Kerzner and Belack (2010), these reasons are defined as the characteristics of a project that is not complex.

The rest of the respondents agree that R&D projects are complex because of the large amount of work required, multiple departments working on the same project, impact of interconnected systems on one another, uncertainties involving scope of work, project funding and project duration. The reasons provided are in agreement with the definitions given by Bosch-rekveldt *et al.*,(2011) and Kerzner and Belack (2010) regarding the elements that make up a complex project.

The emergence and integration of new technology into the project has also been stated as one of the factors that makes R&D projects complex because the project team is required to learn the new technology. According to Kim and Wilemon (2003), this factor adds to technological complexity in R&D projects.

4.2.2.2 Factors contributing to R&D complexity

Data was analysed in Microsoft Excel for each complexity source versus each respondent. The analysis was done using the weighted score method to assess quantitatively the level of agreement (1 to 5 as per the Likert scale) of the respondents pertaining to the factors that contribute to R&D complexity source (Robson, 1993). The results were ranked according to the complexity factor with the highest score as shown in Table 8. The complete results from the questionnaire are in Appendix C.

Table 8: Analysis of R&D complexity factors

Source of complexity	**Factors contributing to project complexity source**	**Weighted score**
Dynamic complexity	Multiple and frequent changes in the project and management process	4.58
Development complexities	Poor management of the R&D process	4.58
Technical complexity	Varying project scope	4.50

Intraorganisational complexity	Poor communication between joint organisations	4.42
Structural complexity	Project manager's level of control over the resources is limited	4.42
Organisational complexity	Interaction between multiple organisational departments	4.33
Structural complexity	Lack of top management support	4.33
Technological complexity	Integration of different sub systems in a project	4.08
Technical complexity	The technical and design requirements of the project	4.08
Intraorganisational complexity	Collaboration between two or more organisations	4.00
Environmental complexity	Multiple stakeholders with different perspectives	3.92
Uncertainty	Uncertain project costs and value	3.83
Organisational complexity	Large multidisciplinary team	3.83
Technological complexity	The incorporation and application of the new technology in to the project	3.83
Uncertainty	Uncertain project goals	3.83
Organisational complexity	High level of reporting structure	3.75
Temporal complexity	Unanticipated future constraints such as change in government or company ownership	3.58
Environmental complexity	Environmental risks associated with the location of the project	3.58
Marketing complexity	High level of competition	3.17
	Unpredictable market changes	3.00

From the analysis in Table 8, it shows that the majority of the respondents from the case study strongly agree that dynamic and development complexities are the highest contributors to complexity in R&D projects. These complexities are due to frequent and multiple changes in the project and management process and poor management of the R&D process. This is an indication that not much attention is paid on the R&D project management process and this adds complexity in the projects.

Structural complexity was not listed as an R&D complexity source in literature, however the results of the case study indicates majority of the respondents agree that the project manager has limited control over the project and this adds more complexity to the project.

Marketing complexity received the lowest score, which shows that the respondents neither agree nor disagree that the unpredictable market changes and high level of competition contribute to the complexity of their R&D projects.

4.2.2.3 Additional complexity factors from the case study

The respondents were asked to list any other source of complexity that they have experienced in their projects and not mentioned in the questionnaire. The following factors were listed and explained and for the purpose of this analysis, each factor and its description were categorised into complexity sources.

- **Technical** - Influence of the previous research, almost every project is influenced by the outcome of the previous project
- **Organisational** - Amount of research work, sometimes the availability of the resources to conduct research is insufficient depending on the amount of research required
- **Organisational** - Inter-departmental relations; most people view R&D as an expense and R&D specialists are known for being the high earners, thus resulting in strained relations between the R&D department and other organisational departments, especially if the project's importance is not properly elaborated across the business.
- **Technical** - Training; lack of training programmes at an early stage of the project

It is evident that different factors contribute to complexity in R&D projects. From the list of factors added as additional complexity factors, organisational and technical complexity appeared to be the top contributors to R&D project complexity. Even though, the factor “interaction of multiple departments in the organisation” was mentioned in the questionnaire, one respondent listed it as an additional complexity factor. The response was elaborated by stressing that even the departments that do not have interaction with R&D projects have a

difference of opinions with the R&D project team and this adds to the level of complexity in R&D projects.

4.2.3 Impact of R&D project complexity on project duration

4.2.3.1 Complexity factors that impact R&D project duration

The analysis of the factors affecting R&D project duration was done using the weighted scoring method and the results are presented in Table 9. The factors with the highest scores are ranked from the top. The full results of the responses from the questionnaire are in Appendix D.

Table 9: Analysis of factors affecting R&D project duration

The following factors, if not managed effectively can result in project delays:	**Weighted score**
The more the project scope increases the more the time taken to execute the tasks increases	4.67
Impractical resource allocation is insufficient to complete the project on time	4.58
Slow decision making due to high level of hierarchy slows down project activities	4.58
Change in project goals adds more time to the execution of project activities	4.50
Conflict due to poor communication between organisations, requires time for resolution thus suspending project execution	4.42
Difficulty to integrate poor R&D project management process results in delayed project milestones, eventually extending project duration	4.42
Late release of funds delays the project execution	4.33
The review and correction of the design errors add more time to the project phases	4.08
Adapting and integration of new technology requires more time, the project activities are paused to learn the new technology and the project duration is extended	3.92
Frequent change management processes delay the project activities and therefore extend the time required to complete the project	3.33
Creation of new marketing and distribution channels could extend the time it	3.00

takes to bring new products to the market	

The results in Table 9 show that most of the respondents agree that the change in project scope and goals has a negative impact on the project duration. The expansion of the project scope results in more activities added to the project and thus requiring more time to complete the project.

The allocation of resources is also identified as one of the factors affecting the project duration considerably. Insufficient and unskilled resources will take more time to complete the project.

Even though in Table 8, the factor “high level of reporting structure” under organisational complexity was not considered as being an R&D project complexity source, the respondents agree that their R&D projects are often delayed because of the time it takes for decisions to be made, because of the high level of reporting structure.

The impact of marketing on project duration received the least score, showing that the R&D team from the case study neither agrees nor disagrees that the activities of marketing delays the project. Although in Table 8 the respondents strongly agreed that dynamic complexity is the highest contributor of R&D project complexity, in Table 9 they have a neutral view that dynamic complexity due to multiple and frequent change management processes can delay the project.

4.2.3.2 Additional factors that impact R&D project duration

The respondents were asked to specify any other factors that impact the duration of R&D projects based on their experiences. The following factors emerged:

- Insufficient skills in the team will take more time to complete the tasks than skilful resources
- Lack of prioritisation on projects; introducing other projects that require the same resources to work on more than one project at the same time will result in first project being delayed.
- Lack of team focus; when the team is not focusing on one project at a time, it is easy to miss the deadlines of the projects
- Uncertainty regarding the resources required for the project leads to longer project duration
- Inability to retain skilled personnel, when the resources leave the project or organisations, time is lost in finding new recruits

- New recruits require to be trained and this is a challenge since it is not catered for in the project timeline

From the additional factors, it is clear that resources play an important role in delivering the project on time, because all listed factors mention the impact that resources have on the project duration. Resources leave the project and time is lost finding and training new resources to carry on with the project. Semi-skilled resources take time to complete the project than skilful resources. When the same resources are working on more than one project, it is easy to miss deadlines.

4.3 Interview analysis

4.3.1 Profile of respondents

Five interviews were initially planned with the managers of the R&D department to obtain additional information pertaining to R&D project complexities and their impact on project duration. Out of the planned interviews, three interviews were conducted successfully, which gives a response rate of 60%. The profile respondent in Figure 10 shows the level of qualification as well as the length of working experience each manager has. It can be seen that the managers have quality educational backgrounds coupled with between 4 and 10 years of working experience in R&D. Although the response rate from the managers is limited, this gives a good indication that the managers have understanding of complexity in the context of the project and that they have experienced it and therefore there is high level of confidence in their responses.

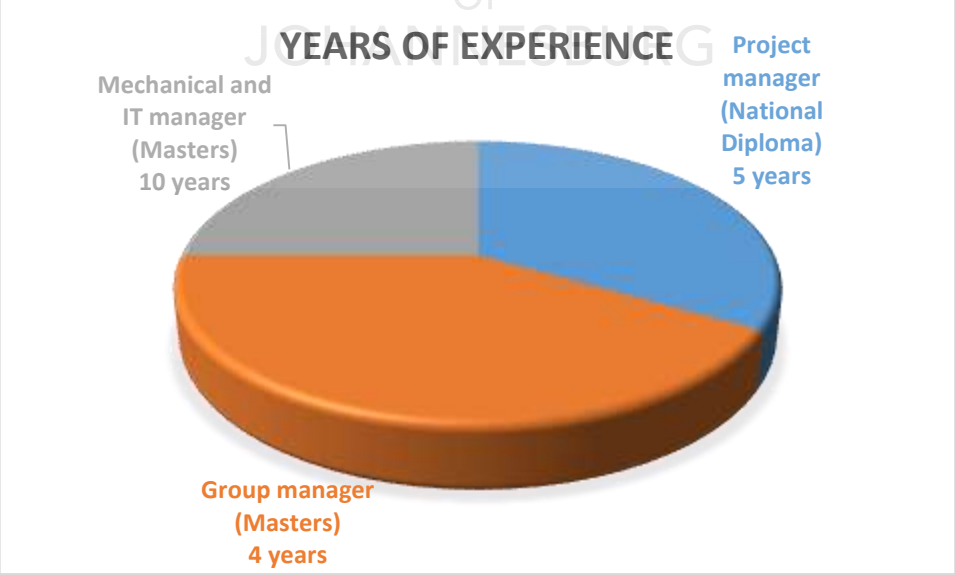

Figure 10: Profile respondents for interviews

4.3.2 R&D project complexity factors

Interviews were conducted to verify the findings of the questionnaire on a higher level. The objective was to triangulate the data for consistency. The interviews were conducted with the managers to understand their perspective with regard to R&D project complexity sources and their impact on project duration. The analysis of the interview is carried out using the categorisation technique and the grounded theory method.

Three questions were asked to understand the meaning of the term complexity in the context of the project, whether R&D projects are complex and to identify the sources that contribute to the complexities.

4.3.2.1 Complexity in the context of the project

The managers were asked to define the term complexity in the context of the projects. This question was asked to understand if the managers have the knowledge regarding the term complexity as used in projects. The objective of the question was to also understand the elements that make up a complex project.

From the responses given, complexity was defined based on the experience of the respondents as follows:

Response 1*: "Complex projects consist of multiple uncertainties in relation to the defined problem; independent and dependent variable may require a number of several assumptions. Complex projects have non-obvious solutions and often require substantial literature review"*

Response 2: "Complexity has to do with the level of functionality in a project. How big the scope is also causes the complexity. The more the scope the difficult or complex it is"

Response 3: "Complexity has to do with the balance between resource, time and quality. Managing resources from different disciplines is complex. Again, the project is complex if the outcome or goal is a new concept or has never been achieved before"

From these responses, complexity has been defined in terms of **uncertainties**, **project scope** and the **project management process**. The definition from the responses is adequate because it relates with the literature regarding how the project scope and high uncertainties of R&D projects make it complex. Response 3 defines complexity in terms of the project management triangle stating that if there is an imbalance between the three constraints then it means the project is complex.

4.3.2.2 Complex R&D projects from the case study

The managers were asked whether the projects they have been managing are complex or not and why. This question was asked to understand from the managerial point of view if R&D projects are complex and what makes them complex. The responses received are as follows:

Response 1*: "Yes. The projects I worked on had specific objectives however; there were a number of unknowns. Thus the project management process as well as methodology provided the necessary guidance*"

Response 2: "*Yes, the scope of work was too big. Complexity arose when the engineering calculations both electrical and mechanical had to be implemented by IT. The code became complex"*

Response 3: *"Yes, the project consists of different disciplines such as software, mechanical, electrical, research and development. So encompassing the different disciplines created complexity in the project because we have different backgrounds and at some point, I was forced to learn the technical aspects of the project in order to properly plan project management. The duration of the R&D projects makes it difficult to plan the start and end of the project"*

From the three responses, it is clear that the managers agree that their R&D projects are complex. The complexity is due to uncertainties surrounding the objectives of the project, technical design, technological integration and multidisciplinary team with different backgrounds and experiences.

4.3.2.3 Sources of complexities from case study

The managers were asked to name the sources of complexities they have experienced in their projects. The objective of the question was to gather the sources of complexities from the management perspective. The analysis of this question is conducted using the grounded theory method, making use of the coding method in three steps.

4.3.2.3.1 Open coding

The initial step of analysis is called open coding. During this stage, raw data is broken down, scrutinized and compared for consistencies or dissimilarities (Jason *et al.*, 2018a). During the interview, data was collected by writing down notes. The notes were transcribed by listing the complexities faced in R&D. A list of complexity factors emerged identified by each respondent is tabulated in Table 10.

Table 10: Complexity factors from interview case study

Response 1	Response 2	Response 3
Competency and skills of researchers	Interactions between multidisciplinary teams	The type of industry the project is in
Adequate support from the executive management team	Technical and design requirements	The nature of the business
Financial support	Uncertainty in project goals	Management priority
	Change of scope of supply	Investment
	Change of management personnel	Lack of specialised resources
	Utilisation and integration of various software	
	Customer approval	
	Management of the R&D process requires improvement	
	Focus or management of other non-R&D projects	
	Different perspectives between R&D department and engineering department in terms of approving the technology	

4.3.2.3.2 Axial coding

The second step after open coding is called axial coding. Axial coding involves linkage of data to disclose the relationship between categories and sub categories (Wicks, 2012; Simmons, 2018). In section 4.3.2.3.1, the responses were given in terms of the factors that contribute to project complexity sources. During the axial coding stage, these complexity factors are categorised according to their sources of complexity and the repetition of other factors are removed from the list as shown in Table 11.

Table 11: Categorization of complexities

Factors of complexity from the responses	**Identified source of complexity**
Competency and skills of researchers	Organisational complexity
Adequate support of from executive management team	Structural complexity
Financial support	Uncertainty
Interactions between multidisciplinary teams	Organisational complexity
Technical and design requirements	Technical complexity
Uncertainty in project goals	Uncertainty
Change of scope of supply	Technical complexity
Change of management personnel	Dynamic complexity
Utilisation and integration of various software	Technological complexity
Customer approval	Marketing complexity
Management of the R&D process requires improvement	Development complexity
Focus or management of other non-R&D projects	Organisational complexity
Different perspective between R&D department and engineering department in terms of approving the technology	Environmental complexity
The type of industry the project is in	Technical complexity

4.3.2.3.3 Selective coding

The final step of analysis is selective coding. The objective of the selective coding is to develop theory from the categories and concepts that emerged from the data during axial and open coding (Jason *et al.*, 2018b). For this analysis, the sources of R&D complexity that emerged from the interview responses are validated with literature.

Some of the complexity sources listed in Table 11 were not identified as R&D complexity sources during the literature review. Such sources are structural and environmental complexities. The factors that contribute to these sources of complexity are inadequate top management support and different stakeholders' perspective. From the management perspective, two responses have identified the lack of top management support, financial

uncertainties and lack of skilled resources as the highest contributors of R&D project complexities. This shows that managers are experiencing these factors of complexity more often.

4.3.3 Impact of R&D complexities on project duration

The objective of this section is to understand how complexities in the project delay the project delivery date. This is achieved by posing two questions to understand the impact of complexities on the project duration and again the impact of a late project on the overall project performance.

4.3.3.1 Impact of project complexities on project duration

Managers were asked whether project complexity affects the planned duration of the projects they work on and how. The responses were as follows:

Response 1: "*Yes. When the available solutions are not sufficient to achieve the research objectives, new solutions are proposed and this could lead to project delays due to results validation which may include experimental work that is lengthy and time dependent"*

Response 2: *"Yes. The amount of work required for the project is too much and it is not broken down proportionally. For example, different disciplines complete different project tasks at the same time and this is realised during implementation, when the parts must be integrated together, so the team must go back and complete the right activities. This causes the delay in the project because the developers must now wait for the right project parts, which means adding more time to the project duration. "*

Response 3: *"Yes. The problem is caused by mismanagement of resources. During the planning stage, resources are allocated accordingly however as the project progresses, there is resource shifting but the project tasks and deadline remain unchanged. In most cases projects end up delayed. Also the more the project scope expands the more the chances of delivering it late"*

From these responses, it is clear that the change in project scope, especially the increased scope of work adds more time to the project duration. From response 2, it is evident that without an enhanced project management process, the project is at a risk of being delayed. Again, the issue of poor communication between different teams appears to affect the project duration. The impractical resource allocation results in delayed project delivery because of unavailability of resources to complete the project on time.

4.3.3.2 The impact of a late project on the overall project outcome

The objective of asking what impact does late delivery have on the overall project duration was to understand if the managers know the importance of delivering the project on time.

Response 1:" *Sometimes late delivery may mean cancellation of the R&D project and this directly impacts on available financial support"*

Response 2:"*Late projects end up losing top management and financial support"*

Response 3:*"Late projects mean loss of competitive edge and thus termination of the project which has a negative impact on the resources that worked on the project since they failed to deliver the objectives"*

The responses from the managers stressed out the fact that a late R&D project loses competitive edge and top management support and results in termination before achieving the objectives due to discontinued financial support. It is clear that the managers understand that it is important to complete the project on time.

4.4 Data triangulation

Triangulation is the process of corroborating data from multiple sources with the aim of enhancing the depth of the understanding of a particular subject and for verification purposes (Stavros and Westberg, 2009). For this research study, a combination of questionnaires and interviews were used to gather primary data regarding the factors that contribute to R&D project complexity sources and their impact on project duration.

4.4.1 Triangulation of complexity factors

The validation of data from literature review, questionnaires, and interviews on the factors contributing to R&D project complexity is done in Table 12. Literature has identified 11 sources of complexity, from which 8 are applicable to R&D projects. Under each source, there are different factors that contribute to the complexity. In Table 12, all eleven sources of complexity together with their contributing factors are listed. The tick (✓) under literature and interview columns indicate that the factors are applicable or have been experienced. The cross (X) indicates that literature or interview results do not recognise the complexity factor as being applicable to R&D projects. The analysis of the questionnaire results is done based on the weighted score indicating the level of agreement. The highest score indicates that most respondents agree that the factor contributes to complexity.

Table 12: Triangulation of factors contributing to R&D project complexity

Source of complexity	Factors contributing to project complexity source	Literature	Questionnaire	Interview
Organisational complexity	High level of reporting structure	✓	3.75	X
	Large multidisciplinary team	✓	3.83	✓
	Interaction between multiple organisational departments	✓	4.33	X
Technical complexity	The technical and design requirements of the project	✓	4.08	✓
	Varying project scope	✓	4.50	✓
Uncertainty	Uncertain project costs and value	✓	3.83	✓
	Uncertain project goals	✓	3.83	✓
Dynamic complexity	Multiple and frequent changes in the project and management process	✓	4.58	✓
Intraorganisational complexity	Collaboration between two or more organisations	✓	4.00	X
	Poor communication between joint organisations	✓	4.42	X
Technological complexity	Integration of different sub systems in a project	✓	4.08	X
	The incorporation and application of the new technology into the project	✓	3.83	✓
Marketing complexity	Unpredictable market changes	✓	3.00	X
	High level of competition	✓	3.17	X

Temporal complexity	Unanticipated future constraints such as change in government or company ownership	X	3.58	X
Development complexities	Poor management of the R&D process	✓	4.58	✓
Environmental complexity	Environmental risks associated with the location of the project	X	3.58	X
	Multiple stakeholders with different perspectives	X	3.92	✓
Structural complexity	Lack of top management support	X	4.33	✓
	Project manager's level of control over the resources is limited	X	4.42	X

From the analysis in Table 12, the following deductions are made between literature, questionnaire results and interview responses regarding the factors that contribute to R&D project complexity:

- There is a strong agreement between literature, questionnaire and interview results that a poor R&D management process, multiple and frequent changes in the project and management process, variation in project scope and the technical requirements of the project are the causes of R&D project complexity.
- Literature review did not identify structural complexity as being applicable to R&D. However, the results of the questionnaires show that there is a strong agreement that the project manager does not have full control of the project, thus resulting in structural complexity in the project. It also emerges from the interviews that the managers believe that the lack of top management support adds complexity in the project.
- Literature identified unpredictable marketing changes and the level of competition as the factors that contribute to marketing complexity in R&D projects. However, the results of the questionnaires could neither agree nor disagree. The results from the interviews did not agree with these complexity factors for marketing but rather added

that the complexity arises when the customer has to approve the changes in the project scope.

4.4.1.1 Triangulation of additional complexity factors identified from the case study

The additional complexity factors added by the respondents at the end of the questionnaire are tabulated in Table 13 together with the factors mentioned by the managers, which are not on the questionnaire. The tick (✓) indicates that the factor was listed as a complexity factor from the interviews or as an additional complexity factor from the questionnaire responses.

Table 13: Triangulation of additional complexity factors identified from the case study

Complexity source	Contributing factor	Questionnaire	Interview
Technical complexity	Influence of the previous research	✓	X
	Lack of training programmes	✓	X
	The type of industry the project is in	X	✓
Organisational complexity	Lack of competency and skills of researchers	✓	✓
	Focus on management of other non-R&D projects	X	✓
Marketing complexity	Customer approval	X	✓

From Table 13, the following deductions can be made:

- Technical R&D specialists and managers believe that unavailability of trained and competent resources in R&D projects contributes to technical and organisational complexities
- From the management perspective, the project becomes even more complex when the managers have to manage other non-R&D projects
- Although the results of the questionnaire have shown that marketing complexity is not a significant contributor to R&D project complexity, the managers still think that the customer's approval of the scope change does add complexity to the project

4.4.2 Triangulation of factors affecting project duration

Data validation for factors affecting R&D project duration is done in Table 14 for data obtained from literature, case study questionnaire, and interview. The same logic followed in section 4.4.1 for interpreting the results is used. The tick (✓) under literature and interview

columns indicate that the factors are applicable or have been experienced. The cross (X) indicates the complexity factor is not recognised as being applicable to R&D projects. The results of the questionnaire are represented using the weighted score average, derived from the Likert scale.

Table 14: Triangulation of factors affecting R&D project duration

The following factors, if not managed effectively can result in project delays:	**Literature**	**Questionnaire (weighted score)**	**Interview**
The more the project scope increases the more the time taken to execute the tasks increases	✓	4.67	✓
Impractical resource allocation is insufficient to complete the project on time	✓	4.58	✓
Slow decision making due to high level of hierarchy slows down project activities	✓	4.58	X
Change in project goals adds more time to the execution of project activities	✓	4.50	X
Conflict due to poor communication between organisations, requires time for resolution thus suspending project execution	✓	4.42	✓
Difficulty to integrate poor R&D project management processes result in delayed project milestones, eventually extending project duration	✓	4.42	✓
Late release of funds delays the project execution	✓	4.33	X
The review and correction of the design errors add more time to the project phases	✓	4.08	X
Adapting and integration of new technology requires more time, the project activities are paused to learn the new technology and the project duration is extended	✓	3.92	X
Frequent change management processes delay the project activities, thus extending the time required to complete the project	✓	3.33	X

Creation of new marketing and distribution channels could extend the time it takes to bring new products to the market	✓	3.00	X

The following deductions are made from the analysis in Table 14:

- There is an agreement between literature, the questionnaire and interview that the increase in project scope and the way in which resources are allocated have a big impact on the project duration.
- From literature and the questionnaire, there is a strong agreement that high level of reporting structure in the organisation slows down the decision making process and thus delays the project. However the managers disagree with this statement
- The results from the questionnaire and interview neither agree nor disagree that new marketing channels and frequent change management processes delay the project

4.4.2.1 Triangulation of additional factors affecting R&D project duration

The validation of data for the additional complexity factors that impact on project duration is done in Table 15. The factors identified, were not listed on the questionnaire.

Table 15: Additional factors that impact project duration

Additional factors that affect R&D project duration	**Literature**	**Questionnaire (weighted score)**	**Interview**
Insufficient skills in the team will take more time to complete the tasks than skilful resources	X	✓	✓
Lack of prioritisation on projects, one resource working on more than one project ends up in missed deadlines	X	X	✓
Inability to retain skilled personnel, when the resources leave the project or organisations, time is lost in finding new recruits	X	✓	X
New recruits require to be trained and this is a challenge since it is not catered for in the project timeline	X	✓	X

From the analysis in Table 15, there is an agreement between the questionnaire and interview results that skilled resources are important in ensuring that the project is delivered

on time. Projects are delayed when skilful resources leave the organisation because time is lost in finding new replacements.

4.5 Conclusion

Primary data was collected from the R&D team using questionnaires and interviews were conducted with the managers. The analysis of data was conducted using the descriptive analysis, categorisation and grounded theory methodologies.

The design of the questionnaire was done such that it included all the eleven sources of complexity. The respondents were asked to indicate their level of agreement on a scale of 1 to 5, whether they have experienced the mentioned source of complexity and its contributing factor.

At the beginning of the questionnaire, respondents were asked to list the number of projects they participated in and state how many were completed on time and how many exceeded planned project time. The results showed that 56% of the projects were completed within planned time whereas the remaining 42% of the projects experienced project delay. This gave confidence in the results because it is an indication that the respondents have experienced project delay and will be able to respond with experience.

The results of the analysis from the questionnaires show that more respondents agree that dynamic, development, technical, organisational, intraorganisational and structural complexities are the major contributors of R&D project complexities. These complexities are caused by frequent and multiple changes of project management processes, poor management of R&D processes and variation in project scope. The interaction between multiple departments or joint organisations is another factor identified from the case study as being a major contributor of R&D project complexity.

The respondents of the questionnaire were asked to include any additional complexity sources that they have experienced in their projects that were not listed on the questionnaire. The response showed that different factors under organisational complexity are the major contributors of R&D project complexity.

The same analysis was done to answer the second research question on what is the impact of R&D project complexity on project duration. The results indicated that the project is delayed because of multiple changes to the project scope adding more tasks to project activities and thus requiring more time to complete. The list of factors mentioned by the respondents of the questionnaire, pertaining to complexity factors revealed that incompetency and unskilful resources are the core reason why R&D projects are delayed.

The results of the interview show that from a managerial point of view, lack of top management support and the different perspective of stakeholders in the project contribute to complexity. The variations in project scope and allocated resources on the project have an influence on the project time. The wider the scope, the longer the project gets.

The main findings of the case study indicate that the perception of R&D technical specialists and managers pertaining to complexity source is different. R&D specialists indicated that dynamic and development complexities are the highest common contributors of R&D project complexity whereas the interview data showed that structural and organisational complexities are the major contributors of R&D project complexity. This shows that managers and technical specialists working on the same project do not experience the same complexities.

Despite the difference in perception between the R&D specialists and the manager, both parties agree that unskilled resources and increased scope of work are the major causes of project delays.

5 Conclusions and recommendations

In this chapter, the research study is concluded by stating whether the two research questions formulated in chapter 1 have been answered as well as establishing whether the research objectives have been met. Conclusions are drawn from the literature review and the results of the case study. Lastly, the recommendations and limitations of the study are outlined.

5.1 Research objective

Many R&D projects have unique characteristics, are complex, flexible and have high uncertainties. More often than not, these projects exceed the planned project time and end up terminated without achieving the objectives (Chroneer and Bergquist, 2012). This research was initiated with the main aim of identifying and gaining in-depth understanding of the complexities faced by organisations regarding R&D project management processes and the impact the complexities have on project duration. In order to achieve the objective of the study, literature review was conducted and primary data was collected through questionnaires and interviews to answer the following research questions:

RQ 1: What are the complexities of R&D project management processes?

RQ 2: What is the impact of the complexities on project duration?

5.2 Findings of research question 1

Literature review was conducted to identify the sources of R&D project complexity and the factors that contribute to each complexity. In order to differentiate R&D complexity from the complexities of other projects, eleven sources of complexity were identified from which eight were classified as being applicable to R&D projects.

From the findings of this study, the sources and factors in Figure 11 have been identified as being the common highest contributors to R&D project complexity.

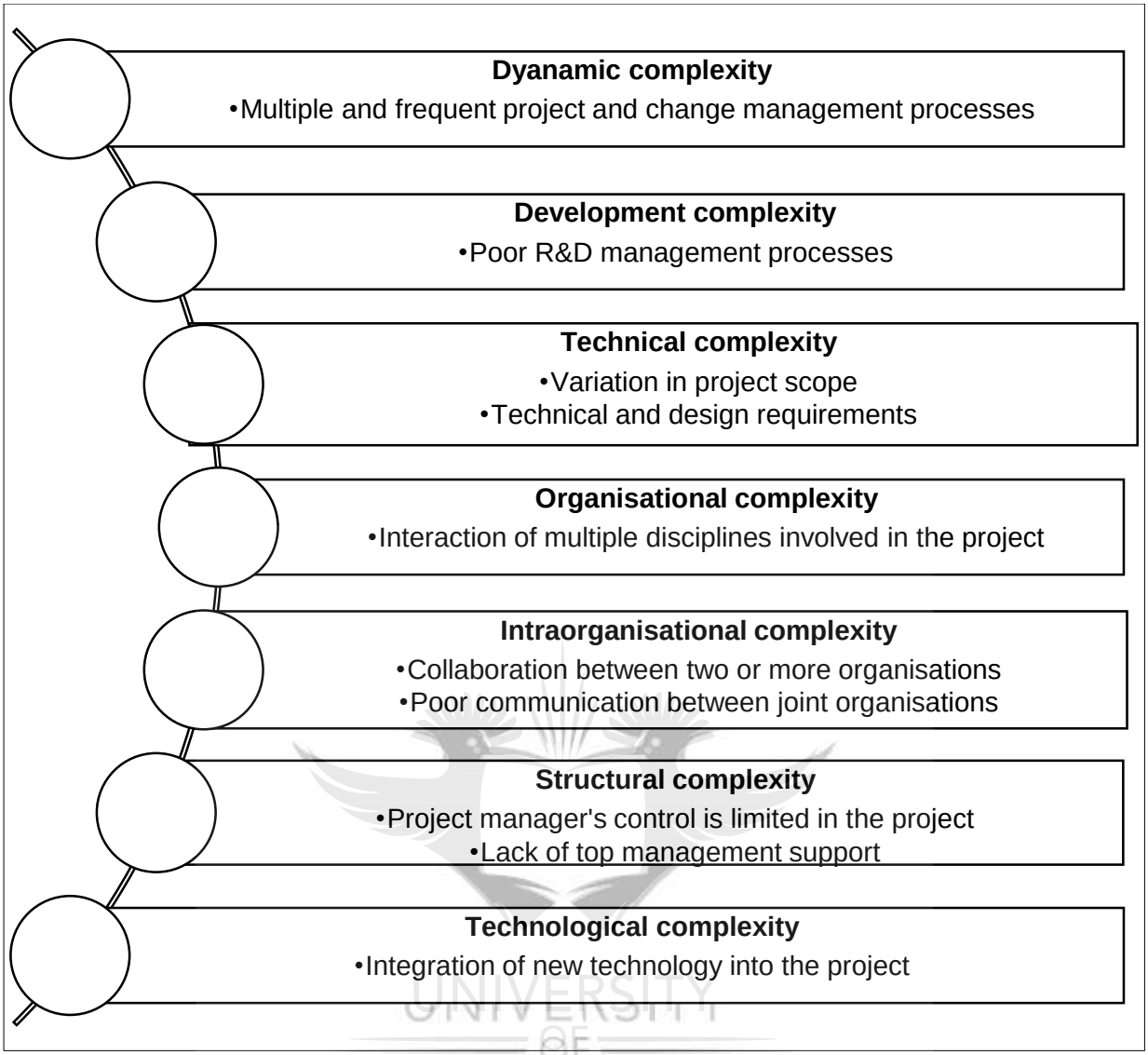

Figure 11: Common R&D complexity sources and factors

In literature review, structural complexity was identified as being inapplicable to R&D projects; however, the results of the questionnaires and interviews indicate that this kind of complexity is experienced in R&D projects.

Although there are different perspectives regarding the complexity sources and the contributing factors experienced by technical specialists and managers, the first research question was answered successfully by identifying in detail the complexities of the R&D project management process.

5.3 Findings of research question 2

Many R&D projects are delivered late to the market and end up losing their competitive advantage. This research was conducted to identify in-depth the impact that R&D project

complexity has on the duration of the project. The factors in Figure 12, as identified from the study, if left unmanaged or uncontrolled will have a negative influence on the project.

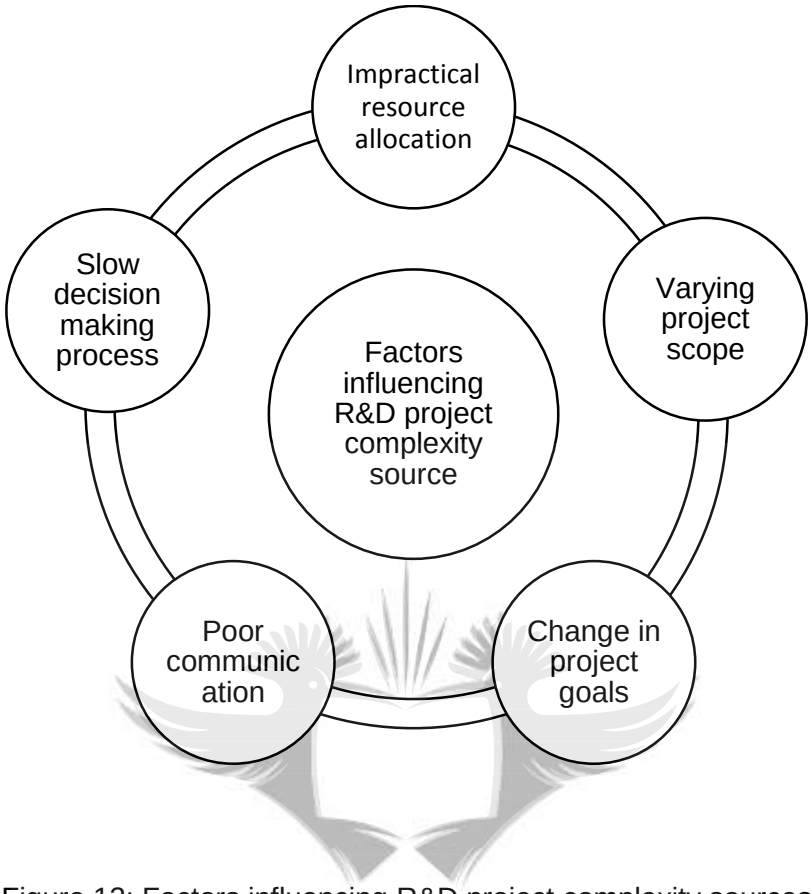

Figure 12: Factors influencing R&D project complexity sources

The second research question was well answered through literature review and the case study by identifying the impact that each complexity factor has on project duration.

5.4 Concluding results

Based on the findings of the literature review and the case study, the following conclusions are drawn regarding R&D project complexity:

- R&D projects have complex characteristics that affect their project management processes
- Project complexity is mainly defined in terms of scope of work, uncertainties, project management processes and multidisciplinary systems
- There are numerous sources of R&D project complexity
- There are multiple factors that contribute to R&D project complexity sources and they differ for different R&D projects
- There is a different perception between technical and managerial personnel regarding the factors and sources of R&D project complexity

Based on the findings of the study, the following conclusions are drawn regarding the impact of R&D project complexity on the duration of the project:

- R&D projects are driven by the scope of work
- Resources are the most essential part of the project. Their skills and competencies are crucial in ensuring the successful completion of projects on time
- The type of organisational structure under which the project is conducted has an influence on the outcome of the project
- Project complexity has a negative influence on the overall project performance. The project that exceeds the planned time incurs additional costs
- R&D projects that exceed planned time loose top management support

5.5 Recommendations

Based on the findings of the study, the following recommendations are made:

1. More research must be conducted to include different case studies with different R&D projects in different industries. There will be variation in responses due to different project backgrounds and experiences
2. Further research must be conducted to develop a complexity assessment model that will be used to assess the level of complexity in a project. This will ensure that proper management processes are put in place to alleviate or control the complexity.

5.6 Limitations

The case study in this research was a holistic single case study type conducted on an R&D team in an engineering organisation. The results are limited to the type of project the team is working on and the type of industry. Different case studies could have yielded different results depending on the project types and industries.

The results are limited to the type of research methodology and data analysis used in this study. Different research approaches, data collection methods and data analysis will yield different results.

6 References

Association for Project Management (2006) *Body of Knowledge*. Available at: http://www.amazon.ca/exec/obidos/redirect?tag=citeulike09-20&path=ASIN/1903494133.

Badewi, A. (2016) 'The impact of project management (PM) and benefits management (BM) practices on project success: Towards developing a project benefits governance framework', *International Journal of Project Management*. Elsevier Ltd. APM and IPMA., 34(4), pp. 761–778.

Basu, R. (2016) *Managing Projects in Research and Development*.

Baxter, P. and Jack, S. (2008) 'The Qualitative Report Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers', *The Qualitative Report*, 13(4), pp. 544–559.

Bosch-rekveldt, M. *et al.* (2011) 'Grasping project complexity in large engineering projects : The TOE (Technical , Organizational and Environmental) framework', *JPMA*. Elsevier Ltd and IPMA, 29(6), pp. 728–739.

Burde, D. (2002) *Project Management Process*. Available at: http://link.aip.org/link/?JMENEA/18/150/1.

Cavone, A., Chiesa, V. and Manzini, R. (2000) 'Management styles in industrial R & D organisations', *European Journal of Innovation Management*, 3(2), pp. 59–71.

CeSTII (2014) *South African National Survey of Research and Experimental Development*.

Chang, S., Li, Y. and Gao, F. (2016) 'The impact of delaying an investment decision on R&D projects in real option game', *Chaos, Solitons and Fractals*. Elsevier Ltd, 87, pp. 182–189.

Chen, H. H., Qiao, S. and Lee, A. H. I. (2014) 'The impacts of different R&D organizational structures on performance of firms: Perspective of absorptive capacity', *Journal of High Technology Management Research*. Elsevier Inc., 25(1), pp. 83–95.

Chroneer, D. and Bergquist, B. (2012) 'Managerial Complexity in Process Industrial R&D Projects: A Swedish Study', *Project Management Journal*, 43(2), pp. 21–36. 10.1002/pmj.

Cristóbal, J. R. S. (2017) 'Complexity in Project Management', *Procedia Computer Science*. Elsevier B.V., 121, pp. 762–766.

Czuchry, A. J. and Yasin, M. M. (2003) 'Managing the project management process', *Industrial Management & Data Systems*, 103(1), pp. 39–46.

Daim, T. U. (2014) *Planning and Roadmapping Technological Innovations*.

Daniel Sherman, J. and Olsen, E. A. (1996) 'Stages in the project life cycle in R&D organizations and the differing relationships between organizational climate and performance', *Journal of High Technology Management Research*, 7(1), pp. 79–90.

Eriksson, P. E., Larsson, J. and Pesämaa, O. (2017) 'ScienceDirect Managing complex projects in the infrastructure sector — A structural equation model for fl exibility-focused project management', *International Journal of Project Management*. Elsevier Ltd, APM and IPMA, 35(8), pp. 1512–1523.

Evo, T., Wang, J. and Kleiner, B. H. (2005) 'The Evolution of R&D Management', *Management Research News*, 28(11/12), pp. 88–95.

Floricel, S., Michela, J. L. and Piperca, S. (2016) 'Complexity, uncertainty-reduction strategies, and project performance', *International Journal of Project Management*. Elsevier

Ltd and Association for Project Management and the International Project Management Association, 34(7), pp. 1360–1383.

Gaus, N. (2017) 'Selecting research approaches and research designs: a reflective essay', *Qualitative Research Journal*, 17(2), pp. 99–112.

Geraldi, J., Maylor, H. and Williams, T. (2011) 'Now, let's make it really complex (complicated): A systematic review of the complexities of projects', *International Journal of Operations and Production Management*, 31(9), pp. 966–990.

Gunasekaran, A. (1992) 'An analysis and experiences on the management of international and joint R & D projects', pp. 669–678.

Izmailov, A., Korneva, D. and Kozhemiakin, A. (2016) 'Project Management Using the Buffers of Time and Resources', *Procedia - Social and Behavioral Sciences*. The Author(s), 235(October), pp. 189–197.

Jalali, A. *et al.* (2016) 'Does lean & agile project management help coping with project complexity ?', *Procedia - Social and Behavioral Sciences*. The Author(s), 226(October 2015), pp. 252–259.

Jason, B. *et al.* (2018a) 'Coding : Open Coding In : Encyclopedia of Case Study Research', pp. 156–157.

Jason, B. *et al.* (2018b) 'Coding : Selective Coding In : Encyclopedia of Case Study Research'.

Joseph, N. (2017) 'Conceptualising a multidimensional model of information communication and technology project complexity', *South African Journal of Information Management*, 19(1), pp. 1–14.

Kerzner, H. (1981) 'The R&D project manager', *Project Management Institute*, 12(2), pp. 20–24.

Kerzner, H. and Belack, C. (2010) 'Project Characteristics', in *Managing Complex Projects*, pp. 2–39.

Khoshnevis, P. and Teirlinck, P. (2018) 'Performance evaluation of R&D active firms', *Socio-Economic Planning Sciences*. Elsevier Ltd, 61, pp. 16–28.

Kim, J. and Wilemon, D. (2003) 'Sources and assessment of complexity in NPD projects', *R and D Management*, 33(1), pp. 15–30.

Kim, J. and Wilemon, D. (2009) 'An empirical investigation of complexity and its management in new product development', *Technology Analysis and Strategic Management*, 21(4), pp. 547–564.

Kiyota, M. and Kubo, H. (2016) 'A Training method Proposal for R&D Project Managers', in, pp. 2088–2095.

Kothari, C. R. (2004) *Research Methodology: Methods & Techniques*, *New Age International (P) Ltd*.

Krause, I. and Liu, J. (1993) 'Benchmarking R & D Productivity'.

Kuchta, D. *et al.* (2015) 'R & D projects in the science sector'.

Kuchta, D. and Skowron, D. (2015) 'Classification of R & D projects and selection of R & D project', *R&D Management*, pp. 1–11.

Labuschagne, C. and Brent, A. C. (2005) 'Sustainable Project Life Cycle Management: The need to integrate life cycles in the manufacturing sector', *International Journal of Project*

Management, 23(2), pp. 159–168.

Laliene, R. and Liepe, Z. (2015) 'R&D Planning System Approach at Organizational Level', *Procedia - Social and Behavioral Sciences*. Elsevier B.V., 213, pp. 812–816.

Lalienė, R. and Sakalas, A. (2014) 'Development of R&D Effectiveness Assessment System in the Research Organizations', *Procedia - Social and Behavioral Sciences*, 156(April), pp. 340–344.

Larsen, C. I. *et al.* (2014) 'Scope Management of R & D Projects Defining scope of a Research and Development (R & D) based project', (October).

Larsen, E. R. (2004) 'Adapting Project Management Principles and Tools for Research and Development', *American Institute of Chemical Engineers (AICHE) Annual Meeting*, (1).

Lebcir, R. M. and Choudrie, J. (2011) 'Impact of Project Complexity Factors on Project Cycle Time : A System Dynamics Modelling Approach', 15, pp. 5–6.

Lee, K., Jeong, Y. and Byungun, Y. (2017) 'Developing an research and development (R&D) process improvement system to simulate the performance of R&D activities', *Computers in Industry*, 92(93), pp. 178–193.

Löhr, K. *et al.* (2018) 'Operational challenges in collaborative research projects', *Kybernetes*, p. K-04-2017-0124.

Loudon, J. (2012) 'Applying project management processes to successfully complete projects in radiation medicine', *Journal of Medical Imaging and Radiation Sciences*. Elsevier Inc., 43(4), pp. 253–258.

Luo, L. *et al.* (2017) 'Construction Project Complexity : Research Trends and Implications', *Journal of Construction Engineering and Management*, 143(7), p. 10.

Manoliadis, O. and Vasilakis, E. (2016) 'Complexity Measurement in Engineering Projects Using Factor Analysis and the Single Multi-Attribute Rating Technique Exploiting Ranks (SMARTER)', 1(2), pp. 36–43.

Marnewick, A. and Nel, H. (2017) 'A model for postgraduate supervision of large student numbers in Engineering Management at the University of Johannesburg', *2017 IEEE Technology and Engineering Management Society Conference, TEMSCON 2017*, pp. 394–399.

Marnewick, C., Erasmus, W. and Joseph, N. (2017) *Complexity of information systems projects in The symbiosis between information system project complexity and information system project success,*.

Maylor, H. R., Turner, N. W. and Murray-webster, R. (2013) 'How Hard Can It Be ?', (August).

De Mera Sánchez, P. D., Gaya, C. G. and Peréz, M. Á. S. (2013) 'Standardized models for project management processes to product design', *Procedia Engineering*. Elsevier B.V., 63, pp. 193–199.

Mikulskienė, B. (2014) *Research and development.*, *Nature*.

Morgan, D. L. (2017) 'Research Design and Research Methods', in *Integrating Qualitative and Quantitative Methods : A Pragmatic Approach*. 55 City Road: SAGE Publications, Inc, pp. 45–62.

Mossalam, A. (2017) 'Projects' issue management', *HBRC Journal*.

Munns, A. K. and Bjeirmi, B. F. (1996) 'The role of project management in achieving project

success', *International Journal of Project Management*, 14(2), pp. 81–87.

Naveh, E. (2007) 'Formality and discretion in successful R&D projects', *Journal of Operations Management*, 25(1), pp. 110–125.

Nicholas, W. (2010) *Research Methods : The Basics*, *Roultedge*.

Nobelius, D. (2004) 'Towards the sixth generation of R&D management', *International Journal of Project Management*, 22(5), pp. 369–375.

Noor, K. B. M. (2008) 'Case study: A strategic research methodology', *American Journal of Applied Sciences*, 5(11), pp. 1602–1604.

Park, Y. and Kim, S. (2005) 'Linkage between knowledge management and R&D management', *Journal of Knowledge Management*, 9(4), pp. 34–44.

PMI (2017) *A Guide to the Project Management Body of Knowledge*, *Project Management Institute*.

Radujković, M. and Sjekavica, M. (2017) 'Project Management Success Factors', *Procedia Engineering*, 196(June), pp. 607–615.

Remington, K. and Pollack, J. (2007) 'Tools for complex projects', in. England.

Robson, C. (1993) 'The Methods of Data Collection', in *Real World Research*, pp. 254–268.

Rolstadås, A. and Schiefloe, P. M. (2017) 'Modelling project complexity', *International Journal of Managing Projects in Business*, 10(2), pp. 295–314.

Salguero, J. *et al.* (2015) 'R&D&i Management System in Distributed Manufacturing Systems', *Procedia Engineering*. Elsevier B.V., 132, pp. 54–61.

Sasidharan, S., Jijo Lukose, P. J. and Komera, S. (2015) 'Financing constraints and investments in R and D: Evidence from Indian manufacturing firms', *Quarterly Review of Economics and Finance*. Board of Trustees of the University of Illinois, 55(December 2010), pp. 28–39.

Saunders, M., Lewis, P. and Thornhill, A. (2015) *Research Methods for Business Students*. 7th edn, *Research methods for business students*. 7th edn.

Scandura, A. (2016) 'University–industry collaboration and firms' R&D effort', *Research Policy*. Elsevier B.V., 45(9), pp. 1907–1922.

Sebestyen, Z. (2017) 'Further Considerations in Project Success', *Procedia Engineering*. Elsevier B.V., 196(June), pp. 571–577.

Shenhar, A. and Dvir, D. (2008) 'Project management research - The challenge and opportunity', *IEEE Engineering Management Review*, 36(2), pp. 112–121.

Shenhar, A. J. (2001) 'One Size Does Not Fit All Projects_Exploring Classical COntingency Domains.pdf', *Management sciences*, 47(3), pp. 394–414.

Simmons, N. (2018) 'Axial Coding', in *The SAGE Encyclopedia of Communication Research Methods*, pp. 80–85.

Soderlund, J. (2002) 'Managing complex development projects : arenas , knowledge processes and time', *R&D Management*, 32(5), pp. 419–430.

Soderlund, J. (2005) *Developing Project Competence: Empirical Regularities in Competitive Project Operations*, *International Journal of Innovation Management*.

Sreejesh, S., Mohapatra, S. and Anusree, M. (2014) *Business research methods*.

Stavros, C. and Westberg, K. (2009) 'Using triangulation and multiple case studies to advance relationship marketing theory', *Qualitative Market Research*, 12(3), pp. 307–320.

Suomala, P., Kanniainen, J. and Lönnqvist, A. (2012) 'Managerial lessons on relevance and measurability in R&D project valuation', *Measuring Business Excellence*, 16(1), pp. 21–30.

Tashakkori, A. and Teddlie, C. (2009) 'Integrating qualitative and quantitative approaches to research', in *Handbook of Applied Social Research Methods*, pp. 283–317.

Thompson, C. B. (2009) 'Descriptive Data Analysis', *Air Medical Journal*. Air Medical Journal Associates, 28(2), pp. 56–59.

Tonchia, S. (2008) *Industrial Project Management*, *Studies of the modern corporation*.

Too, E. G. and Weaver, P. (2014) 'The management of project management: A conceptual framework for project governance', *International Journal of Project Management*. Elsevier Ltd, 32(8), pp. 1382–1394.

Verma, D., Mishra, A. and Sinha, K. K. (2011) 'The development and application of a process model for R&D project management in a high tech firm: A field study', *Journal of Operations Management*. Elsevier B.V., 29(5), pp. 462–476.

Wang, J. and Yang, C. Y. (2012) 'Flexibility planning for managing R&D projects under risk', *International Journal of Production Economics*. Elsevier, 135(2), pp. 823–831.

Wang, N. *et al.* (2017) 'The role of project management in organisational sustainable growth of technology-based firms', *Technology in Society*. Elsevier Ltd, 51, pp. 124–132.

Wei, L. (2010) 'Manager ' s challenges -- managing constraints', in *PMI Global Congress 2010*.

White, P. A. F. (1980) *Effective Management of Research and Development*.

Wicks, D. (2012) 'Coding: Axial Coding', in *Encyclopedia of Case Study Research*, pp. 154–158.

Yin, R. K. (2014) *Case Study Reserach - Design and Methods*, *SAGE*. SAGE Publications, Inc.

Zandhuis, A. and Stellingwerf, R. (2012) *ISO21500: Guide on project management- A pocket Guide*.

Appendix

A Questionnaire design

Effective management of R&D project complexities to ensure on-time delivery

This research is done as part of the Masters studies for which the objective is to identify complexities in R&D projects and their impact on project duration. Please help me complete the research by answering the questions on this questionnaire, as objectively as possible and note that all the information provided will be treated as **strictly confidential**.

Section A: Profile background (Indicate with "X" where applicable)

1.	Level of qualification	National Diploma		B.Tech		B.Eng/B.Sc	
		Masters		PhD		Other	
2.	Years of experience	3-5		5-10		Above 10	
3.	Position						

Section B: R&D project complexity (Indicate with "X" where applicable)

4.	How many R&D projects have you worked on?		
5.	How many projects were completed on time?		
6.	How many projects were not completed on time?		
7.	A project is considered complex if it has several interconnected systems and it is characterised by high uncertainties. R&D projects are classified as complex, do you agree with this statement?	Yes	No
8.	Elaborate on your answer from question 7.		

9.		Different sources of complexities have been identified. Under each complexity source, there are different factors that contribute to the complexity. Based on your experience, on a scale of 1-5, do you agree that these factors contribute to the source of R&D project complexity?					
	Source of complexity	**Factors contributing to project complexity source**	**1** Strongly disagree	**2** Disagree	**3** Neither agree or disagree	**4** Agree	**5** Strongly agree
	Organisational complexity	High level of reporting structure					
		Large multidisciplinary team					
		Interaction between multiple organisational departments					
	Technical complexity	The technical and design requirements of the project					
		Varying project scope					
	Uncertainty	Uncertain project costs and value					
		Uncertain project goals					

	Dynamic complexity	Multiple and frequent changes in the project and management process					
	Intraorganisational complexity	Collaboration between two or more organisations					
		Poor communication between joint organisations					
	Technological complexity	Integration of different sub systems in a project					
		The incorporation and application of new technology in to the project					
	Marketing complexity	Unpredictable market changes					
		High level of competition					

	Temporal complexity	Unanticipated future constraints such as change in government or company ownership					
	Development complexities	Poor management of R&D processes					
	Environmental complexity	Environmental risks associated with the location of the project					
		Multiple stakeholders with different perspectives					
	Structural complexity	Lack of top management support					
		Project manager's level of control over the resources is limited					
	Others	Please describe					

Section C: Impact of R&D project complexities on project duration (Indicate with "X" where applicable)

10.	**The following factors, if not managed effectively can result in project delay:**	**1** Strongly disagree	**2** Disagree	**3** Neither agree or disagree	**4** Agree	**5** Strongly agree
	Impractical resource allocation is insufficient to complete the project on time					
	Slow decision making due to high level of hierarchy slows down project activities					
	Conflict due to poor communication between organisations, requires time for resolution thus suspending project execution					
	Adapting and integration of new technology requires more time, the project activities are paused to learn the new technology and the project duration is extended					
	Creation of new marketing and distribution channels could extend the time it takes to bring new products to the market					
	The more the project scope increases the more the time taken to execute the tasks increases					
	The review and correction of the design errors add more time to the project phases					

	Difficulty to integrate poor R&D project management processes results in delayed project milestones, eventually extending project duration					
	Frequent change management processes delay the project activities and therefore extend the time required to complete the project					
	Late release of funds delays the project execution					
	Change in project goals adds more time to execution of project activities					
	Others, (please describe)					

Thank you for your participation.

B Interview design

Interview Questions

This interview is conducted as part of the Masters studies to acquire additional information pertaining to R&D project complexities and their impact on project duration.

Section A: profile background

Level of qualification: ……

Years of experience: …….

Position: ……..

Date of the interview: ……

Section B: R&D project complexities

1. What is your understanding of the term "complexity" in the context of the project?

……
……
……

2. Would you say the projects you work/worked on are complex? And why?

……
……
……

3. What are the sources of complexities in R&D projects?

……
……
……

Section C: Impact of R&D project complexities on project duration

4. Do project complexities affect the duration of the project? How?

……
……
……
……

5. What is the impact of late delivery on the overall project outcome?

……
……
……

Thank you for taking your time to do this interview.

C Responses of factors contributing to complexity source

	Different sources of complexities have been identified. Under each complexity source, there are different factors that contribute to the complexity. Based on your experience, on a scale of 1-5, do you agree that these factors contribute to the source of R&D project complexity?							
Source of complexity	**Factors contributing to project complexity source**	**1** Strongly disagree	**2** Disagree	**3** Neither agree or disagree	**4** Agree	**5** Strongly agree	**Points**	**Calculated weighed score**
Organisational complexity	High level of reporting structure	0	1	3	6	2	45	3.75
	Large multidisciplinary team	0	1	3	5	3	46	3.83
	Interaction between multiple organisation departments	0	0	1	6	5	52	4.33
Technical complexity	The technical and design requirements of the project	0	2	1	3	6	49	4.08
	Varying project scope	0	0	1	4	7	54	4.50
Uncertainty	Uncertain project costs and value	0	0	4	6	2	46	3.83
	Uncertain project goals	0	2	3	2	5	46	3.83

Dynamic complexity	Multiple and frequent changes in the project and management process	0	0	1	3	8	55	4.58
Intraorganisational complexity	Collaboration between two or more organisations	0	1	2	5	4	48	4.00
	Poor communication between joint organisations	0	1		4	7	53	4.42
Technological complexity	Integration of different sub systems in a project		1	2	4	5	49	4.08
	The incorporation and application of new technology in to the project	0	1	2	7	2	46	3.83
Marketing complexity	Unpredictable market changes	0	4	5	2	1	36	3.00
	High level of competition	0	4	4	2	2	38	3.17

Temporal complexity	Unanticipated future constraints such as change in government or company ownership	0	1	5	4	2	43	3.58
Development complexities	Poor management of R&D process	0		1	3	8	55	4.58
Environmental complexity	Environmental risks associated with the location of the project	0	1	4	6	1	43	3.58
	Multiple stakeholders with different perspectives	0	1	3	4	4	47	3.92
Structural complexity	Lack of top management support	0	1	1	3	7	52	4.33
	Project manager's level of control over the resources is limited	0	1	0	4	7	53	4.42
Others	Please describe							

D Responses of the impact of complexity factors on project duration

The following factors, if not managed effectively can result in project delay:	**1** Strongly disagree	**2** Disagree	**3** Neither agree or disagree	**4** Agree	**5** Strongly agree	**Points**	**Calculated weighed score**
Impractical resource allocation is insufficient to complete the project on time	0	0	0	5	7	55	4.58
Slow decision making due to high level of hierarchy slows down project activities	0	0	1	3	8	55	4.58
Conflict due to poor communication between organisations, requires time for resolution thus suspending project execution	0	1	0	4	7	53	4.42
Adapting and integration of new technology requires more time, the project activities are paused to learn the new technology and the project duration is extended	0	2	1	5	4	47	3.92
Creation of new marketing and distribution channels could extend the time it takes to bring new products to the market	0	4	4	4	0	36	3.00

The more the project scope increases the more the time taken to execute the tasks increases	0	0	0	4	8	56	4.67
The review and correction of the design errors add more time to the project phases	0	0	2	7	3	49	4.08
Difficulty to integrate poor R&D project management processes result in delayed project milestones, eventually extending project duration	0	1	0	4	7	53	4.42
Frequent change management processes delay the project activities and therefore extend the time required to complete the project	0	4	2	4	2	40	3.33
Late release of funds delays the project execution	0	0	1	6	5	52	4.33
Change in project goals adds more time to the execution of project activities	0	0	2	2	8	54	4.50
Others, (please describe)