

# **The theory of measurement for projects:**

A methodology to enhance the execution of projects

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Thesis submitted in fulfilment of the requirements for the  
degree *Doctor Philosophiae* in *Engineering*  
*Development and Management* at the Potchefstroom  
Campus of the North-West University

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November 2015

## **Preface and acknowledgements**

I dedicate this research and my life to the living God.

I owe a debt of gratitude to my family, Yollanda, Ruhann and Wian for supporting and tolerating me during the conclusion of this research and thank my parents for instilling the ambition and determination to conclude this work. I especially appreciate the opportunity to complete this research afforded me by Charles Kroukamp, George Farndell and CGR. I specifically acknowledge Professor Piet Stoker for his support and guidance.

I acknowledge the project owner for allowing the data to be used for research purposes, even though the identifying information was removed or altered as per request.

I submit this work to the project management community in a belief that it will contribute one more step towards improved project success and delivering projects early.

# Abstract

## *Scope*

This research focused on **time-critical projects**, i.e. where the strategy of the organisation is at stake if projects are not completed in time. Execution management, specifically improvements in measurement, is addressed in preference to improvements in planning and estimation accuracy.

This research challenged the rationality normally taken for granted when looking at measurement in projects.

To support the management of time in time-critical projects, the objectives of this study were (1) to develop a theory of measurement for projects (TOM-P) and (2) to validate the theory through empirical testing.

## *Approach*

The experimental design was modelled on the Wallace process and comprised a scoping study, theory development and a validation study.

The research addressed two hypotheses:

**$H_1$**  : There is an association between project task time measurement methodology and project duration, and

**$H_2$**  : Implementing a measurement methodology based on the TOM-P reduces project duration (compared to not implementing the measurement methodology based on the TOM-P).  **$H_2$**  evaluates the TOM-P and demonstrates how value is created through implementation of the TOM-P.

The scoping study was executed between 2008 and 2010 to evaluate research viability. Five time-critical industrial projects (50-100 days, 10-20 million USD) were used as test projects, with six previous projects from the same industry as control cases.

The theory of measurement for projects was developed, complying with the four basic requirements for a theory: (1) definitions of concepts, (2) definition of domain and limitations, (3) definitions of key relationships, and (4)

predictive claims. The theory is also evaluated in terms of the requirements for scientific knowledge and theory building as documented in the academic literature (Reynolds 1976; Koskela & Howell 2002; Choi & Wacker 2011; Quine & Ullian 1980; Amundson 1998).

The research was further supported by a validation study to evaluate the results from applying TOM-P to industry projects. The validation study was executed between 2012 and 2014 on eighteen engineering management projects, with a control group of 66 similar projects.

Significant attention was given to research rigour during the design and execution phases to support the reliability and validity of research findings. Internal validity, construct validity, external validity and reliability were addressed, based on acknowledged academic literature.

### ***TOM-P***

To reduce tasks and project duration in time-critical projects, the theory of measurements for projects provides a deeper understanding of task time. Task time is decomposed into heterogeneous and interdependent task components.

TOM-P provides the understanding how differentiated measurements are utilised to reduce task duration.

### ***Findings***

The scoping study results demonstrated a significant correlation between measurement methodology and project duration ( $r_{pb} = 0,79$ ) and a similar result was reported by the validation study ( $r_{pb} = 0,74$ ). Effect sizes were  $w=0,8$  and  $w =1$  for the two studies, where  $w >0,5$  is considered practically significant. In both cases the null hypothesis was rejected at a statistical significance level of  $< 10^{-3}$ .

**$H_2$**  considered the impact of applying TOM-P to projects, specifically whether project duration is reduced. Hill's criteria for causation is referenced and extensive descriptions are provided to demonstrate how confounding

parameters were considered and eliminated.  $H_2$  was supported by the empirical data from the validation study.

### ***Research limitations***

TOM-P is specifically relevant and applicable for time critical projects, and has limited application in project environments where the importance of on-time completion is secondary to cost saving, resource availability or strategic decisions.

### ***Significance***

TOM-P creates value in terms of improved on-time completion performance and reduced risk of delay for time-critical projects. This improvement in reliability of completion date is achieved without adverse impact on cost, quality or safety. TOM-P can also support a long-term sustainable competitive edge for project-based organisations through efficient strategy implementation.

### ***Originality***

This research contributes additional understanding of the effect of project measurements on project success, specifically the measurement of time on project duration. The author's original contribution to the science of project and engineering management is contained in the theory of measurement for projects (TOM-P) and its validation.

### ***Keywords***

Project management, project time measurement, project measurement theory, time critical projects, theory of measurement for projects.

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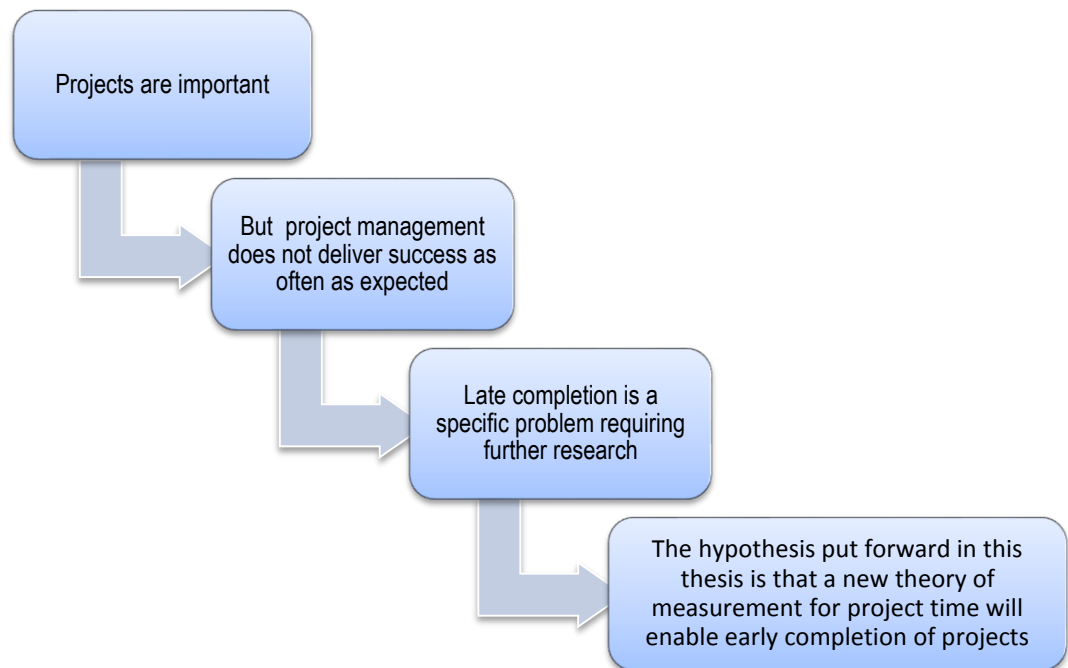
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# 1 Introduction



Chapter 1 introduces project management as an important research area and presents the challenges of on-time completion. The research problem is identified; the scope is defined, and the original contribution is summarised.

## 1.1 Project management is important to humanity

Projects and project management (PM) are fundamental to human and business activity. The planning and execution of a sequence of events, to achieve an objective, is based on project management principles. Support for these statements is widespread.

Pinto declares that projects “*are the principal means by which we change our world*” (Pinto 2010), and the management of projects is a primary delivery methodology for all human endeavours.

Morris admires the contribution of PM over centuries, stating:

***We stand in awe of the achievements of the builders of pyramids, the architects of ancient cities, the masons and craftsmen of great***

***cathedrals and mosques; of the might and labour behind the great wall of China and the wonders of the world (Morris 1997).***

Juran even defined a project as “*a problem scheduled for a solution*” (Juran 1981). Frame claims that competition is the underlying reason for projects and PM becoming the central focus of management activity in many organisations (Frame 1999).

PM has established itself as an important management process with strategic and bottom-line impact in organisations (Srivannaboon 2005). This line of thought is supported by Shenhar, who presents projects as “*powerful strategic weapons, initiated to create economic value and competitive advantage*” (Shenhar *et al.* 2002) and there is even talk of the “*projectification of society*” (Lundin & Söderholm 1998).

The strategic value of PM was the topic of significant research in the past 60 years. As many as 30% of research articles in project management (in twelve mainstream journals) addressed the strategic contribution of project management to the organisation (Kwak & Anbari 2009).

Project management has therefore developed from an operational discipline in the mid-1900s to being viewed as a primary contributor to achieving organisation strategy in the 20<sup>th</sup> and early 21<sup>st</sup> century. In this 21<sup>st</sup> century, increasing international competition demands project management to contribute much more to organisational success and strategy delivery. Kendall defined the very value of PM as ensuring that the goals of the organisation are achieved (Kendall & Rollins 2003). Srivannaboon specifically explored the application of PM to achieve business strategy (Srivannaboon 2005).

The link from PM to organisational strategy could either be very direct or through a hierarchical structure of projects, programmes and portfolios as presented in Figure 1-1. Figure 1-1 demonstrates further that project success, as an important determinant of programme and portfolio success, ultimately also contributes to the strategic success of the organisation.

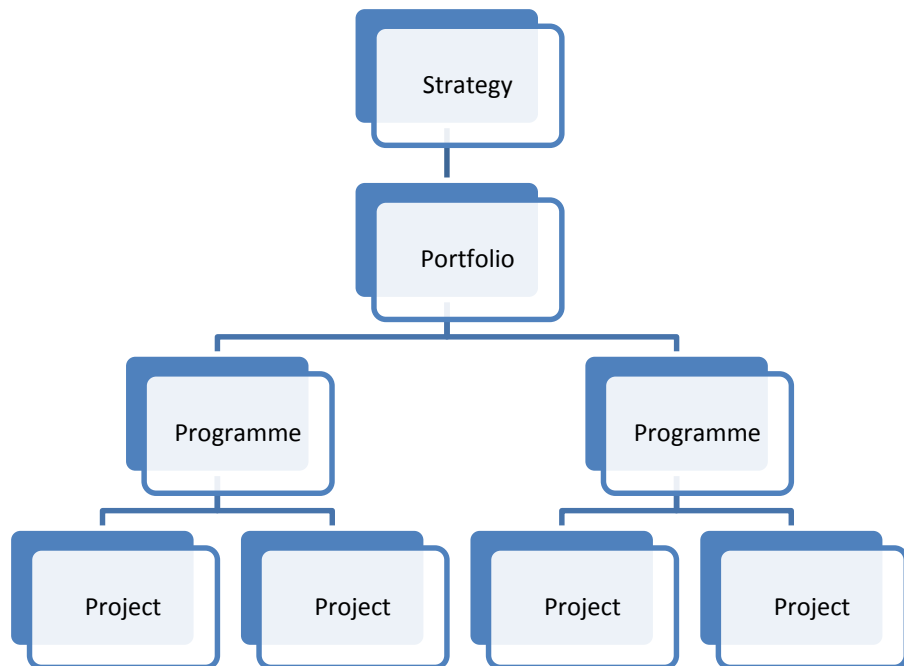


Figure 1-1: Linking strategy to projects (adapted from Cleland and King)

In a similar hierarchical structure of programmes, portfolios and strategies, projects contribute to the strategic success of countries and economies. Consequently, projects also contribute to the failure of programmes and eventually also to the failure of strategies.

A current and relevant example in the African context is the impact of energy projects on the economy and growth strategies of countries. Delayed completion of power and energy projects hinder economic growth, which has a concomitant effect on the achievement of development and growth strategies, as well as the socio-economic success of nations. Examples in the African context include the mega coal-fired power station project at Medupi (Sovacool & Rafey 2011), (Rafey & Sovacool 2011); many power projects in Africa as reported by Africa Research Bulletin (from 2008 to 2015 in Issues 45-52) (Bulletin n.d.; Anon 2010) as well as power projects in 22 emerging economies (Sadorsky 2010).

PM makes a valuable contribution to the achievement of strategies through the successful implementation of projects. With projects this important, it is unfortunate that project success is not as consistent as one would prefer.

## 1.2 PM is not delivering success consistently

Research into the success and failure of projects indicates that project management is not delivering the levels of success intended. Morris stated, “*despite the enormous attention project management has received over the years, the track record of projects stays fundamentally poor*” (Morris 1990).

The Standish Group scanned more than 800 software engineering projects for its 1994 report. They concluded that only 16% of the projects were able to meet the time, budget and quality goals originally agreed (Standish Group 1994). Success improved to a meagre 28% by 2010 (Standish Group 2010), and 39% by 2012 (Standish Group 2013) as presented in Figure 1-2.

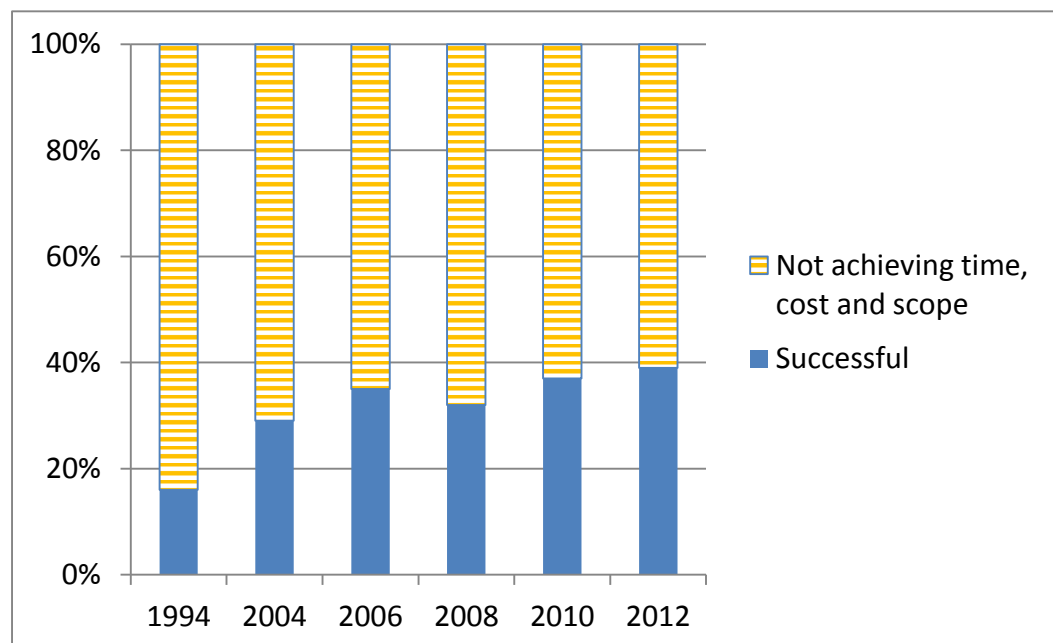


Figure 1-2: Project success according to Standish 1994 - 2012

Challenges to the Standish Group survey results include comments on the limited transparency of data as well as definitions being limited to the iron triangle (Eveleens & Verhoef 2009). Even acknowledging this critique, project performance is significantly less than desired.

Independent Project Analysis Inc. (IPA) defines project success as less than 25% late and less than 25% over budget. Even with this expanded definition of project success, IPA’s research of industrial projects indicated only 35%

of projects were successful (Merrow 2011). Morris reported similar results, stating that between 60% and 82% of projects fail (Morris 2008).

These alarming statistics on project success, as well as many high-profile project failures, cause significant concern. Steyn agreed that *“the implications of overspending on capital projects and of late delivery by such projects can hardly be overemphasised”* (Steyn 2009).

Several authors criticised the traditional approach to PM. The assumption of predictability, which in turn overemphasises planning, is ineffective for managing dynamic projects with high levels of complexity and uncertainty (Kapsali 2013; Söderlund 2004; Sebaux *et al.* 2011; Cullen & Parker 2015).

Concerns were raised and calls were made for additional research. Alternative theoretical approaches to the study of projects are required, specifically with regards to how we organise and manage projects. The dominant doctrines in PM must be re-examined for their failure to deliver on their promises (Koskela & Howell 2002; Winter *et al.* 2006; Morris *et al.* 2006; Morris *et al.* 2000; Cicmil & Hodgson 2006; Whitty & Maylor 2009; Frame 1999).

In summary, current PM theory does not support consistent on-time delivery of projects, which is specifically problematic for time-critical projects. Additional research is required to support PM as an important delivery methodology.

### **1.3 Scope of research**

The particular focus of this research was the duration and on-time completion of time-critical projects, i.e. where the strategy of the organisation is at stake if projects are not completed in time. This could take the format of either catastrophic failure of the organisation or significant financial loss due to late completion of a project. Examples of projects where on-time completion is of the utmost importance include (1) achieving the launch date of a product or event e.g. the Olympic Games opening event and engineering construction projects or software development projects which supports a particular strategic launch date. (2) Commissioning of mega-capital projects,

for example, a nuclear or fossil fuel power station, or construction of commercial property, where delayed commercial availability has financial implications far in excess of the cost of construction.

A solution to the problem of late completion of projects can be used as a strategic weapon in a competitive business environment. Against this backdrop, Steyn asks “*why has the problem not yet been solved?*” (Steyn 2009).

## 1.4 Identification of the research problem

As early as 1981 Schonberger demonstrated that the accepted deterministic project scheduling mechanisms of CPM and PERT understated the likely project duration (Schonberger 1981). The key reasons being the interdependency of network paths, leading to the conclusions by Schonberger that:

- The project will **always** be late, relative to the deterministic critical path.
- “Lateness” is exacerbated by activity time-variability, driving comparable levels of late completion.
- Lateness is directly proportional to the number of tasks in the network (as it multiplies the opportunities for interdependency, which drives this phenomenon).
- Simulating the network, through for example Monte Carlo analysis, provides additional information but there is no good way to compensate for the discrepancy between the critical path duration and the “true” duration because Parkinson’s law tends to counter one’s best efforts.

Schonberger concludes with “*the project manager should rather subjectively evaluate the duration and determine a “good” commitment for project completion*”(1981).



This conclusion by Schonberger provides valuable insight, but very limited guidance to project managers on how to determine a “suitable commitment”. Even when a duration commitment is determined, it provides no guidance on how the project should be managed or time should be measured and controlled, as the critical path schedule is “inherently flawed” (Schonberger 1981).

Acebes contributes that the schedule and budget resulting from traditional methods like PERT are statistically very optimistic and from their research they resolve that the probability of achieving the PERT time is under 30% (Acebes *et al.* 2014).

Critical path analysis further ignores workforce behavioural issues. Ignoring behavioural issues in modelling project activity durations is equivalent to assuming that there is no relationship between the actual amount of work to be done, the deadline set for the worker to finish that work, and the actual completion time of the work (Gutierrez & Kouvelis 1991).

Williams stated that the underlying assumptions of the PM bodies of knowledge, particularly PMBOK (Project Management Institute 2013) will lead to “*extreme overruns when projects, which are structurally complex, have high levels of uncertainty and have tight time constraints, are managed conventionally*”. Williams further states: “*The current prescriptive dominant discourse of project management contains implicit underlying assumptions with which the systemic modelling work clashes, indeed showing how conventional methods can exacerbate rather than alleviate project problems*” (Williams 2005).

Contributors to project management research (Flyvbjerg *et al.* 2003; Shenhar & Dvir 2008; Koskela & Howell 2002) “*attempt to explain overruns and overspending simplistically as the result of risk and uncertainty but the fact that some projects - including high-risk projects - are sometimes completed well within budget and on time, opposes such a proposition*” (Steyn 2009).

***In summary, current project management theory, specifically time measurement theory, is not sufficient to support frequent and low-risk on-time completion of projects.***

The contribution of this research is located in the area of **project time management**, as one of the knowledge areas defined by the Project Management Body of Knowledge (PMBOK). The ten knowledge areas are (1) project time management, (2) project scope management; (3) project cost management, (4) project quality management, (5) project human resources management, (6) project risk management, (7) project communication management, (8) project procurement management, (9) project integration management and (10) project stakeholder management (Project Management Institute 2013).

There is limited research available regarding task and performance measurement. Kwak reviewed a series of articles in mainstream magazines (Kwak *et al.*, 2009:435.) and reported that published research from the 1950s to 2000 only addressed the concept of task and performance measurement in 5% of the 675 papers. Attention to task and performance measurement improved to 10% in the 2000s.

The limited focus of research related to PM measurement is in contrast with the requirement by industry. During the update process of the APM PMBOK, a survey of 10 industries found that 90% of respondents wanted further research into project control and earned value measurement, under which task performance measurements were included (Morris *et al.* 2006). Rai contributed further research, stating that monitoring and control was “*one of the best distinguishing factors between projects that achieved on-time completion and delayed projects*” (Rai *et al.* 2003).

From these research reports, it is derived that a dominant factor contributing to the late completion of projects is inadequate PM knowledge regarding time management to support the planning and execution of projects. Time management in this context refers to project time planning, project time measurement and project time control.

The research problem was summarised by stating that project time measurement as a driver for project success was not well understood. Additional research and new contributions in the field of project time management, measurement and control were required.

## 1.5 Research objectives

The objectives of this study were:

- To establish a theory of measurement for project time measurement.
- To validate the theory through empirical testing.

This research focused on projects in complex environments where on-time completion is valuable or critical to the organisational strategy. Execution management, specifically improvements in measurement and control, was addressed in preference to improvements in planning and estimation accuracy. The motivation for the preference to execution management relates to complex project environments and is presented in Chapter 2.

## 1.6 Research hypothesis

The research addressed the two hypotheses:

$H_1$  : There is an association between project task time measurement methodology and project duration, with corresponding  $H_{1,0}$  that there is no association between project task time measurement methodology and project duration.

$H_2$  : Implementing a measurement methodology based on the TOM-P reduces project duration (compared to not implementing the measurement methodology based on the TOM-P).  $H_2$  evaluates the TOM-P and demonstrates how value is created through implementation of the TOM-P.  $H_{2,0}$  is stated as: Implementing a measurement methodology based on the TOM-P *does not* reduce project duration.

## 1.7 Original contribution

This research contributes additional understanding of the effect of project task time measurement on project success, specifically project duration and on-time completion. The contribution to project management knowledge to support improved project time management is further enriched through the

development of the theory of measurement for projects (TOM-P), specifically addressing project time.

The essence of the research is to demonstrate how an alternative measurement theory contributes to reducing project duration, improves on-time completion of projects and reduces the risk of late completion. The research demonstrated the impact of measurement theory on project duration and on-time completion. Measurement theory impacts project performance through a particular measurement methodology and the research demonstrated the robust relationship between the project progress measurement methodology (for time) and project duration, specifically driving on-time completion.

The author's original contribution to the science of project and engineering management is contained in the theory of measurement for projects (TOM-P) and its validation.

The research has relevance and value for project managers, risk managers and specifically business executives and investment sponsors.

### ***Significance***

TOM-P supports improved on-time completion of projects. The significance of the contribution is summarised in terms of the value it provides to project stakeholders:

TOM-P creates value in terms of:

- Improved on-time completion of projects and reduced risk of delay, without any adverse impact on cost, quality or safety. Hameri summarises the cost of late completion to include: (1) additional financing costs, (2) cost of delay in succeeding projects, (3) lost sales and (4) potentially shorter time to reap benefits in a world of reduced product life spans and significant first mover advantage.(Eisenhardt 1989b)

- Reduced cash-flow risk, relating to the on-time commercial operation of the asset and resulting revenue.
- Improved long-term sustainable competitive edge for project-based organisations through efficient strategy implementation.

## 1.8 Thesis overview

Chapter 2 presents an overview of the academic literature on project management, measurement theory and organisational control as it relates to measuring project time. Chapter 2 further summarises the challenges related to project time management and demonstrates the requirement for additional research, presenting the background to the development of TOM-P.

Chapter 3 presents the experimental design utilised and justifies the use of multiple case studies in a series of experiments to develop and validate the results of this research study.

Chapter 4 presents the scoping study and the results that demonstrated early support for the development of the TOM-P. Five time-critical industrial projects with durations between 50 and 100 days and a value range of USD 10-20 million were utilised.

Chapter 5 documents the development of the TOM-P based on acknowledged principles of utilising case studies for theory building. Chapter 5 concludes by discussing TOM-P in the light of accepted definitions of good theory, the role of theory, the characteristics of theory and the purpose of theory. Chapter 5 systematically documents the author's original contribution to the science of project and engineering management.

Chapter 6 presents a validation study utilising empirical research findings on the application of TOM-P.  $H_2$  was evaluated utilising eighteen test case projects and 66 control projects. It further presents an extensive discussion on research rigour and verification, contributing to the reliability and validity of the research.

Chapter 7 presents the conclusions and recommendations from this research.

## 2 Literature review

*Good theory has good definitions that are conservative... and unique (Wacker 2008).*

Conservatism requires that existing knowledge be considered and integrated, and uniqueness requires unique definitions. To comply with the conservatism and uniqueness requirements for a good theory, Chapter 2 provides a high-level overview of the key research that frames the context of the TOM-P.

The knowledge areas addressed in Chapter 2 comprises project management, measurement theory and organisational control theory, as presented in Figure 2-1.

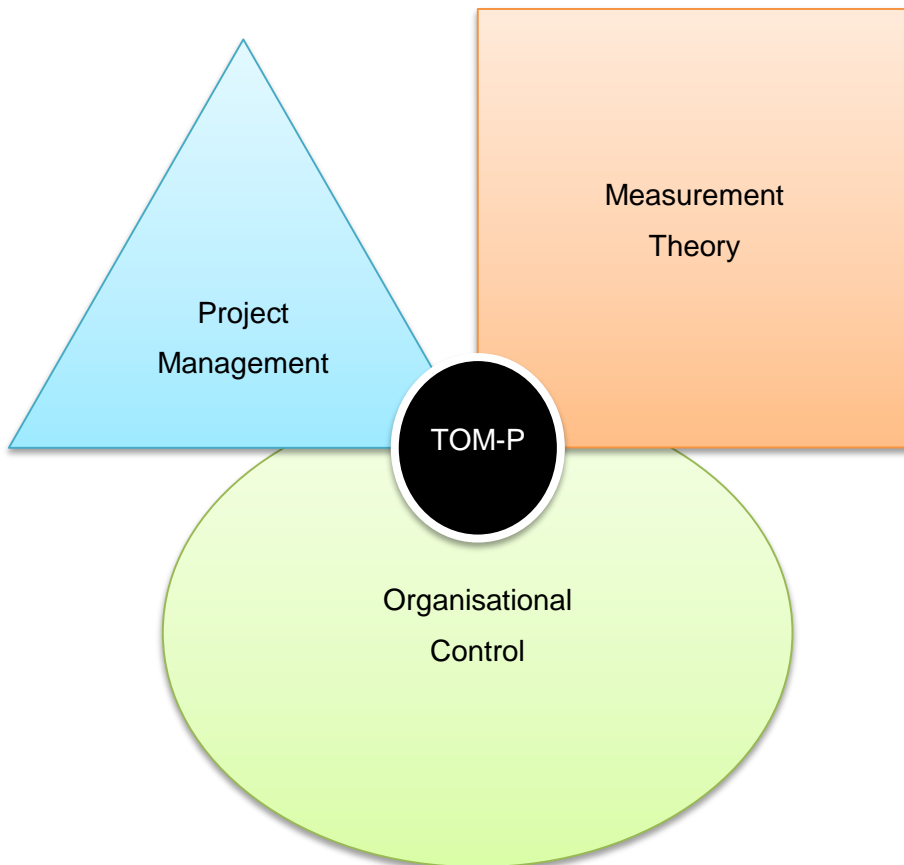


Figure 2-1: Knowledge areas covered by the literature review

In each case definitions, concepts and views are highlighted in terms of its applicability.

## 2.1 Project management

The literature review commences with definitions of projects, project management and project success. It further highlights how these definitions influence the current paradigm of project management and specifically project progress measurements.

Definitions originate from paradigms, and then definitions, practices and empirical results affect the further development of paradigms in an iterative pattern. A paradigm is broadly defined by the *Oxford Dictionary* as a “pattern or model”, for example, the worldview underlying the theories and methodology of a particular scientific subject.

### 2.1.1 A project

The concept of a project, as a temporary endeavour to achieve a specific and unique outcome, has existed since the start of civilisation. The formalisation of project management theory, tools and techniques reportedly started in the 1950s with the Polaris Project. During the past 60 years, many contributions have been made to the development of definitions for the concept of a project and the following definitions by institutions are presented as summarised view of the PM domain:

- The project management body of knowledge (PMBOK) published by the Project Management Institute defined a project as a “*temporary endeavour undertaken to create a unique product or service*” (Duncan 1996).
- ISO 10 006:2003 defined a project as “*a unique process consisting of a set of coordinated and controlled activities with start and finish dates, undertaken to achieve an objective conforming to specific requirements including constraints of time, cost and resources, as part of the ISO guidelines for quality management in projects*” (ISO 2003).
- The Association for Project Management (APM) defined a project as a “*unique, transient endeavour undertaken to achieve the desired outcome*” (APM Body of Knowledge, 5<sup>th</sup> edition).

- The International Project Management Association (IPMA) defined a project as a “*time and cost constrained operation to realise a set of defined deliverables to quality standards and requirements*” (IPMA Competence baseline V3.0).
- The British Standards Institute defined a project as “*a unique set of coordinated activities, with defined starting and finishing points, undertaken by an individual or organisation to meet specific objectives with defined schedule, cost and performance parameters*” (BS6079-1: Guide to Project Management).

Although the definitions differ to address specific views, they all agree on the core concept of achieving something specific in a specific time duration (even when the deterministic quality of the core components of duration, scope and resources varies).

This study intimates that these definitions, which focus heavily on a defined duration and specified end date, might be at the core of the thinking which guides project measurement methodologies and, therefore, a source of the problem.

### **2.1.2 Project management**

The definitions of project management, as the management process to deliver projects, have in common that it entails aspects of planning and controlling of resources to achieve project success, as illustrated by the following examples:

- The PMBOK defined project management as “*the application of knowledge, skills and techniques to execute projects effectively and efficiently. Project management is a strategic competency for organisations, enabling them to link project results to business goals and thus, better compete in their markets*” (Duncan 1996).
- Turner reported from the 1995 IPMA conference that project management was described as “*the art and science of converting vision into reality*” (Turner 1996).



Definitions for project management abound and contain two main components, i.e. work methods and a purpose. The following are examples. For clarity, the work method is underlined and purpose double underlined.

- “Project management is planning, directing and controlling resources (material, equipment, people) in order to fulfil the technical, cost and time constraints of a project” (Chase et al. 2006).
- Project management “involves three major categories of activities, namely planning, scheduling and controlling, all aimed at achieving the project's/stakeholders' objectives” (Lewis 1999).
- Project management is the “application of skills, knowledge, tools and techniques to project activities to fulfil or exceed the stakeholders' expectations and needs from a project” (Cook 2005).

Project management therefore clearly exists for the primary purpose of project success, which leads to questions regarding the definition of project success.

### **2.1.3 Project success**

Any study on project management is challenged by the definition of project success. The erstwhile definition of project success was compliance with the schedule, cost and quality requirements. This iron triangle has limitations, and Atkinson contributed that “*it has become an impossible, and, most likely, non-"value-adding" endeavour to define project management in terms of the traditional "iron triangle" principles, emphasising the achievement of time, cost, and quality objectives as the major justification for the role of project management*” (Atkinson 1999).

Hameri reported four projects where the perception of success was inconsistent with the iron-triangle results (Hameri & Heikkila 2002):

- The Fulmar oil field project in the North Sea was late but extremely profitable to the owner.
- The Thames Barrier Project was late and over budget, but it is a tourist attraction and was profitable for most of the contractors.
- The Concorde was late and overspent, but a technical success and it created an aerospace.
- In contrast, the Heysham II Nuclear Power Station project was nearly on time and on budget, but the perception of success was clouded by the public's perception of the nuclear industry and, therefore, judged to be unsuccessful.

In this cloud of what is “project success”, Shenhar went as far as stating that “*there is little agreement in research on what constitutes project success*” (Shenhar *et al.* 2002).

A considerable body of project management research reflects the investigation of the criteria for project success (Söderlund 2011). Soderlund proposed seven “*schools of thought*” to categorise the development of project management knowledge of which one is fully dedicated to “*matters of how to determine what a successful project is and what seems to cause project (management) success*”.

The definition of project success has changed and matured over the past 40 years. Key questions when defining project success relate to how much context of the **project** lifecycle, **product** lifecycle and **organisational** lifecycle are included. Can the project be a success if the product fails to satisfy key stakeholders or is the project a success if the organisation fails? These questions also relate to the field of systems engineering, which is considered in paragraph 2.1.6.

In the context of rapid changing environments and increased global competitive pressures, the requirement for projects to support organisational strategy increases. Projects and project managers provide a critical contribution to organisational success. With the changing contribution of

projects, from classic operational value to more strategic value, the definition of project success require corresponding changes.

Four phases can be identified in the development of definitions for project success as depicted in Figure 2-2 (Jugdev & Muller 2005; Ika 2009).

PROJECT LIFE CYCLE					
PROJECT LIFE CYCLE					
Conception	Planning	Production / Implementation	Handover	Utilization	Close Down
		<b>Period 1: Project Implementation and Handover (1960s - 1980s)</b>			
	<b>Period 2: CSF Lists (1980s - 1990s)</b>				
	<b>Period 3: CSF Frameworks (1990s - 2000s)</b>				
<b>Period 4: Strategic Project Management (21st century)</b>					

Figure 2-2: The history of "project success" definitions from Jugdev & Muller

### ***The 1960s to 1980s***

During the early period after the formalisation of project management, most definitions of project success focused on the iron-triangle. Success parameters were more operational and internally focused.

### ***The 1980s to 1990s***

During the 1980s to 1990s, more focus was placed on lists of critical success factors, and it was acknowledged that project success and organisational or product success was intertwined. Table 2-1 provide examples of lists of critical success factors which demonstrates the widespread attempts at identifying the core drivers for project success.

Define goals Select project organisational philosophy General management support Organise and delegate authority Select project team Allocate sufficient resources Provide for control and information mechanisms Require planning and review (Martin 1976)	Make project commitments known Project authority from the top Appoint competent project manager Set up communications and procedures Setup control mechanisms Progress meetings (Locke 1984)	Top management support Client consultation Personnel recruitment Technical tasks Client acceptance Monitoring and feedback Communication Troubleshooting Characteristics of the project team leader Power and politics Environment events Urgency (Pinto & Slevin 1988)
Project summary Operational concept Top management support Financial support Logistic requirements Facility support Market intelligence Project schedule Executive development and training Manpower and organisation Acquisition Information and communication channels Project review (Cleland & King 1983)	Project objectives Technical uncertainty innovation Politics Community involvement Scheduled duration agency Financial contract legal problems Implementation problems (Morris & Hough 1987)	Clear goals Goal commitment of project team On-site project manager Adequate funding to completion Adequate project team capability Accurate initial cost estimates Minimum start-up difficulties Planning and control techniques Task orientation (vs, social) Absence of bureaucracy (Baker <i>et al.</i> 1983)

Table 2-1: Examples of critical success factor lists

### ***The 1990s to 2000s***

The 1990s to 2000s provided the groundwork for the development of extensive critical success frameworks, during which both internal project measures and external environmental measures were acknowledged as determinants of project success. Hartman provided a broad definition of project success requiring “*the stakeholders to be satisfied with the outcome*”

(Hartman 1999). Shenhar specifically placed stakeholder satisfaction ahead of the iron-triangle (Shenhar & Levy 1997).

### **Early 2000s**

Since 2000, the focus of definitions for project success trended towards the contribution of projects to achieving the organisational strategy. This includes dimensions of strategic organisational success, commercial success, organisational learning, successful integration with neighbouring projects and user community satisfaction. To achieve these dimensions, an active relationship between the project owner and the project manager is required, which acknowledges that both key stakeholders and their success requirements might change during the lifecycle of the project.

The pressure on organisations to incorporate the principles of sustainability into business practises, including project management, are increasing. Labuschagne contributed that “*the current project management frameworks do not effectively address the three goals of sustainable development, i.e., social equity, economic efficiency and environmental performance*” and outlined a sustainable project lifecycle management methodology for application in manufacturing. (Labuschagne & Brent 2005). Sustainable development in the business context was defined by the International Institute for Sustainable Development as “*adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today, while protecting, sustaining and enhancing the human and natural resources that will be needed in the future*” (IISD 1992).

Shenhar identified four major success dimensions of projects, (1) project efficiency, (2) impact on the customer, (3) direct business and organisational success and (4) preparing for the future (Shenhar *et al.* 2002) which is summarised in Table 2-2.

<b>Success dimension</b>	<b>Measures</b>
Project efficiency	Meeting schedule goal Meeting budget goal
Impact on the customer	Meeting functional performance Meeting technical specifications Fulfilling customer needs Solving the customer's problem The customer is using the product The customer is satisfied
Business success	Commercial success Creating a large market share
Preparing for the future	Creating a new market Creating a new product line Developing a new technology

Table 2-2: Project success dimensions according to Shenhar

These dimensions are also time-related, as presented in Figure 2-3 (Shenhar *et al.* 2002).

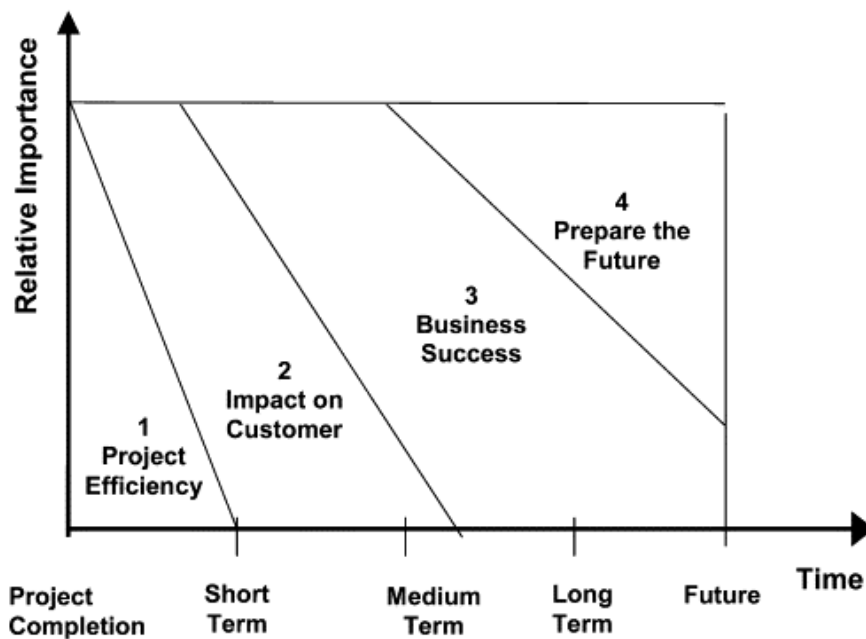


Figure 2-3: Time-related importance of project success dimensions according to Shenhar

The diagram demonstrates clearly that project efficiency is most important during project implementation and directly on completion. In the medium term, the impact of the project deliverables on the client is most important, and several examples exist where the classic iron triangle success parameters were not met for a project, but the project was successful for the client, e.g. Sydney Opera house and the channel tunnel.

In the longer term, the focus moves towards the contribution the project makes to business and organisational success, and preparing and developing for the future, which might include organisational learning, competitiveness, strategic product foundations and market positioning.

### ***Time as the critical success factor***

In summary, all the definitions of a project include mention of the “defined end”. This generally accepted requirement for an end date, as well as the discussion in the global context of a project and systems engineering, and the content of Figure 2-3 lead to a challenging question on the definition of the “end date”. For example, how should the end date be defined for a project that creates a new product? Is it (1) on completion of product design,

(2) on completion of product manufacturing tests, (3) on product launch, (4) on quarterly or annual financial results, (5) or on product decommissioning?

The choice of which “end date” is used, influences the identification and evaluation of project impact, which further fundamentally impact the measurements during the project.

Turner demonstrated three ways in which the organisation is impacted if projects do not adhere to expected timescales. (1) When the output only has value at a specific time, e.g. Olympic Games opening event. If the project is late, all the benefit is lost. (2) When the output has value within a limited time window, e.g. product availability in the six weeks before Christmas. If the project is late, the benefit is not totally lost, but the benefit is lost in proportion to any time the project is delayed. (3) When a project is delayed, the additional time most often requires additional resources resulting in extra costs (Turner 2006).

Steyn highlighted the impact of the project and project success on the organisation, compared to previous authors who focused mainly on the project as an end in itself. According to Steyn, projects often only exist to create another system or product in the value chain of achieving the organisational strategy. Three specific impacts of project delays are mentioned. (1) When projects result in revenue to the organisation, early completion can contribute significant value in the form of early positive cash flow, e.g. when an industrial processing plant is completed early, the revenue generated could far exceed the marginal cost of construction for early completion. (2) The opportunity cost of delays, which could include losing first-mover advantage or market share when launching a new product late, e.g. an insurance product taking advantage of specific tax allowances. (3) Time delays could create an additional incentive for changing user requirements, especially when requirements are not unambiguously defined (or definable) at project start.



### ***In summary, project success as defined by this study***

This research acknowledges the multi-variate nature of a 21<sup>st</sup>-century critical success factor framework of project success, specifically as it relates to supporting the strategy of the organisation. This research focuses specifically on time-critical projects, where the strategy of the organisation is at stake if projects are not completed in time. This could take the format of either catastrophic failure of the organisation or significant financial loss due to late completion of a project.

For the purposes of this research, project success is therefore specifically defined as “achieving the strategic intent of the organisation through completion of the project as early as possible within the expected timeframe, while complying with requirements of the key stakeholders with respect to safety, budget, quality, environment and legislation”.

Delivering project success as defined above requires a review of management and project management thinking.

#### **2.1.4 Management-as-planning**

The PMBOK Guide describes core project management processes, of which ten are planning processes, one addresses project execution and two deal with project control (Project Management Institute 2013). Planning is fundamentally important to the success of any project – but so is execution. The over-emphasis on planning in the PMBOK, based on an underlying paradigm of viewing “management-as-planning”, contributes limited value during execution to achieve project success and organisational benefits. Additional theory and methodology are required to support project execution and project control, specifically project time management.

Koskela stated that “*the future of project management is in crisis and that a paradigm change is overdue*”. Project management in its current state is based on three theories of management (1) management-as-planning, (2) dispatch model as the theory of execution, and (3) cybernetic model, as the theory of control (Koskela & Howell 2002). Both management-as-planning and the dispatch model as a theory of execution have limitations and do not adequately describe organisational reality.

The prevailing theory of management is dominated by the concept of “management-as-planning”, where the organisation is assumed to comprise a management part and an effector part. Plans are compiled, and plans are implemented by two relevant parts of the organisation. Execution management reduces to some degree to communicating the plan. This operational management view assumes a strong cause-effect relationship between plans and results, and “*takes plan production to be essentially synonymous with action*” (Koskela & Howell 2002).

Drucker reported in 2001 that the command model, with a very few at the top giving orders and a great many at the bottom obeying them, remained the norm for nearly one hundred years (Drucker 2001). (To which we add that it is based on the assumption that “those few at the top know best”.)

Koskela further contributed that the underlying theory of execution relates to dispatching jobs. This originates from manufacturing where job dispatch provides the interface between plan and work, as documented by Emerson in 1917. Tasks are allocated to machines or work teams according to a central management plan. Dispatch comprises two components, (1) developing the central plan and (2) issuing orders. In project management, the project plan is a substitute for the central management plan that is developed a priori. Execution in project management, according to the dispatch theory, therefore, reduces to communicating the work. To some degree, this can be compared with a “fire-and-forget” guidance control systems, as the cause-effect relationship between plan and results is assumed clear and robust.

The assumption is that improved planning a priori improves results. Disproportionate value is then attached to the contribution of planning to project results vs. execution control. In many instances, project control is further reduced to re-planning during the project and communicating the revised plans, contributing to a further negative feedback loop and increased instability. Belassi reports that, since the 1950s, most of the work in project management focused on project scheduling, based on the conviction that planning and scheduling are the primary contributors to better project management and successful completion of projects (Belassi & Tukel 1996).

In dynamic and complex environments, this clear and robust cause-effect relationship between the plan and the result is not available, which in turn demands a balance between planning and execution. One example of complex and dynamic execution environments are the military milieu. Military leaders are clear that striving too long for a perfect plan can result in the situation being overtaken by circumstances before anything useful is produced, i.e. *“a good plan executed in time is better than a perfect plan hatched in a prison camp”* (Patton 1983).

Dynamic and complex project environments, therefore, contribute significant additional demands on project management theory and the management-as-planning model potentially leads research attention astray when it does not address the execution phase of projects. A more dynamic execution process is required, addressing the correct project variables and improving the project measurement and control cycle.

#### **2.1.5 Dynamic project environments**

The environment in which projects are executed is often characterised by changes during the lifecycle of a project that affect project objectives, resources, tasks, timelines and risks. These environments are defined as dynamic environments by this study. This definition is similar to the definitions of dynamic project environments by (Collyer & Warren 2009) and (Petit & Hobbs 2010).

In dynamic environments, external forces often require significant changes to project methods and goals. Collyer and Warren stated that *“materials, methods and goals are always moving, making projects (in dynamic environments) more akin to stacking worms than stacking bricks”* (Collyer & Warren 2009). The concept of a dynamic project is compared to operational and classic projects in Table 2-3 adapted from Collyer and Warren.

Project Type	Description of the environment
Operational project	Established controls, more standardised or operational processes and lower levels of unknowns
Classical project	A classical project requires the creation of new controls, usually in the format of a project plan, for a significant new body of work usually only executed once. The project may have high levels of unknowns at the start, but they are mostly resolved early in the project lifecycle, and few emerge during execution.
Dynamic project	A dynamic project requires the creation of new controls and which requires regular changes during execution. The project has high levels of unknowns at the start and a high rate of adding new unknowns throughout. The unknowns must be resolved at a faster rate than they appear, and in time for completion

Table 2-3: Project types (Collyer & Warren 2009)

Kapsali noted that the failure of conventional project management is due to its inability to capture the *serendipitous, evolutionary and experimental nature of complex* projects in dynamic environments (Kapsali 2013).

Dynamic projects further challenge the management of people with specialised skills. Frequent change imposed by the external environment leads to a perpetually inadequate level of knowledge about the project details and methods. It can be regarded as almost impossible to stay fully technically qualified as well as to perform effectively as a manager at the same time. Staff promoted to management has to decide between maintaining their specialised technical expertise (and qualifications) and giving up good management. If they choose to be effective managers, they have to do so without completely understanding the work their staff performs. This makes it harder to manage, understand issues, and gauge performance (Collyer & Warren 2009) and (this study adds) measure or estimate task time performance in unfamiliar environments.

Projects in dynamic environments which are tightly integrated with the customer industry, also often require advanced insight into the client business and therefore related significant specialisation and customisation

of methods and processes, in comparison with organisations which can execute relatively vanilla projects for a range of customers (Collyer & Warren 2009). Due to customers also operating in dynamic environments of uncertainty and change, their requirements, goals and integration points with the project also have a tendency to change.

In dynamic environments, new events that compromise project plans surface often, and frequently throughout project delivery. The quantity and frequency of change make detailed plans difficult to maintain due to the time it requires to adjust the plan, during which the rate of change is maintained unabated. Plans with excessive detail are often found to be misleading and abandoned in favour of a higher level plans or a rolling wave approach. (Collyer & Warren 2009).

In a typical portfolio environment, projects are integrated, and a change in one project can have significant impacts on other projects. This high level of integration, combined with high rates of change, make planning (and execution) very challenging. The requirement for integration can be extended to external business units (with might operate at much lower standards of dynamism), who may not respond as quickly or even understand the challenges being faced.

Shenhar argues that the classical drivers of project management are no longer sufficient in the current business environment. The traditional model fits only a small group off today's projects. Most modern projects are uncertain, complex and changing, and they are strongly affected by the dynamics of the environment, technology or markets (Shenhar & Dvir 2007).

In summary, many projects executed in the early 21<sup>st</sup> century, are dynamic and requires significant new research to support and improve success probability.

### **2.1.6 Systems engineering and project management**

Systems engineering and project management evolved about the same time around the 1950s to address the problems of both highly complex and novel technology and products. Johnson stated: "*Project management is a specific institutional and organisational response to the technical and organisational*

*problems of novel, complex “high technology” developed in specific projects”*. Project management is the method dedicated to the “*management of knowledge creation and primarily addresses the organisational issues while systems engineering addresses the technical coordination and operations*” (Johnson 2013).

The most commonly accepted definition of systems engineering was published by INCOSE states: Systems engineering is an interdisciplinary approach to enable the realisation of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs (INCOSE 2010).

It is evident that there is significant overlap between the fields of project management and systems engineering. Examples include:

- Systems engineering is the discipline developed to deliver successful projects (and systems) in complex environments (INCOSE 2010).
- Systems engineering is a multidisciplinary approach and means to enable the realisation of successful systems in complex environments (INCOSE 2010).
- Systems engineering provides the competencies required for successful project management i.e. shared leadership; social competence and emotional intelligence; communication; skills in organisational politics; and the importance of visions, values, and beliefs have emerged as competencies that are required from project managers in complex environments (Thomas & Mengel 2008).
- There is an overlap between systems engineering governance and project management governance in requirements

management, specifically the management of the project business, budget and technical baselines. (Forsberg *et al.* 2005).

- Systems engineering improves the governance and therefore also the performance of projects by transforming the governance from pure “project management” to a more holistic system view of “system management” (Locatelli *et al.* 2014).

Sharon confirms that most systems engineering applications use some subset of traditional project management methods and tools, and specifically that systems engineering management involves “*continuous cognitive zigzagging between systems engineering—the product domain—and project management—the project domain*” (Sharon *et al.* 2011).

The most frequent conflicts between the functions of programme management and systems engineering were summarised as (a) insufficient systems engineering in the product development process, (b) insufficient budget and tight schedule, and (c) inadequate risk management. These three problems eventually led to the mishaps and failure of the Hubble telescope, the Mars Polar Lander, the Demonstration of Autonomous Rendezvous Technology programme, and the Constellation programme. (Santiago 2013).

Perhaps the most eloquent attempt at separation is described as: *Project management focuses on the tasks required to support the development of the product with emphasis on schedule, budget and performance. Systems engineering focuses on the technical aspects related to meeting the customer’s needs through the design and development of a solution or product. Project management is concerned with managing budgets and schedules while systems engineering is concerned with developing products and systems.*

### ***In summary***

For the purposes of this research, it is safe to state that both project management and systems engineering suffer the same fate: Projects are still

completed late, and both contribute, or rather both fail to contribute sufficiently to delivering the project on time.

### **2.1.7 Critical chain project management**

Both critical chain project management and lean project management developed from their beginnings in the manufacturing industry into applications in the project management world (Steyn & Stoker 2014).

Critical chain project management (CCPM) contributed towards improved project planning and execution (Goldratt 1997). In essence, the critical chain is the longest chain of dependent activities, including resource constraints. Without resource constraints, the critical chain and the critical path are similar. A primary contribution of CCPM is the introduction of the project buffer which protects the due date. Goldratt stated that a typical project schedule is developed from “worst-case” estimates, or at least estimates that are in the 80%+ confidence interval. A significant contingency margin is therefore included in each duration estimate (compared to a 50% confidence estimate). This contingency margin is required because the proverbial “Murphy’s law” will contribute to unforeseen delays in some tasks. Experience has nonetheless demonstrated that although there will inevitably be the unforeseen impact on some tasks, most tasks will **not** be affected. However, the contingency allocation embedded in each task does not contribute to improve on-time completion of projects (due to student syndrome and Parkinson’s law) (Goldratt 1997). CCPM creates the project buffer by removing some contingencies from task duration estimates and accumulating contingencies into one project buffer. The buffer is established by requesting estimates without contingency margins, which in practice is found to be very difficult. An alternative is to reduce all task durations by 50%, utilising 25% for the project buffer and allocating 25% to the client as an early completion benefit. It is accepted that most of the 25% project buffer will be consumed during the project by unforeseen events.

However, the concept of introducing a project buffer is not new. Most project managers, having been “bitten” by late completion, developed a mechanism to add contingency time (project buffer) to protect his reputation and project completion.



However, unless a fundamentally new “way of managing progress” is utilised during the execution phase, there is only a minimal difference from traditional attempts to reduce project duration or improve the reliability of the completion date.

A key towards this new “way of managing” progress, as introduced by Goldratt, is the realisation that it is not important to complete each task on time; however, it is imperative to complete the entire project on time. This, however, is not trivial, and experience has shown that CCPM is often difficult to implement as it requires decisions that are counter-intuitive. The change from local optimisation to global optimisation and alignment of all efforts towards the global goal underlies Goldratt’s theory of constraints.

Steyn reports, as does McKay and Morton, that there is insufficient academic literature on practical results of the implementation of CCPM (Steyn 2002; McKay & Morton 1998). Lechler evaluated CCPM and defined several questions requiring further research, including the sustainability of requesting estimates without contingency margins (Lechler *et al.* 2005). Academic research on the implementation of CCPM is growing, but as both these references indicate, there is a requirement for additional empirical research results to provide insight into the value and challenges of CCPM.

Steyn further states that “one intuitively feels that compressing project duration could increase project risk and... certain methods of expediting projects do, in fact, increase risks. The benefits of doing projects faster should, therefore, outweigh any risk caused by the acceleration. Approaches that would enable duration compression without increasing business risk would provide several benefits” (Steyn 2001).

The primary mechanism available to conventional project management to ensure projects are completed on time is to ensure that each task is completed on time. Owing to the change in focus towards completing the project on time, and the realisation that completing individual tasks on time is “less” important, new measurements are required. Improved project measurement theory can contribute to both the conventional project management and the CCPM bodies of knowledge.

### **2.1.8 Lean project management**

Lean project management evolved from the development and application of lean in manufacturing. Lean methodology relies on reducing the “seven wastes” of (1) defects, (2) over-production, (3) transportation, (4) waiting, (5) inventory, (6) motion and (7) processing.

Goldratt’s theory of constraints provides a focusing mechanism to identify the specific “waste” which provides the best benefit. In the translation of the principles of lean from manufacturing to project management, particular attention is paid to reducing time waste.

In a somewhat similar context, Han used the concept of “non-value added time” (NVAT) which refers to wasted time on projects, and specifically on the critical path (Han *et al.* 2012).

NVAT is defined as “any time on the critical path that does not contribute to customer value”, a definition that requires supporting measurement methodologies to identify, measure and focus attention on reducing non-value adding time.

### **2.1.9 Project measurement and control**

The project measurement and control cycle is the primary mechanism used by the project manager to “manage” the project towards successful completion.

The PMBOK describes control in two sub-processes (1) performance reporting and (2) change control. Based on the former, corrections are prescribed for the executing processes, and based on the latter; changes are prescribed for the planning processes. Performance reporting in this context includes performance monitoring, measurement and reporting. This process of control is based on the cybernetic model of management control. Hofstede describes the cybernetic model of control as the process using the “*negative feedback loop represented by setting goals, measuring achievement, comparing achievement to goals*” and using variances to correct the process (Hofstede 1978). This cybernetic model of control is widely used in systems theory and management sciences. More than 100 books and articles on

management control theory, based on the cybernetic model, were published between 1900 and 1972 (Bedeian & Giglioni 1974).

The cybernetic model of control is presented in Figure 2-4. The model comprises (1) a standard of performance, (2) a performance measurement at the output and (3) identifying the variance between the reference and the measured value. The variance is used as input to correct the process to reach the defined performance standard (Hofstede 1978). The model is summarised as measure – compare – compute – correct.

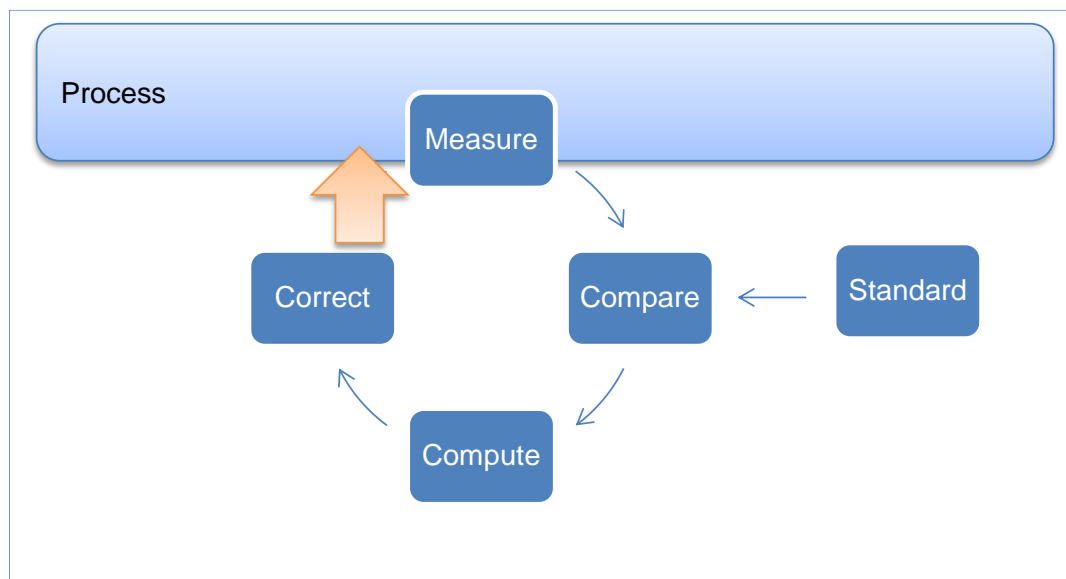


Figure 2-4: The cybernetic model of management control

This cybernetic model of control has limited application in uncertain environments. Either (1) the standard for performance is not clearly defined or not available or (2) the output is not readily measurable in unambiguous quantitative format or (3) the variance cannot be identified or the feedback data cannot be used for control purposes. The latter specifically applies in the project environment, as projects are unique events (by definition).

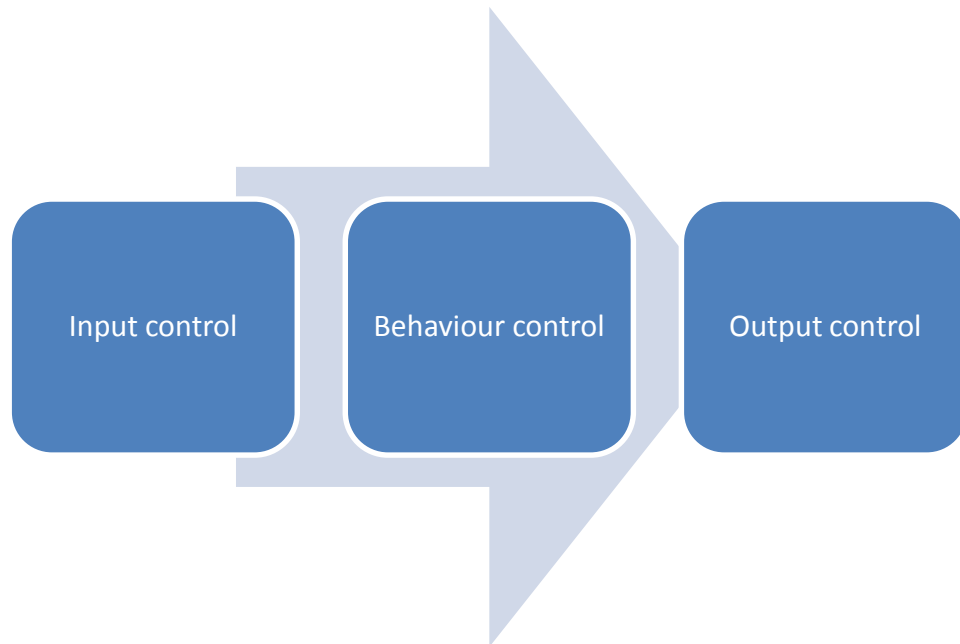
### ***Defining project control in the project management context***

Project control is defined by the PMI PMBOK as the process of comparing actual performance with planned performance, analysing variances, evaluating possible alternatives, and taking appropriate corrective action as needed (Duncan 1996). In contrast, Collyer states that control is the mechanism through which resources are managed to achieve objectives

(Collyer & Warren 2009). The significant difference relates to the control reference. The first refers to the plan, whereas the latter refers to objectives.

### ***Control cycle***

Snell described management control in terms of input control, behaviour control or output control, which can be depicted in Figure 2-5.



**Figure 2-5: Control options adapted from Snell**

According to Snell, (1) extensive cause-effect knowledge and crystallized standards of desirable performance are required for behaviour control; (2) output control is used when cause-effect knowledge is limited whilst standards of desirable performance are crystallized and (3) input control is utilised when cause-effect knowledge is limited and standards of desirable performance are ambiguous (Snell 1992).

Project management, as defined by the various bodies of knowledge, is mostly focused on behaviour control as a way of directing and regulating actions (Williams 2005). A project plan is developed and a baseline is created. Adherence to the process is monitored and deviations corrected (as per the PMBOK definition). This mechanism of control requires a thorough understanding of the project scope, task programmability and the

development of a reasonably stable project plan (Collyer & Warren 2009). Therefore, control is dependent on a clear understanding of the cause-effect relationship between the plan and the results.

The project control cycle from PMBOK, as depicted in Figure 2-6, is the accepted primary mechanism through which project management achieves project objectives.

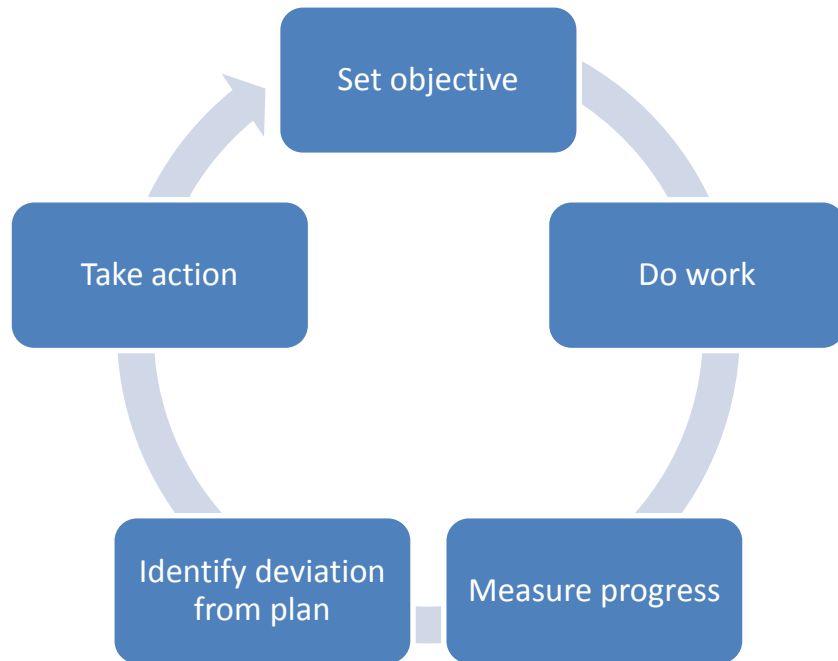


Figure 2-6: The project control cycle

This control cycle can be depicted in a different way to clarify the interaction and information flow between the measurement and control process and the work activities (refer Figure 2-7). This version is generalised to utilise a reference standard, which could be the project plan or the project objectives.

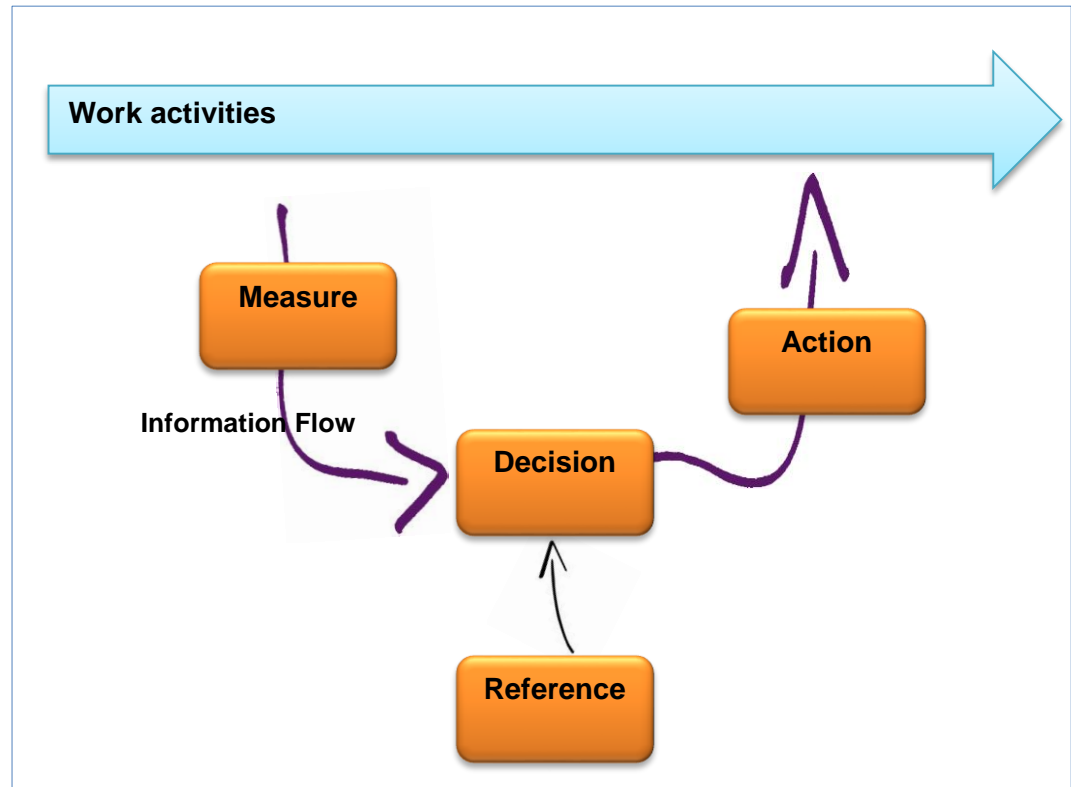


Figure 2-7: Measurement and control cycle with information flows

This research supports the view that by focusing on the quality of the inputs to the decision process (both the measurement information as well as the reference information), significant improvements can be achieved in the quality of the decision and therefore also the impact on the project's work activities.

### ***Project measurement and control cycle frequency***

The frequency of control, i.e. the rate at which this control cycle is executed, is a function of the rate at which the project experiences internal and external change influences. Collyer and Warren specifically describe the rate of resolving unknowns. The rate at which unknowns are resolved must not only be sufficient to deal with those unknowns that existed at the start, but also those that appear during execution. Therefore, assuming linear appearance

and resolution of unknowns, the resolution rate must at least be equal to the appearance rate, plus enough to resolve unknowns that existed at the start without delaying critical tasks (Collyer & Warren 2009).

The appearance rate will be relatively high in dynamic project environments where unknowns may appear in inconvenient bursts and certainly after planning is “complete”. Therefore, the rate of resolving unknowns is a particular hazard for projects conducted in dynamic environments. This also introduces the concept of resolution lag, which appears when the rate of resolving unknowns is limited. Resolution lag is due to a large number of initial unknowns, large numbers of changes due to the dynamic project environment or a slow resolution process by the project management team.

Large numbers of unknowns and the challenge of dynamic environments contribute to significant data integrity challenges. Lingle reports that “*close to 50 percent of executive managers place no confidence in the numbers presented to them*” (Lingle & Schiemann 1996). Frolick expands by stating that vague objectives lead organisations to measure the wrong activities. Organisations measure what is “*easily accessible and simple*”, and these measures over time become standards, “*providing a false sense of security and of progress made*” (Frolick & Ariyachandra 2006).

Determining what to measure and how to measure it lie at the core of this discussion, leading to the discussion of measurement theory.

## **2.2 Measurement theory**

The importance of measurement, as the basis of knowledge, is well accepted, but research in measurement, specifically applicable to project management, is limited (Steyn & Stoker 2014).

### **2.2.1 Measurement is older than two centuries**

Measurement is a fundamental tool to acquire knowledge and Mari summarised the historical context in two sentences: In the first instance, “*the epistemology of measurement theory is based on the fundamental assumption that each thing that can be accessed through our knowledge, possesses a number, since without numbers we can neither understand nor*

*know*" (translated from an excerpt of Pythagorean school, around 5th century BC). In the same sense, "*the elements of numbers were supposed to be the elements of all things, and the whole heaven a musical scale and a number*" (translated from Aristotle, *Metaphysics*, about 350 BC) (Mari 1998).

The word "measure" originates from "mensura" (Latin), derived from the ancient "mitis", which exists with minimal variations in Latin, Greek, German and Indian languages. "*This term plausibly meant wisdom, measure in psychological sense, thus measurement is essentially a wise subjective evaluation*" (Mari 2003).

Galileo Galilei (1564–1642) is recognised as the founder of modern physics based on measurement. His scientific programme for modern science was based on his motto of: "*Count what is countable, measure what is measurable, and what is not measurable make measurable*", based on the premise that the "*great book of nature cannot be understood, but by learning its language and knowing the characters in which it is written: it is written in mathematical terms*" (translated from G. Galilei, *Il Saggiatore*, 1632) as reported by Aumala (Aumala 1999). Lord Kelvin already verbalised in 1883, "*when you can measure what you are speaking about and express it in numbers, you know something about it*", as reported by (Aumala 1999).

However, significant challenges emerge when "human perception" is utilised in the measurement process and the concept of "measurability" is introduced. In the first half of the 20<sup>th</sup> century "measurability" was considered of such importance that the British Association for the Advancement of Science appointed a committee (composed of physicists and psychologists) to report on the possibility of providing quantitative estimates of human perceptions. The committee reported that the views of the physicists and psychologists, towards a shared understanding of measurement, were impossible to reconcile (Ferguson *et al.* 1940). The physicists took a strong stance against "making measurements" in the behavioural sciences. This led to parallel but separate developments of measurement science in the physical sciences vs. the behavioural sciences, with consequences that exist to the present (Rossi 2007). Mari stated the two categories of definitions for measurement as:



- Measurement is the set of operations to **determine** the value of an attribute.
- Measurement is the process of **assigning** a number to an attribute (Mari 1998). (in essence the definition formulated by Stevens in 1946 (Stevens 1946).

Measurement can be defined as the practice of attempting to identify the magnitude of a quantitative attribute by estimating the ratio between that magnitude and an appropriate unit, and the associated margin of uncertainty. Where attribute refers to the property to be measured, for example time, cost, quality, etc. and where magnitude refers to a specific level of a quantitative attribute, for instance, the length of this page or the duration of a particular task (Michell 2005).

Michell further argues that measuring involves both the task of demonstrating that the attribute is quantitative (specifically additive) and constructing procedures for numerically estimating magnitudes (Michell 1997) while seemingly rejecting ordinal scales of measurement.

Measuring non-physical attributes, as in the case of many project progress measurement, leads to analogies with further forms of evaluation, such as estimation and judgement. This requires the acknowledgement of a subjective component of measurement, at least as it relates to the unavoidable presence of the measurer's judgement (Mari 1998), leading to measurement becoming an activity of decision-making (West Churchman 1959). This has far-reaching implications for project management, yet the impact of human dynamics is not widely included in project management measurement methodologies.

## **2.2.2 Measurement theory in the project management context**

Measurement theory, in general, is motivated and shaped by intertwined philosophical assumptions about (a) the world investigated by science (ontology), (b) the ways and means by which science conducts its investigations of the world (methodology), and (c) the scope and limits of what can be known about the world as a result of scientific investigations (epistemology)(Domotor & Batitsky 2010).

The representational theory of measurement (Scott & Suppes 1958) is the current dominant theory (Narens 2002) as comprehensively described in Foundations of Measurement (Krantz *et al.* 1989). In essence the representational theory of measurement **assigns** numbers to an attribute by (1) specifying the basic procedures for assigning numbers to objects on the basis of qualitative observations of attributes, and (2) using the procedures to justify “*passage from simple qualitative observations to quantitative ones*” (Krantz *et al.* 1989) (Domotor & Batitsky 2010).

Mari confronts the dominant theory and contributes extensively regarding the difference between **assigning** numbers to an attribute vs. **determining** the value of an attribute (Mari 1996; Mari 1998; Mari 2003; Mari 2005). He distinguishes between “*measurement as the set of operations having the objective of **determining** the value of a quantity*” and on the other hand measurement as the process of “*empirical, objective **assignment** of numbers to the attributes of objects and events of the real world, in such a way as to describe them*”.

Mari and Finkelstein agree that for a measurement to be “objective” and “empirical”, it requires (a) the standard adopted in the measurement operation must be well-defined and external to any specific measurer, and (b) the operation of comparing the thing under measurement to the standard must be well-defined and carried out independently of any specific measurer (Finkelstein 1994). It will be difficult to justify in any way that project time measurements comply with either of the above requirements. Therefore, project time measurements are not fully “objective” and “empirical”, which leads Mari to refer to other forms of evaluation, such as estimation and judgement. The unavoidable presence of a measurer's judgement in reaching a measurement result, emphasises the subjective component of measurement (Mari 1998).

Furthermore, the ISO Guide to the expression of uncertainty in measurement (ISO 1995) recommends that any measurement result must be “*an estimation of both the measurand value and its uncertainty. The evaluation of the latter being a task that must keep into account personal experience,*

*beliefs, and sometimes even ethics. All these components that can hardly be formalized in terms of morphic mappings” (ISO 1995).*

In the views of the author and project managers interviewed, project time measurements (or estimates) are significantly influenced by the personal experience of project and task managers as well as their beliefs, and sometimes even ethics. Beliefs include the often optimistic bias of project and task managers in order to present positive progress reports.

These challenges to the usability of project time measurements, as well as the inherent uncertainty of projects, which inter alia cause changing values based on changing perceptions of future difficulties, result in a conundrum for project managers in practice. How does one utilise measurement values of which the consistency and integrity are so variable?

In summary, notwithstanding much research on project success, there is limited research on the underlying theory to support project time measurement. On-time completion of projects is still not consistently achieved and (too) many projects are late or subjected to significant risks of late completion. **The requirement for additional knowledge, specifically relating to time management, presents the background to the research problem for this study.**

### **2.2.3 The purpose of project measurements**

For the purposes of this research, the purpose of measurement with its operative requirements demands more exact expansion than its terminological and definitional needs. Mari reports three distinct areas of the application of measurement (Mari 2003):

- Ontological reasons (in which case measurement is an evaluation able to determine those numbers that are essential properties of things).
- Formal reasons (in which case measurement is an evaluation producing symbols that can be formally dealt with in a well-defined way).

- Informational reasons (in which case measurement is an evaluation whose results are informationally adequate to given goals).

Project management, however, does not exist purely in the physical world, and progress measurements are not only for ontological reasons. Many, perhaps most, project progress measurements are for informational reasons and more related to psychophysics or psychology as project progress measurements are often subjective evaluations of progress (akin to decision-making, as previously mentioned), whose primary purpose is to guide future actions. Project management measurement information is required to evaluate progress against the expectation (plan) and to make decisions regarding the future (refer to the discussion of the project management control loop in paragraph 2.1.9).

Neely and Bourne stress the importance of measurements as a strategic tool and specifically its importance as a means of communication and aligning and supporting implementation energy (Neely & Bourne 2000).

Task progress measurement information is one input into the decision-making process of the project control cycle (with the reference being the other) as discussed in paragraph 2.1.9. Without this information, the control cycle could not exist and project decisions would be difficult to make or to justify.

However, there is a variety of views on the purpose of project measurements. Atkinson states that the *“overarching purpose of a measurement system should be to help the team rather than top managers to gauge its progress”* (Atkinson 1999). Somewhat in contrast, Bassioni states that *“performance measurement systems have no use if not used as guidance for management decisions”*. The feedback loop and consequent decision-making are necessary to convert measurement information into management information. (Bassioni *et al.* 2004). Failure to take actions and manage based on measurement data has been considered an “ultimate management sin”, which Neely reports as a common and increasing issue in many organisations (Neely & Bourne 2000)

In the context of this research, the purpose of project measurements is defined in relation to the purpose of project management. In a broad sense, the purpose of **project management** is to complete the project successfully, specifically on time. The purpose of **project measurements** is subordinate and must support project management to achieve its purpose. Project measurements, therefore, exist to support on-time completion of projects, in part as component of the project control loop (paragraph 2.1.9) and in part dealing with organisational control and the dynamics of people in teams (paragraph 2.3).

#### **2.2.4 The challenges of measuring time in projects**

Although time is one of the seven fundamental SI units, and measurement technology exists to measure duration to accuracies of better than nanoseconds, time estimation and measurement are challenged in the project management context. The challenge relates to the vague consistency of defined start and finish points, as well as the “unavoidable presence of the measurer’s judgement” in the form of bias, subjectivity, perceptions and intentions.

Furthermore, the mere act of observation or the act of measurement influences the measurement and both the quantum and quality of the measurement. Therefore, the way we interact with the attribute to be measured could have a significant impact. In this respect, we can refer to Heisenberg’s comment: “*What we observe is not nature itself, but nature exposed to our method of questioning*” (Heisenberg 1958).

#### ***But***

Do we measure task progress - or do we measure the performance of the team executing the task?

If we measure the performance of the team, then task progress management is akin to measurement and control in the context of organisations and people.

## 2.3 Organisational control

Organisational control theory considers how an organisation exerts influence to achieve its objectives (Ouchi 1977; Ouchi 1979; Eisenhardt 1986; Liu *et al.* 2014). Performance management, which deals with the measurement and control of individuals and teams towards achieving desired outcomes, is rooted in organisational control theory. Influence, measurement and control of people are as applicable in the project management domain, though better developed in the organisational domain.

The definition by Bass clearly demonstrates how closely related organisational control theory is to the project management domain. He describes organisational control theory as “*the study of how men at work are affected by systems, money, and materials within which they work*”. He further considers how resources in turn, “*exert influence on the conversion of the inputs of human energy, money, and materials*”. Bass further specifically mentions that “*organisational psychology connects with other disciplines, including economics as well as the physical and behavioural sciences*” (Bass 1965). To this sentence, the author adds the ‘connection’ with the project management domain.

The application of organisational control concepts in project management is almost suggested by Anthony when he defined management control as the process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of the organisation’s objectives (Anthony 1965).

### ***Cross-discipline application***

Katz and Kahn supported this interdisciplinary approach by stating that “*social psychological principles can be applied to all forms of collective organized effort*” (Katz & Kahn 1978). In a similar vein, Anthony stressed that social psychology is the source discipline of “management control” (Anthony 1965).

Drucker stated that “*management is about human beings*” (Drucker 2001) and suggested that managers should “*draw on all the knowledge and insights of the humanities and social sciences - on psychology and philosophy, on*

*economics and history, on the physical sciences and ethics*" (Stein 2010; Witzel & Warner 2013).

The application of organisational control in the project management domain led to research calls "*to make social science matter in the context of project work*" (Cicmil & Hodgson 2006; Flyvbjerg 2001).

This section, therefore, presents an introduction to organisational control, its definitions and objectives, and further investigates how it relates to measurement and control in the project management domain. Challenges and key concepts for application in the project management domain are highlighted.

### **2.3.1 From management control to performance management**

Demartini observed that "management control" was replaced by "performance management" in the decades since Anthony's definition. Specifically that the "*negative meaning of 'control systems' has changed into a more constructive, steering meaning of 'performance management', which enables (instead of constrains) managerial activity to achieve organisational goals*" (Demartini 2014),

The frameworks for organisational performance management systems have shifted from a command-and-control approach towards a more psychological and cultural based approach (Demartini 2014). Fletcher reports the inclusion of social and motivational aspects (Fletcher 2001) while others research the role of the performance management systems as a learning tool (Canonica *et al.* 2015).

According to Baron and Armstrong performance management focuses more on the future by stating that it increases the effectiveness of organisations by improving the performance of the people who work in them and by developing the capabilities of teams and individual contributors (Armstrong & Baron 1998).

DeNisi defined performance management to comprise the range of activities engaged in by an organisation to enhance the performance of a target person or group, with the ultimate purpose of improving organisational effectiveness

(DeNisi 2000) Fletcher further notes the change of the performance management approach towards recognition of the importance of social and motivational aspects (Fletcher 2001).

All of these led to the more comprehensive definition, that performance management systems are the evolving formal and informal mechanisms, processes, systems, and networks used by organizations for conveying the key objectives and goals elicited by management, for assisting the strategic process and ongoing management through analysis, planning, measurement, control, rewarding, and broadly managing performance, and for supporting and facilitating organizational learning and change (Ferreira & Otley 2009). The definition provides several links to managing teams and performance in the project management domain.

However, the project management domain, having developed from an operational foundation, is driven by different views. The Soderlund study reports that the engineering tradition and the social science tradition are incompatible on important issues. One avoids uncertainty to achieve determinateness while the other assumes uncertainty and indeterminateness. His argument is that the major part of research on project success does not provide deeper knowledge about real life project management and does not acknowledge the dynamics and the social embeddedness of project management. Sunderland therefore highlighted the social and human aspects of project management and specifically relates it to the differing views on uncertainty and indeterminateness (Söderlund 2004).

In time-critical projects, the subject of this research, the success of the project is inherently intertwined with the social and strategic success of the organisation. Parsons even mentioned that the distinguishing characteristic of organisations (from other types of social systems) are its "*primacy of orientation to the attainment of a specific goal*" (Parsons 1951).

These definitions provide the background to the consideration of organisational control theory in the project management domain.



### 2.3.2 Organisational control theory

The work of Thompson (1967) and Ouchi (1979) provides the dominant framework for studies in organisational control (Thompson 1967; Ouchi 1979; Cardinal *et al.* 2004; Eisenhardt 1986; Rustagi 2008).

They propose a contingent framework for the choice of control strategy. The choice is modelled as a function of the task programmability and outcome measurability. Task programmability refers to the ability to specify the steps that need to be followed, and outcome measurability refers to the ability to measure outputs easily, uniquely and effectively.

On the one hand, in cases where tasks can be programmed in detail, control can be effected through the evaluation of **behaviour**. Conversely, if objectives can be clearly defined and outcomes can be measured, control is effected through evaluation of **outcomes**. However, if the task is neither programmable nor has an easily measurable outcome, then clan control becomes appropriate. Clan control refers to utilising the selection process for selecting team members to minimise divergences of preferences (Ouchi 1979; Eisenhardt 1986). The mapping of outcome measurability and task programmability to control strategy is depicted in Figure 2-8.

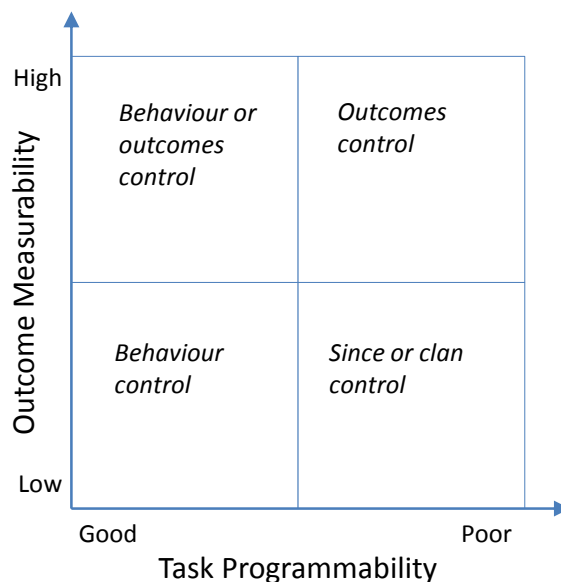


Figure 2-8: Control Strategy =  $f(\text{Task characteristics})$  adapted from Ouchi

### *Interpretation in the project management domain*

The measurement and control processes underlying project management are based on similar fundamental concepts to those underpinning scientific management: *“the fragmentation of work and the maximisation of visibility and accountability”* (Cicmil & Hodgson 2006).

The concepts of task programmability and outcome measurability are therefore clearly also applicable in the project management domain, and can be mapped at two levels. Either with the **project** as research entity or with the project **task** as research entity:

- **High outcome measurability** is translated to the project management domain as “SMART” outcomes for the project (or task) with project outcomes typically documented in the project charter.
- **Low outcome measurability** is translated to the project management domain as project (or task) outcomes which are not documented, agreed or “SMART”.
- **Perfect programmability** is translated to the project management domain as well-defined, documented and agreed project tasks, e.g. in the format of a comprehensive work breakdown structure, as well as detailed and complete project logic network. The project logical network includes all definitions of predecessor tasks and successor tasks.
- **Imperfect programmability** is translated to the project management domain as limited details in the documentation or agreement of project tasks and the logical relationships of project tasks.

The mappings defined above result in four options:

	<b>Perfect programmability</b>	<b>Limited programmability</b>
<b>Outcome measurability is high</b>	A	B
<b>Outcome measurability is low</b>	C	D

- **A:**  
Stable and well-known projects in a stable and well-known project environment. Basic construction projects or tasks on basic construction projects are examples.
- **B:**  
The project outcome is well-defined, but the detailed tasks (or project logic) to achieve the outcome are not well known or clearly documented. An example would be the project to lay the Seacom optic fibre cable along the east coast of Africa. The project outcome is well-defined but the many unknown project challenges required re-planning, rescheduling or even development of new project tasks. At task level an example could be the development of a specific functionality of a software systems project, where the expected outcome is well-defined and can be measured, while the development effort often contains significant trial and error iterations.
- **C:**  
Project tasks are well-defined but the project outcome is difficult to measure. The project to rebrand a global corporate comprises a well-defined set of tasks, though the outcome is difficult (or significantly subjective) to measure on initial completion of the project.

- D:  
Innovation, new product development and blue sky research projects are potential examples where the outcome neither clearly defined nor easily measurable. In addition, there is limited knowledge of the detailed tasks and detail project logical network to achieve the outcomes.

For the purposes of this research, the concepts of outcome measurability and task programmability are extended to implementation aspects. Though task programmability might be high, the level of actual task programmability is dependent on the quality of implementation. Task programmability translates to the project plan and the task details in the project management context. The “programmability” of the project tasks is dependent on the quality of project planning and how well “programmability” was implemented during planning. “Programmability” includes the identification and definition of tasks, the documentation of the logical relationships between tasks and extends to the “quality” of common understanding between the project manager and task resource.

In a similar vein outcome measurability is dependent on the quality of implementation. A task might have a very measurable outcome, but unless the specific outcome was agreed between the project manager and task resource, the value of outcome measurability of the specific task is lost.

Therefore, the concept that control strategy is a function of task programmability and outcome measurability is extended to include the quality of implementation.

### ***Application to the scope of this research***

The classical drivers of project management are no longer sufficient in the current business environment. The traditional model fits only a small group of today's projects. Most modern projects are uncertain, complex and changing, and they are strongly affected by the dynamics of the environment, technology, or markets. (Shenhar & Dvir 2007).

In time critical and dynamic projects, task programmability is often available to a very limited degree. Outcomes are often difficult to define or measure at the task level. Organisational control theory, therefore, guides towards the use of social or clan control, which is inherently difficult in temporary project organisations where resource availability often supercedes alternative selection mechanisms.

The alternative is to improve the task programmability, as well as the definition of task outcome and task completion measurability – which is what current attempts at more and more detail planning try to achieve. This alternative is challenged by uncertainties, complexity and dynamism of time critical projects, and as previously stated, uncertainty cannot be addressed by more detailed planning.

### **2.3.3 Agency theory**

Agency theory addresses the ubiquitous agency relationship, in which one party (the principal) delegates work to another (the agent). Two problems arise (1) the potential goal conflict between principal and agent, and (2) the cost of verifying agent behaviour (Eisenhardt 1989a).

In the simple case of complete information, both parties, principal and agent, know the behaviour and results of the agent's work. In the more usual application environment, the principal has incomplete information about the agent's behaviour.

The measurement and control of **behaviour** in complex and dynamic environments require significant sophistication in the measurement system. The alternative to behaviour control, i.e. outcomes control, does not distinguish between environmental effects and the performance of the agent. Both excellent results and poor results can be the result of either (and usually both) agent behaviour and external environmental effects. The result is that, to some degree, the risk is transferred to or shared with the agent (Eisenhardt 1986).

Agency models recognise two key features of organisations. (1) On the one hand the divergence of preferences among team members. Preferences of behaviour that might not necessarily align with those of the organisation. The

purpose of measurement and control is to provide the incentive structure for agents to pursue the organisation's interests. (Note: Where there is no divergence of preference, social or clan control is in effect) (Eisenhardt 1986).

(2) The second key feature is the outcome uncertainty of organisations. The risk of the uncertain future is of course primarily borne by the owners, but agents (employees) also share some risk for the outcome. (Note: Where there is no outcome uncertainty, the choice between behaviour and outcomes control reduces to a model of minimising cost) (Eisenhardt 1986).

### ***Interpretation in the project management domain***

Eisenhardt notes that "*agency theory reminds us that common problem structures do exist across the research domains*" (Eisenhardt 1989a). Though the purpose of this study is not to comprehensively research the application of agency theory in the project management domain, indications of its application were found at two levels in the project management domain.

The first application addresses the case of the project owner as principal and the project manager as agent.

The outcomes of projects are uncertain, and project owners, as well as project managers, share, to some degree, in the risk of success. For example, this shared risk is visible in the financial risk of project owners, and the risk in job security and potential future job opportunities for project managers.

The alignment and measurement of goal congruence between project owner and project manager require significant attention (and costs). Clan control is difficult in the project management domain due to the finite nature of projects.

An additional application of agency theory in the project management domain considers the project manager as principal and the task team member as agent.

Divergences of preferences are often very visible. One example, often witnessed, is when the project manager requires a task to be finished by a

certain date. In uncertain environments, resources are often contracted for effort (not outcome). In this case, the interests of the project manager (to finish early) are not aligned with the interests of the resource, which is to maximise income (and achieved through delayed completion). Measurement processes are challenged to address these misalignments, and the typical fast-paced and challenging project environment does not contribute when analysing the communication transactions between the project manager and the task resource.

#### **2.3.4 Transaction analysis**

Transaction analysis (TA) provides tools to analyse communication transactions and how we relate and communicate with others. Developed by Berne (Berne 1966) it is primarily utilised in the sociology and psychology domains. Improving communication has widespread applicability, and the utilisation of TA was found in supply chain (Dani *et al.* 2004), tourism (Wachtel 1980), organisational change (DeZanet *et al.* 2004) and pharmaceutical services (Lawrence 2007) (though no application in the project management domain could be found).

TA is based on three states in which one interacts with others, called Parent (P), Child (C) and Adult (A). These states are responsible for the way one thinks, feels and behaves.

The parent state operates with rules, norms and pre-judgements from an authoritative model. P is activated when one tries to control something. Two subsets were defined, the nurturing parent who is focused on caretaking, and the controlling (critical) parent, who focuses on transferring values and beliefs (ensuring compliance). The parent state often framed sentences around the words “You must...” and “You should...”.

The adult state enables one to process information and is invoked whenever decisions are involved. The adult state is emotionally mature and reasonably autonomous, talks level-headedly and does not try to control others.

The child state is associated with emotional and affective responses to communication transactions, depending on the perception of nurturing parent or critical parent. Doubts, fears and uncertainty, and rebel behaviour

is characteristic of the child state. Sentences are often framed around words of insecurity (“ I don’t know...”) or emotional responses (“ I won’t...”).

Berne defined complementary, angular and crossed communication transactions. Complementary or reciprocal transactions occurred when both parties address the other in their current state. Examples are PC-CP as depicted in Figure 2-9(i). A further example of AA-AA is depicted in Figure 2-9(ii). During complementary communication transactions, neither the message nor the communication process is jeopardised and the parties continue to exchange ideas.

Angular communication transactions occur when a change of state is triggered. An example is depicted in Figure 2-9(iii) where AA follows CA.

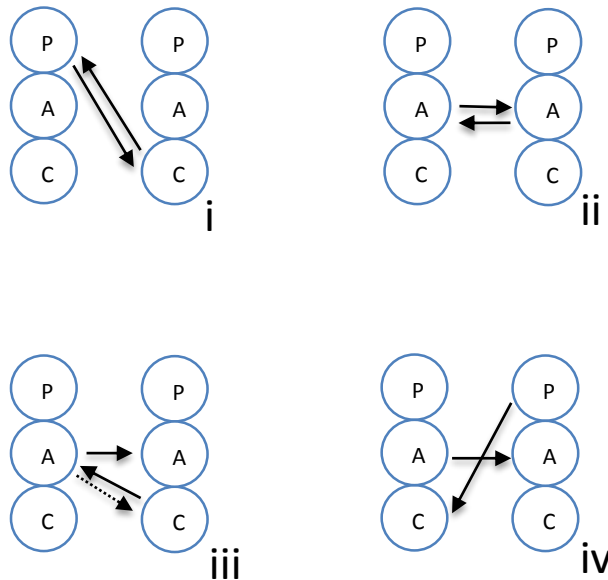


Figure 2-9: TA communication transaction examples

Crossed transactions occur when the response is from a different state than the one being addressed. An example is depicted in Figure 2-9(iv). If PC follows AA, the communication process downgrades and usually fail. As an alternative if AA follows PC, the communication process is upgraded and can potentially succeed.



When the verbal message is not congruent with the non-verbal message, it is referred to as duplex communication transactions.

Following the definition of the basic concepts, Berne stated three rules for the communication process:

- While transactions are complementary, people keep communicating.
- When crossed transactions occur, the communication stops. Either party should change state to resume the dialogue.
- Psychological maturity (and not social level) drives the outcome of a duplex communication transaction.

### ***Application to project management***

The communication transactions between the project manager and the task owner are often moulded on the inherent management communication model of the organisation. AA-AA reciprocal communication transactions are conceptually most appropriate, but PC-CP communication transactions, characterised by “You should...” and “I don’t know...” (or non-verbally “I won’t...”) are very often the standard of communication between the project manager and the task owner.

Considering these states and their application in project communication, specifically as it relates to communication on the subject of measurements, provides valuable insights into the development of measurements theory in the project management domain.

### **2.3.5 Summary**

In summary, organisational control is about influence. Organisational control theory provides a model for control strategies as a function of task programmability and outcome measurability, which this research expands with the inclusion of implementation quality. However, detailed task programmability and perfect outcome measurability are challenged by uncertain, dynamic and complex project environments.

Agency theory discussed the balance between behaviour control and outcomes control based on the level of information and the risk alignment. However projects and project measurement occurs in the human domain, and measurement responses are “considered”, contributing to the asymmetry of information available.

Communication transactions in the fast-moving, complex and dynamic project environment are further challenged by communication models among project role players. TA provides a structure to understand the challenges in project communication based on the parent, child and adult states.

The utilisation of organisational control theory, agency theory and transactional analysis to support measurement theory is new. Research is required to guide how this knowledge can be mobilised and leveraged in the project management domain.

## **2.4 Conclusion**

One wonders how much project management has evolved in the past 60 years, if we consider the words of Gaddis, probably the first formal writings on project management, who wrote in 1959 that “*the project manager often finds himself as a pilot flying blind, assisted by a relatively unproven set of instruments*” (Gaddis 1959). Much research is still required in the field of project management instruments.

The significant shortage of knowledge, specifically measurement knowledge to support on-time completion of time-critical projects, requires additional research. This research makes a contribution to the indicated knowledge gap.

### 3 Experimental design

*You can tell whether a man is clever by his answers. You can tell whether a man is wise by his questions.*  
(Naquib Mahfouz, 1988 Nobel Prize for Literature)

Chapter 3 provides an overview of the experimental design to address the research gaps identified in the literature review of Chapter 2. The high-level overview of the experimental design is presented in Figure 3-1. The scoping study was executed to evaluate research viability and was followed by theory development. The research was further supported by a validation study to evaluate the results from the application of TOM-P.

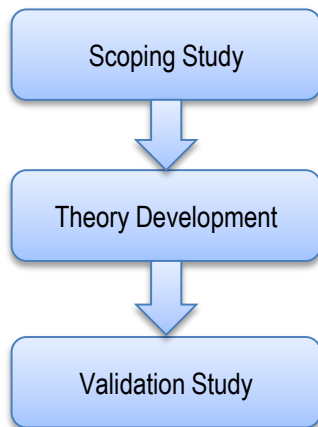


Figure 3-1: Overview of the experimental design

Chapter 3 is structured in the following sections:

- Development of hypotheses
- The scientific theory-building process
- Research step 1: Scoping study
- Research step 2: Theory development
- Research step 3: Validation
- Verification

### 3.1 Development of hypotheses

Two hypotheses with their corresponding null hypotheses were developed to evaluate the applicability and validity of the theory.

Project progress measurement methodology (MM) includes all the decisions of which parameters to measure during the project, when and how frequently, by whom, in which measurement unit and against which standard. For the purpose of this research, MM specifically refers to the measurement of project *time*.

#### 3.1.1 Hypothesis 1

In the first instance, a hypothesis was developed which evaluated the relationship between the MM utilised on a particular project and project duration.

The detailed descriptions of  $H_1$  and the corresponding null hypothesis  $H_{1,0}$  are:

- $H_1$  : There is an association between project task time measurement methodology and project duration
- $H_{1,0}$  There is no association between project task time measurement methodology and project duration.

Chapter 4 addresses the evaluation of  $H_1$  during the scoping study.

#### 3.1.2 Hypothesis 2

Hypothesis 2 evaluates the contribution of TOM-P and demonstrates how value is created through implementation of the TOM-P.

$H_2$  is stated as:

$H_2$  : Implementing a measurement methodology based on the TOM-P reduces project duration (compared to not implementing the measurement methodology based on the TOM-P).

$H_{2,0}$  : Implementing a measurement methodology based on the TOM-P *does not* reduce project duration.

Demonstrating that MM reduces project duration contributes new knowledge. It shows that the selection of MM to measure time is not a trivial decision. Accepting  $H_2$  indicates that the singular process of selecting the MM has a significant impact on the project duration and therefore project success.

It is also during the evaluation of  $H_2$  that the role of performance management on project performance is addressed. In fields as far apart as sales, medicine and general management, it has been demonstrated that the selection of the particular measurement parameter (KPIs) has a significant impact on the results. Through the selection of specific parameters and unit of measure, the measurement process in itself has a significant impact on the results.

What you measure has a direct effect on results or as more popularly stated “What you measure is what you get” (WYMIWYG).

The concept of WYMIWYG was first mentioned by Hummel and Huitt in the context of education (Hummel & Huitt 1994). A search in EBSCOHOST (on 1 October 2015) found that the related concept of “What gets measured, gets done” was reported in 21705 academic articles between 1994 and 2015. It is primarily reported in healthcare (Knopf *et al.* 2007; Thacker) and education (Wilson *et al.* 2006), while it is also mentioned in a variety of fields, including public sector (Berman 2002; Castrucci *et al.*) safety and occupational health (Bond 1991), customer relations (Buchanan & Gillies 1990), law (Chriqui *et al.* 2011), supply chain management (Fawcett & Magnan 2004), business process management (Lee & Dale 1998), strategic planning (Lefkowitz 2001) performance indicators (Likierman 1993), facilities management (Varcoe 1993) and agriculture (Woodard 2004).

Unexpectedly, there was only one mention in the project management domain – a project in the medical field.

$H_2$  demonstrates that WYMIWYG is also at play in project management and supports the importance of developing new measurement theory to improve project success (on-time completion).

The evaluation of  $H_2$  during the validation study is detailed in Chapter 6.

## 3.2 The scientific theory-building process

This research supports the concept of theory-driven empirical research, which is defined by Melnyk and Handfield as an approach to providing better insight and understanding into issues by using empirical data to build and develop better theories. Melnyk and Handfield describe the theory-driven empirical research approach as a methodology where the researcher starts with a theory and then uses data to build further, test and modify the theory. They quote Allison Barber from Michigan State University: “*Theory without data is a bother; data without theory is a nightmare*” and conclude with “*theory-driven empirical research is becoming increasingly important over time. It is no longer adequate to simply provide the answer. The demand is for understanding, for uncovering the ‘why’ of events*” (Melnyk & Handfield 1998).

Gibbert summarises that case studies, as tools for generating and testing theory, have provided the strategic management field with ground-breaking insights (Gibbert *et al.* 2008). Case studies are considered most appropriate as tools in the critical, early phases of a new management theory when key variables and their relationships are being explored (Eisenhardt 1989b).

The most common themes on which science is built are observation, induction, and deduction. Bergmann postulated these three themes in 1957 (Bergmann 1957), and it was reiterated over the years by several others (Popper 1961; Bohm 1957; Kaplan 1964; Stinchcombe 1968; Blalock 1969; Greer 1969). This school of thought was later summarised into a series of elements and first mapped by Wallace (Wallace 1971).

Handfield specifically noted that there is no distinct pattern in which the theory building process unfolds. The process is often iterative with various steps building on one another, not necessarily in a consistent sequence. The Wallace model provides a useful way of conceptualising the primary themes. (Handfield & Melnyk 1998).

The process to develop theory from case studies is therefore presented by summarising the contributions of Wallace and Eisenhardt. The summary

provides the foundation for the experimental design as described in sections 3.3 to 3.5.

### 3.2.1 The Wallace process map for theory building

During 1994 and 1995 workshops were conducted in Washington DC and Honolulu, Hawaii on theory-driven empirical research. This culminated in a series of articles in the *Journal of Operations Management* in 1998 edited by Melnyk and Handfield. These articles summarised the latest thinking in theory-driven empirical research and the article by Handfield and Melnyk on the scientific theory building process confirmed the Wallace-process for theory construction (Melnyk & Handfield 1998). The Wallace process was a summary of prior knowledge which he mapped into a series of elements. (Wallace 1971). The Wallace process, addressing the information components, methodological controls and information transformations of the scientific process is depicted in Figure 3-2.

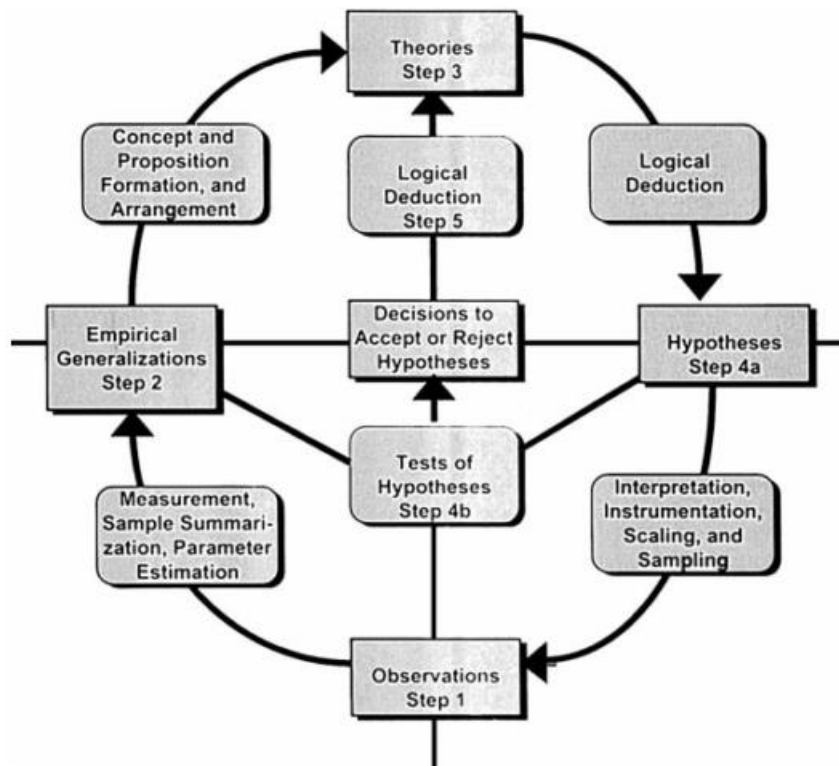


Figure 3-2: The Wallace process (Wallace 1971)

The left half of the model addresses the inductive construction of theory from observations. The right half represents the deductive application of theory to

observations. Similarly, the top half of the model represents theorising, via the use of inductive and deductive logic, while the bottom half represents empirical research.

The theory building process is initiated by observations, specifically observations which raise the attention of the researcher. Iterations of various measurements, sample investigations and order-of-magnitude parameter estimations are utilised by the researcher to identify potential theory development opportunities.

From the empirical data, generalisations are developed as step 2. Concepts and propositions are contemplated as building blocks towards initial theory development.

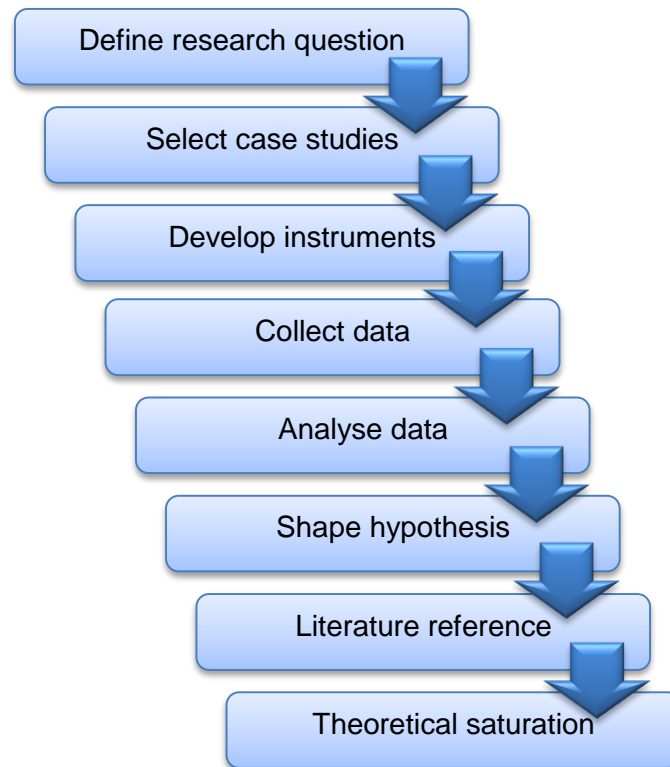
Step 3 comprises the development of theory, followed by logical deduction processes to guide hypothesis development (step 4) and empirical testing. From the empirical results, the hypothesis can either be accepted and further development of the theory can continue, or the hypothesis can be rejected and the data can be reviewed for alternative generalisations, concepts and propositions.

### **3.2.2 The Eisenhardt 8-step process for theory building**

Eisenhardt stated that “many pieces of the theory-building process are evident in the literature. Nevertheless, at the same time, there is substantial confusion about how to combine them when to conduct this type of study, and how to evaluate it”.

According to Eisenhardt, the theory-building process comprises the eight steps depicted in Figure 3-3 and described below (Eisenhardt 1989b)





**Figure 3-3:** Eight-step theory building process by Eisenhardt

Step 1 defines the research question to focus research efforts and identify possible a priori constructs to provide a better grounding of construct measures.

Step 2 selects case studies, which includes specifying the population to limit extraneous variation and to sharpen external validity. Step 2 further addresses theoretical (not random) sampling, in order to focus attention on useful cases, i.e., those that replicate or extend the theory by filling conceptual categories.

The third step is to develop instruments and protocols, including multiple data-collection methods to support theory building through triangulation of evidence. The instruments further integrate qualitative and quantitative data to develop a synergistic view of the evidence and utilises multiple observers to nurture divergent perspectives.

The fourth step is data collection and overlapping initial analysis. This step includes flexible and opportunistic data-collection methods to accelerate analyses and surface adjustments to data-collection processes, which

enables investigators to take advantage of emergent themes and unique case features.

Step 5 entails analysing the data, which includes within-case analysis to gain familiarity with data and support preliminary theory generation. Cross-case pattern searches using divergent techniques is completed to force investigators to look beyond initial impressions and see evidence through multiple lenses.

Step 6 is the shaping of the hypotheses, which includes an iterative tabulation of evidence for each construct, to sharpen construct definition, validity, and measurability. Replication across cases (not sampling) confirms, extends, and sharpens theory. Step six further searches for the "why" behind relationships to support internal validity.

The seventh and second last step is a literature reference. Comparison with conflicting literature supports internal validity, raises the level of theoretical contribution, and sharpens construct definitions. Comparison with similar literature sharpens generalisability, improves construct definition and also raises the theoretical level of contribution.

The eighth and last step in Eisenhardt's process is indicated by theoretical saturation when marginal improvements become small.

### **3.2.3 Summary of theory-building process as utilised by this research**

*Thus the discovery, invention and construction of scientific knowledge begins with a) a wild hypothesis that gets thought into (b) a reproducible idea, which becomes realized in (c) an observable instance, to be interpreted as (d) a concrete ordinal that is carefully built into (e) an abstract measurable suitable, finally, for analyses in relation to other measurables and so to the construction of (f) promising theories(Wright 1999).*

By integrating the core components of both the Wallace and Eisenhardt models, the model for theory building adopted for this research is summarised in the following research steps:

- Research step 1: Scoping study
- Research step 2: Theory development
- Research step 3: Validation
- Verification

### 3.3 Research step 1: Scoping study

Research step 1 is mapped to the Wallace model as depicted in Figure 3-4 and is addressed by the scoping study as described in Chapter 4.

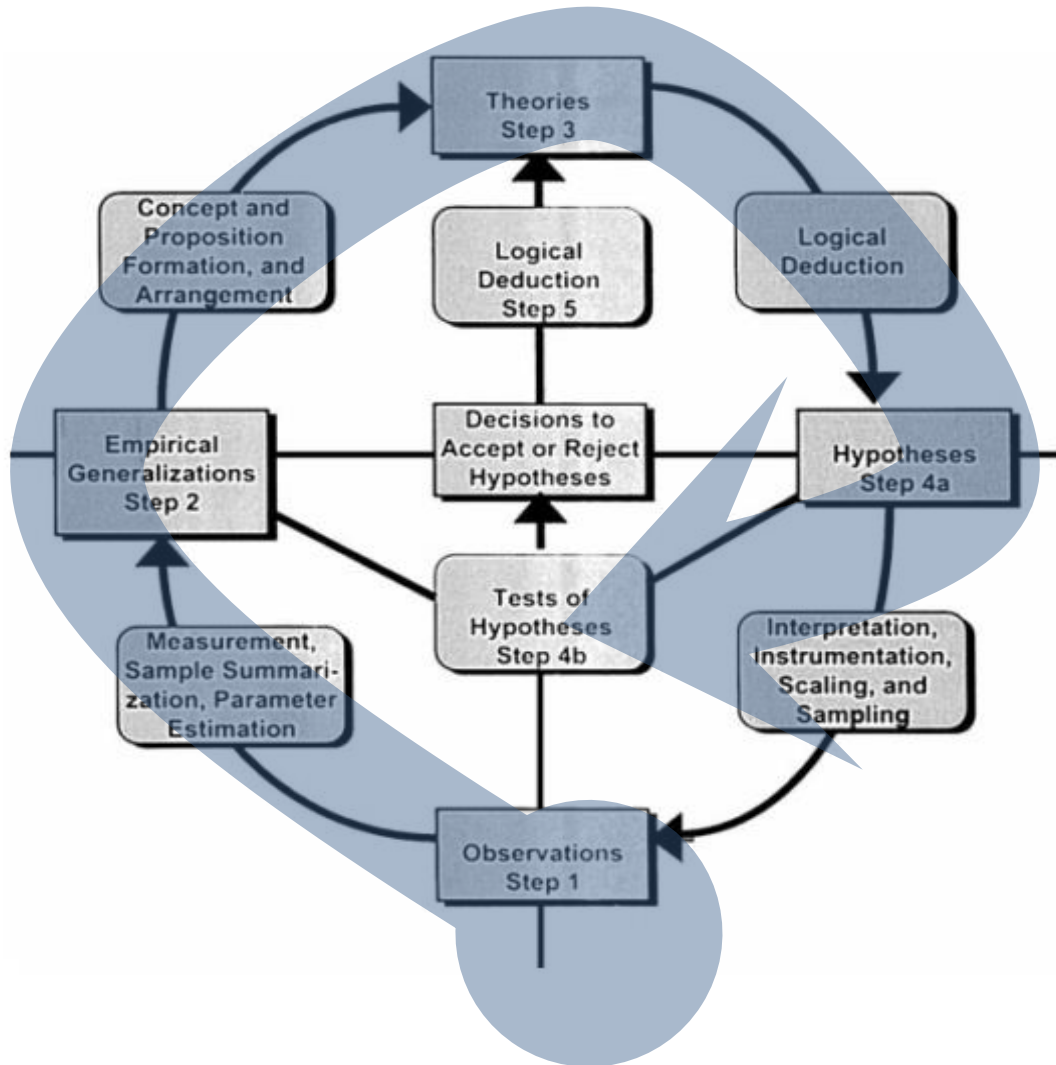


Figure 3-4: Research step 1 mapped to the Wallace model

#### 3.3.1 The application of the Wallace and Eisenhardt models in this research on TOM-P

It all starts with observation. Nagel points out that “*scientific thought takes its ultimate point of departure from problems suggested by observing things and events encountered in common experience*” (Nagel 1961). Combining the contributions from Wallace, Eisenhardt and Handfield, we note that observations are shaped by the observer’s experience, background, system

of beliefs and what “should” be. Unexpected observations led to questions, which were developed into research questions.

Research questions were evaluated in relation to existing scientific literature, which supported the questions while providing further context, details and background.

Once research questions had been clarified, case studies were selected, and instruments developed to collect data. The data were analysed in the light of the particular research questions and initial hypotheses.

### **3.3.2 Execution of scoping study**

Research step 1 was executed in the format the scoping study. The scoping study consolidated the observations and research questions into initial generalisations. An initial theoretical construct was developed and the initial hypotheses evaluated.

The purpose of the scoping study was to assess the association of MM and project duration ( $H_1$ ). In addition, macro environmental and organisational factors that impact implementation, were identified and evaluated, especially with regards to identifying potential internal and external validity concerns that will require addressing during further experiments.

A group of mid-sized engineering projects, where extensive reference data were available for control group evaluation, was selected. The scoping study is discussed in detail in Chapter 4.

### 3.4 Research step 2: Theory development

Research step 2 comprised the theory building process and is referenced to Wallace’s model as the top-left quadrant (refer Figure 3-5).

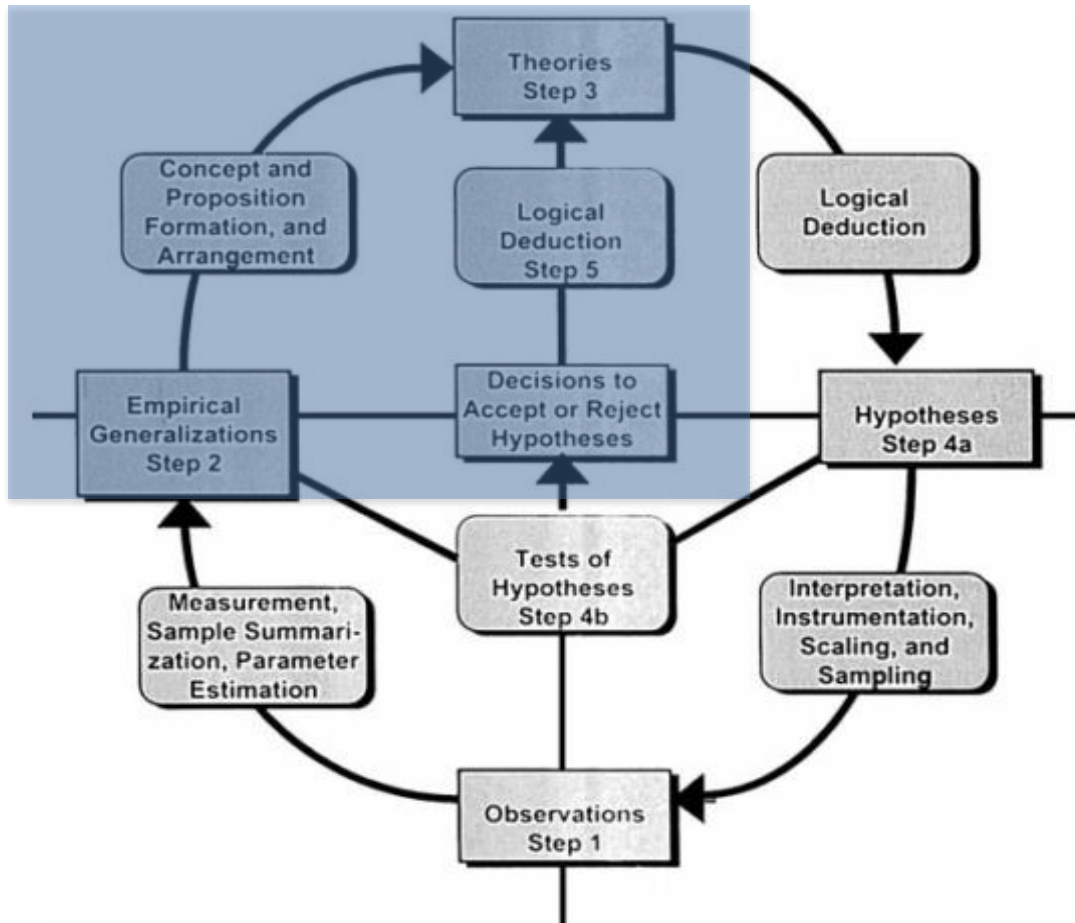


Figure 3-5: Research step 2 focuses on theory building and maps to the left-top quadrant of the Wallace model

Generalisation is developed through what Weick calls “disciplined imagination” (Weick 1989) Postulating a theory should comply with the basic requirements of good theory as discussed in Chapter 5.

The theory must further be evaluated by developing specific hypotheses and evaluating these with the assistance of data from case study research until theoretical saturation is achieved.

The first stage was to generalise the relationship between key variables MM and project duration addressing the “what” and “how” components of theory. The second stage of theory development must address the “why” of the



A series of 84 similar projects were identified, of which eighteen were executed as test cases and 66 were executed during the same period and utilised as a control group. The validation study is discussed in Chapter 6.

### **3.6 Verification**

*“Without rigor, research is worthless, becomes fiction and loses its utility”.* Verification, therefore, needs to confirm the rigour, providing assurance of data and process integrity. Verification was defined by Morse as the mechanisms used during research to *“incrementally contribute to ensuring reliability and validity and, thus, the rigour of a study”* (Morse *et al.* 2008).

Four criteria are commonly used to assess the validity and reliability of case study research (Campbell *et al.* 1963; Gibbert *et al.* 2008; Gibbert & Ruigrok 2010). They are

- Internal validity
- Construct validity
- External validity
- Reliability

The rigour underlying this research to support reliability and validity must be motivated based on these four criteria

Chapter 6 includes a summary of actions during the design and execution to address the reliability and validity of this research. These actions are discussed based on the four criteria prescribed above.



### **3.7 Conclusion of experimental design**

Chapter 3 describes the experimental design to support this research on time critical projects and the development of the theory of measurement for projects

The experimental design is modelled on the Wallace process, and structured into a scoping study followed by theory development and concludes with a validation study.

Significant attention was given to research rigour to support the reliability and validity of the research results.

The conclusion of the experimental design leads logically into the scoping study as research step 1.

## 4 Scoping study

### *Abstract*

This chapter on the scoping study presents the first round of observations, generalisations, theoretical concepts, hypothesis and empirical test results based on the Wallace model of theory building (as previously pictured in Figure 3-4).

The pilot study was used to evaluate hypothesis 1. The test projects comprised five industrial projects, compared to six control projects. These time-critical projects were completed on-time or in three cases on average 27% early. The results demonstrated support for the hypothesis.

### 4.1 Introduction

As discussed in Chapter 3, the Research step 1 was executed in the format of the scoping study, which consolidated observations and research questions into initial generalisations. An initial theoretical construct was developed and hypothesis evaluated. Research step 1 is mapped to the Wallace model as depicted in Figure 3-4. The scoping study was previously partly reported by the author (Steyn & Stoker 2014).

The scoping study is presented in the following sections, following the Wallace model:

- Observations
- Parameter identification and generalisation
- Initial propositions and theoretical constructs
- Hypothesis
- Approach for scoping study
- Control project results
- Test project results

## 4.2 Observations

Referencing the models of Wallace and Eisenhardt, observations lead to questions, since observations are shaped by the observer's experience, background, system of beliefs and what "should" be.

Observations by the researcher during more than twenty years of intensive involvement in the project management industry surfaced questions regarding frequent late completion of projects. Accepting that mistakes are a fundamental component of progress, making a mistake once is a learning experience. However, consistently making the same mistake over several decades must indicate some fundamental learning opportunity not being internalized.

In addition, on-time completion is paramount to project stakeholders for time critical projects. Since late completion impacts both impact financial performance and organisational survival, both strategic and dramatic initiatives are inevitable.

Many attempts by the industry, most notably the frequent extension of due dates as well as attempts at more detailed planning and utilising resource "hockey-sticks", did not contribute to a significant and sustainable solution.

According to Wallace and Eisenhardt, research questions are structured, and the literature review either supports or invalidates these research questions, while providing further context, details and background.

The observations by the researcher were both preceded and supported by widespread scientific research on project success, or rather the frequent lack thereof. As previously noted, this research specifically considers due date performance of time-critical projects.

These observations, considered in the light of CCPM theory, lean methodology and Schonberger's comment, lead to questions. (a) Why is NVAT consistently visible on the critical path? (b) What research should be considered that can contribute to improving on-time completion of projects? These questions were further refined to: (c) How can measurement theory contribute to improved on-time completion of projects? And later extended

to: (d) How can due date performance and project duration be developed to provide an additional competitive advantage to project-based organisations? The very significant impact of late projects on business strategy requires additional research contributions towards an improvement to this strategic dilemma in project management.

Proceeding with the Wallace model, parameters and generalisations should be identified towards the development of concepts, propositions and theoretical constructs.

### 4.3 Parameter identification and generalisation

Handfield references Merton when defining empirical generalisation as “*an isolated proposition summarising observed uniformities of relationships between two or more variables*” (Handfield & Melnyk 1998; Merton 1957). Merton further differentiates empirical generalisation from a scientific law, which he defines as “*a statement of invariance derivable from a theory*” and theory as “*a statement of relationship between units observed or approximated in the empirical world*” (Merton 1957).

The parameters utilised by this research, which will support the process towards empirical generalisation, are briefly described:

Project duration is generally accepted as the summation of all task durations on the critical path.

For the case of N tasks on the critical path and where

$D_i$  = duration of task i on the critical path

$$Project\ duration = \sum_{i=1}^N D_i$$

For the purposes of the scoping study,  $D_i$  was disaggregated into three components:

$W_i$  = work time on task<sub>*i*</sub>

$C_i$  = contingency time allowance for task<sub>*i*</sub>

$G_i$  = duration between task<sub>*i*</sub> finishing and task<sub>*i+1*</sub> starting, and

$G_N$  = duration between last task finished and project reported complete

It is generally accepted that

$D_i = W_i + C_i$  and

$$\text{Project duration} = \sum_{i=1}^N (w_i + C_i + G_i)$$

Both  $G_i$  and  $C_i$  are often assumed to be zero, or at least much smaller than  $W_i$

The simplified case of a project comprising two tasks is graphically depicted in Figure 4-1.

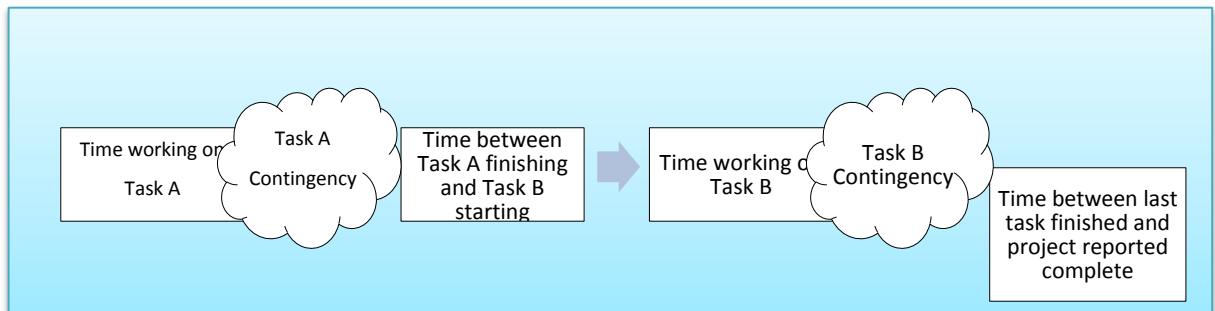


Figure 4-1: Summarised components of project duration

Acknowledging the disaggregation of task duration (into components), it is further relevant to recognise that these different components are impacted by different external factors, while components are also not all under the same level of control of the task owner. Two examples are:

- Contingency is a planning concept, and is a function of both the level of perceived risk and the perceived result of not achieving the deadline. Perceptions are further impacted by time and the

information asymmetry between project members, specifically between the project manager and the task owner.

- $G_i$  is often assumed to be zero, and frequently not allocated a responsibility owner. It can either be included in the responsibilities of the task owner of task  $i$  or the task owner of task  $i+1$ . Often it should be included in both task owner's responsibilities, and in some cases, neither have significant control over it (as in curing time of cement).

The practising project manager, who is responsible for on-time completion of the project, therefore typically focuses most attention on driving and fast-tracking the execution of the task (focusing on managing, measuring and reducing  $W_i$ ). This takes the form of initiatives to weld faster, build faster, design faster or execute faster.

This management energy from the project manager is further focused on measuring the task and the task owner, which, apart from not ensuring on-time completion of the task, also leads to the typical acrimonious and adversarial relationship between task owner and project manager. Utilising TA to analyse the words used in communication transactions between the project manager and the task owner, PC-CP transactions are frequently observed, leading to difficult and sometimes failing communications. The strained relationship provides an incentive to both parties to maintain and even expand the information asymmetry.

The core observations are summarised as:

- Only one standardised measurement is used for all task components
- Projects are (too often) late.
- Relationships frequently deteriorate in late projects (e.g. between project manager and task manager)

Handfield specifically notes that the theory-building process should at this stage “*not be constrained by issues of testability, validity, or problem solving*”.

The researcher develops various conjectures of relationships that are “*interesting, plausible, consistent, or appropriate*”. The generalisation suggests some of the key variables and supports further by even hinting at a relationship (Handfield & Melnyk 1998).

#### 4.4 Initial propositions and theoretical constructs

Weick referred to the development of theories from empirical observation as “*disciplined imagination*” (Weick 1989), which involves a series of thought trials and imaginary outcomes in hypothetical situations (Handfield & Melnyk 1998).

For the purposes of the scoping study, following many early trials, the following propositions were eventually developed:

- $\sum_{i=1}^N G_i$  is significant in relation to the project duration and  $G_i$  should be managed separately and differently from  $W_i$ , i.e. a different and new measurement methodology.
- There is a correlation between MM and project duration.

These propositions enable the development of specific hypotheses.

#### 4.5 Hypothesis

The purpose of the scoping study was to evaluate  $H_1$  and the corresponding null hypothesis  $H_{1,0}$

$H_1$ : There is an association between project task time measurement methodology and project duration, with corresponding

$H_{1,0}$  There is no association between project task time measurement methodology and project duration.

The purpose of the scoping study further included identifying potential additional requirements in the macro project environment which are necessary for successful implementation. Moreover, to identify potential internal and external validity concerns that will require addressing during further experiments.

## 4.6 Approach for the scoping study

Returning to the Wallace model, once research questions are clarified, case studies can be selected, and instruments developed to collect data. The data can then be analysed in the light of the particular research question and initial hypotheses.

This research utilised data from multiple case studies of industrial and engineering construction projects. Case studies were preferred as research methodology, since “how” and “why” questions are asked, rather than an investigation into frequencies and incidences (Yin 2013). As Hameri states, “*the purpose of case study research is to compare theory and data, iterating towards a practical theory that closely fits the data*”. Replicating a series of experiments, in the format of a series of case studies, provides empirical data that can support or refute the hypothesis, and provide additional insight (Hameri & Heikkila 2002). Cases that confirm the hypothesis under study enhance the confidence in its validity, while cases that do not confirm the relationships provide an opportunity for richer understanding (Eisenhardt 1989b).

The scoping study was executed between 2008 and 2010. Time-critical projects were selected, which included five industrial projects with durations between 50 and 100 days and a value range of USD 10-20 million. The value of early completion was in the order of USD 1 million per day. Six previous projects from the same industry were used as control cases. Two of the test projects were executed on the same industrial site and by the same teams as the reference cases. The reference cases were executed in prior years. Care was taken to ensure no obvious external factors were different between the test projects and the reference projects. Specific attention was accorded to ensure there were no negative impacts on cost, quality, safety, environmental and regulatory compliance. The role of the researcher was as an advisor, though not present full-time on all test project sites.

The scoping study was executed in three phases, i.e. (1) identify test and control projects, (2) execute the test projects and (3) evaluate the results.



## 4.7 Control project results

The historical on-time performance of the project series, as demonstrated by the control projects, was not acceptable to the project owner. None of the control projects was completed on time. The traditional mechanism to reduce risk and improve on-time performance was to request additional time for each subsequent project. Due to the significant value of one day's delay in the project, an initiative was required to address these excessive project duration extensions. All the control projects utilised "percentage complete per task" as progress measurement. Due date performance of the control projects is presented in Table 4-1:

Control projects	Planned Duration	Actual Duration	Comments	Commercial impact
Project A1	86	96	10 days late	USD 11 million loss
Project A2	37	49	12 days late	USD 13 million loss
Project A3	58	74	16 days late	USD 17 million loss
Project A4	62	85	23 days late	USD 25 million loss
Project A5	56	57	1 day late	USD 1 million loss
Project A6	42	53	11 days late	USD 12 million loss

Table 4-1: Performance of scoping study control projects

The average performance of the control projects was twelve days late. This resulted in a total net loss of USD 79 million with an average loss of USD 13 million per project.

## 4.8 Experimental procedure

Utilising the knowledge bases of CCPM and lean methodology, as well as the initial concepts for the development of the TOM-P, attention was focused on  $G_i$ . A specific measurement methodology was developed to focus both management and task owner attention on  $G_i$ . The MM addressed the differentiated task components following the disaggregation.

The test projects were planned utilising the principle of critical chain project buffers. Critical chain methodology requires a 50% cut in the duration of tasks, utilising 25% as a project buffer, with 25% being presented to the client as the benefit. Due to local management and labour demands, only 25% could be cut and the full 25% made available as the project buffer. Daily reports, focusing on the measurements suggested, were utilised to guide project decision-making.

Coaching was provided to support appropriate management action and decision-making, based on the measurement information received. It was observed that management actions significantly affected the integrity of measurements reported the next day (this requires further research). Integrated daily reports were developed to demonstrate to management and the project team what impact differentiated measurements has.

The case study research methodology proved invaluable. Actions taken by both management and team members were reviewed in detail, which provided insights and further opportunity to leverage results. Actions to actively support the measurements were witnessed and documented, as were actions to undermine the measurements. In-depth interviews were utilised to understand the underlying motivations and intentions. This provided valuable data for further research.

## 4.9 Test project results

The results from the test projects are presented in Table 4-2:

Test projects	Planned duration	Actual duration	Comments	Commercial benefit (profit)
Project B1	100	82	18 days early	USD 19 million
Project B2	96	68	28 days early	USD 20 million
Project B3	50	50	On time	
Project B4	58	59	1 day late	USD 1 million loss
Project B5	100	64	36 days early	USD 39 million

Table 4-2: Results from scoping study test projects

Comparing the results from the control group with the test group, the average twelve days late performance was transformed into an average of sixteen days early. This improvement of 28% is of significant strategic value and provided valuable impetus towards further investigation.

The early completion of the test projects demonstrated that significant benefit can be derived from enhanced measurement methodologies, delivering USD 77 million of net benefit from the test projects.

The results further established that due date risk can be substantially reduced without negative impacts on cost, quality, safety, environmental or regulatory compliance.

Of interest was the various actions initiated by task owners that delayed task completion. Unfortunately, these have significant detrimental effects on the test group results, and the scoping study MM and measurement processes were not sophisticated enough to address these actions early and successful. Separate attempts at quantifying the impact of these external effects resulted in estimations of no less than ten days and potentially as many as 25 days. Project B4 was severely impacted by delays due to contractual incentives not being aligned with project goals, e.g. resources

were contracted with cost-based contracts, resulting in reductions of earnings for early completion.

It was very evident that additional requirements exist, specifically related to the macro-organisational environment, which impact on the successful implementation of the test projects. Specific examples include the alignment of corporate incentives with project measurements and demands, addressing the suspicion created by the new MM due to past negative experiences and challenges in the trust relationship between workforce and management.

## 4.10 Evaluation and analysis of test results

### 4.10.1 Correlation analysis

The correlation analysis of the test and control data required a methodology to accommodate the nominal data of measurement methodology. The point-biserial correlation coefficient is a special case of Pearson in which one variable is quantitative and the other nominal.

The statistical data are summarised in Table 4-3 utilising days early/(-late) as the dependent variable.

	X0=Control Projects	X1=Test projects	Total
n	6	5	11
$\sum Y$	-73	81	8
$\sum Y^2$	1151	2405	3556
SS <sub>Y</sub>	262,8333	1092,8	3550,1818
mean <sub>Y</sub>	-12,1667	16,2	0,7273

Table 4-3: Scoping study statistical data

The point-biserial correlation coefficient was calculated as  $r_{pb} = 0,79$  with  $t=3,82$  (degrees of freedom = 9) (P two-tailed =  $4 \times 10^{-3}$ ).

The high correlation coefficient indicated towards significant correlation, but further analysis was required.

#### 4.10.2 Goodness-of-fit analysis

The Pearson's Chi-square test for independence evaluates how likely the observed distribution can be considered to be seen as chance. It analyses categorised data and evaluates the null hypothesis. The Chi-square value is calculated utilising the following formula:

$$\chi^2 = \sum_{i=1}^n \frac{(f_{observed} - f_{expected})^2}{f_{expected}}$$

For the purposes of the Chi-square test, the data from the scoping study are categorised as detailed in Table 4-4.

	<b>Control projects</b>	<b>Test projects</b>
<b>Late projects</b>	6 Projects	1 project
<b>On-time or early projects</b>	0 projects	4 projects

Table 4-4: Data from scoping study categorised for Chi-square test

From the data above, the Chi-square statistic is calculated as  $\chi^2 = 7,5$

The probability of independence, the p-value is calculated to be  $P = 6 \times 10^{-3}$  at confidence level  $p < 0,01$  which strongly supports the rejection of the null hypothesis. The probability that this distribution of late projects vs. on-time projects from the scoping study is due to chance is less than 1%.

However, the chi-square test is challenged when the data sample includes small frequencies (e.g. < 5) and Ellis suggested effect sizes in cases where it is important to know “*whether a relationship between two variables is practically significant*” (Ellis & Steyn 2003). Effect size is calculated as  $w = \sqrt{\frac{\chi^2}{n}}$ , where  $\chi^2$  is the Chi-square statistic and n the sample size.

Cohen provided guidelines for interpreting effect sizes by stating that for a small effect  $w = 0,1$  and for a large effect  $w = 0,5$ . A relationship with  $w \geq 0,5$  is considered as practically significant (Cohen 1988)

For the scoping study  $\chi^2 = 7,5$  and  $n=11$ . Therefore the effect size  $w = 0,83$  is practically significant according to Cohen.

An alternative independence test can be performed utilising either the Yates correction to Pearson’s Chi-squared statistic or utilising Fisher’s exact test.

Utilising the same data, the Yates correction is calculated to be  $\chi_{Yates}^2 = 5$  and the Fisher exact test produces a result of  $P=0,015$ , both supporting the conclusion from the Chi-squared test, that the null hypothesis, which states that there is no correlation between MM and project duration, is rejected.

Utilising the paired t-test statistical evaluation, the two-tailed P value =  $3,7 \times 10^{-3}$  ( $t=6,08$  and  $df =4$ ) supporting the previous results that the difference between the control projects and the test projects is statistically significant.

#### **4.10.3 Evaluation of type I and type II errors**

Type I errors occur when the null hypothesis is incorrectly rejected. The various statistical calculations detailed in section 4.10.2 and especially the effect size  $w = 0,83$  support the rejection of  $H_{1,0}$

Type II errors occur when the null hypothesis is incorrectly accepted.

The tests indicate that the probability that  $H_{1,0}$  should be accepted is less than 1,5%, which indicates that neither a type I error nor a type II error is applicable.

*In summary hypothesis  $H_1$  was supported and the null hypothesis  $H_{1,0}$  was rejected*

#### 4.11 Conclusion derived from the scoping study

The purpose of the scoping study was to consolidated observations and research questions into initial generalisations as research step 1 based on the experimental design and the Wallace model. The initial theoretical construct was developed and  $H_1$  evaluated.

The scoping study was executed between 2008 and 2010 and utilised five time-critical industrial projects with durations between 50 and 100 days and a value range of USD 10-20 million. The value of early completion was in the order of USD 1 million per day. Six previous projects from the same industry were used as control cases.

***Hypothesis  $H_1$  was supported and the null hypothesis  $H_{1.0}$  was rejected***

$H_1$ : There is an association between project task time measurement methodology and project duration, with corresponding

$H_{1.0}$  There is no association between project task time measurement methodology and project duration.

The results of the scoping study were encouraging and demonstrated significant support for the hypothesis that there is a relationship between project progress measurement methodology and project on-time completion.

It further confirmed the significant monetary value of early completion on time-critical projects and supports the intention of this study – to contribute additional knowledge to improve project success, specifically reduce project duration and due date risk.

From the initial theoretical constructs, the next step in theory building was to develop the theory of measurements for projects

## 5 The theory of measurement for projects

*“Nothing is so practical as a good theory” (Lewin 1945).*

*“Theory is the vehicle that links data to knowledge” (Handfield & Melnyk 1998).*

### 5.1 Introduction

Chapter 5 contributes to engineering and project management knowledge by documenting the development of the TOM-P. The structure for Chapter 5 is graphically presented in Figure 5-1.

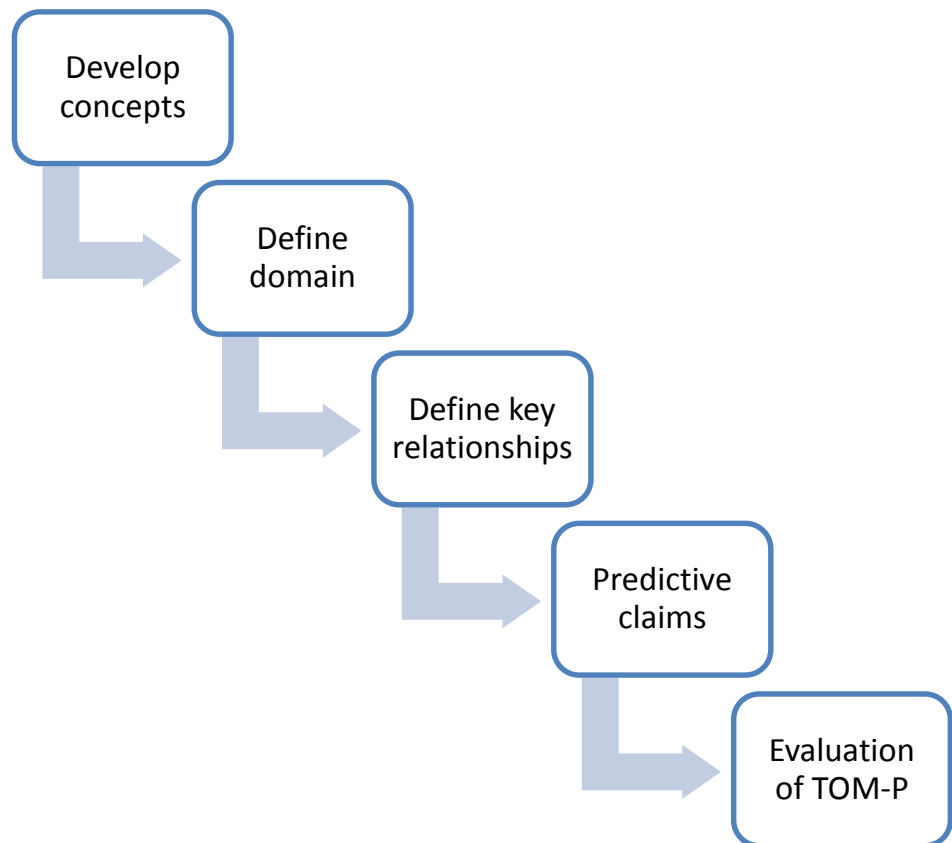


Figure 5-1: Structure of Chapter 5

The word “theory” is derived from the Greek word “theōria” meaning contemplation or speculation, which in turn originated from theōros, referring to the spectator (*Oxford Dictionary*). We deduce that all theories are mental



models of the perceived reality. Suppe defines a theory as “a system of conceptual constructs” (Suppe 1974) while Pickett expanded the definition to “a system of conceptual constructs that organises and explains the observable phenomena in a stated domain of interest” (Pickett et al. 2013). Pickett’s definition explains why theory is important for both researchers and practitioners, which Wacker summarises as (1) it provides a framework for analysis; (2) it provides an efficient method for development of the field of knowledge, and (3) it provides clear explanations of the pragmatic world (Wacker 1998).

For a theory to provide benefit to researchers and practitioners, four requirements must be met: (1) concepts, (2) key relationships and (3) domain and limitations must be defined, and (4) predictive claims must be stated (Wacker 1998; Hunt 1991; Bunge 1967; Reynolds 1976). Chapter 5 documents the contents to comply with these four requirements of a theory, after which TOM-P is evaluated in terms of guiding contributions from academic research regarding “good” theory.

In conclusion, Chapter 5 systematically documents the author’s original contribution to the science of project and engineering management, references this contribution to academic requirements and establishes the framework for the validation study in Chapter 6.

## **5.2 Development of concepts**

**The core concepts required for the development of TOM-P relate to the improved detail understanding of task duration and the components of task duration.**

Project are decomposed into activities or tasks, depending on the terminology utilised in the work breakdown structure. The tasks then provide the building blocks to calculate actual project duration, through

$$Project\ Duration = \sum_{i=1}^N D_i$$

Where:

N = Number of tasks on critical path

$D_i$  = Duration of task  $i$  on the critical path

**The scoping study contributed a direction for further investigation, by demonstrating that (actual) task time durations comprised several components. This section describes the components and concepts towards TOM-P.**

**Task duration,  $D_i$  is decomposed into three components which are defined in equation 1 and then described in detail in the next three sections to motivate their existence, difference and interdependence.**

$$D_i = \lambda_i + \gamma_i + \varphi_i \quad \text{(Equation 1)}$$

**where**

**$\gamma$  = Component of task duration  $D_i$  to execute the scope of work (“actual work”, “touch-time”). Refer section 5.2.2 for a detail description.**

**$\lambda$  = Component of task duration  $D_i$  before the start of  $\gamma$ . Refer section 5.2.1 for a detail description.**

**$\varphi$  = Component of task duration  $D_i$  after completion of  $\gamma$ . Refer section 5.2.3 for a detail description.**

## 5.2.1 Description and discussion of component $\lambda$ (pre- $\gamma$ delay on critical path)

This section describes  $\lambda$  and motivates why  $\lambda$  is different, though interdependent with other components of  $D_i$

All time on the critical path before the commencement of  $\gamma$  is included in  $\lambda$ . For example,  $\lambda$  includes delays based on student syndrome and delays on handover.

### 5.2.1.1 Student syndrome

The student syndrome is indicated by an initial start of execution activities and a reduction in activity level. After some delay and a trigger, the activity level increases rapidly to an extended peak of energy. Steyn presented it graphically as demonstrated in Figure 5-2 (Steyn 2002). Bartoska even developed a mathematical model in the format of a parameterised goniometric function (Bartoska & Subrt 2011).

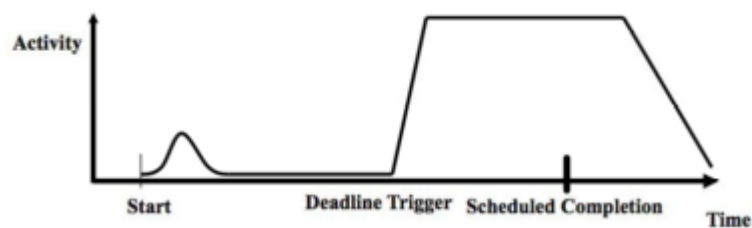


Figure 5-2: Activity intensity demonstrating student syndrome, from Steyn

For ease of reference, the delay based on the student syndrome is referred to as C2.

### Observations

C2 is the responsibility of the task owner and often exists due to multi-tasking demands and the perception of large contingency allowances available in the task duration. CCPM focuses management attention on C2 through monitoring the project buffer after initially reducing the task duration by 50%. The nature of C2 is, therefore, different from other components, though

interdependent through multi-tasking demands and the management of contingency allowances.

#### 5.2.1.2 **Delay in accepting handover**

A further contribution to  $\lambda$  is the delay in accepting handover (C3), which originates when the preceding task presents handover that is not accepted immediately.

#### ***Observations***

The time difference between handover received and handover accepted relates among others to the preceding work complying with the acceptance criteria of the succeeding task manager. Rework might be required to enable the succeeding task to start, e.g. minor changes to scaffolding, or sign-off procedures and documentation requirements between tasks in high-risk or legislated environments. There is often uncertainty regarding responsibility for C3. The preceding task is completed according to the preceding task manager while the succeeding task cannot start according to the succeeding task manager. Often, neither of the task managers accept responsibility.

The researcher observed that in high risk and highly regulated environments,  $C3 > 0$  in more than 90% of tasks and the magnitude of C3 was observed to be directly proportional to the perception of risk. It was further observed that the magnitude of C3 was inversely correlated with team spirit. This observation is consistent with research that demonstrated that team performance is correlated with the team environment (Thamhain & Gemmill 1974; DeCotiis & Dyer 1977; Dyer 1977; Belassi & Tukel 1996).

Due to C3 being located on the critical path, reduction of C3 will reduce project duration. With the involvement of the succeeding task manager in the (closing stages of the) preceding task, challenges to acceptance can be identified early and addressed, to limit (or eliminate) delays in accepting handover. This is one example how components require fundamentally different measurements and control actions.

However, accepting handover is not the same as starting the task.

### 5.2.1.3 Delay to start

The time from acceptance of handover to the full start of the task (C4) is often motivated by project managers as mobilisation time.

#### *Observations*

In practice, C4 is accepted to have some positive value and is often a source of conflict between project owner and project manager or task manager. The project owner prefers  $C4 = 0$  while the task manager prefers a “reasonable” time for mobilisation. C4 is seldom specifically indicated on project plans and accepted to be completed prior to task start. The task manager is responsible for C4, and while the task manager prefers C4 to be off the critical path, this is seldom the case. C4 is usually on the critical path (due to C4 following handover) and C4, therefore, impacts project duration directly.

Reducing C4 towards zero is possible by including most of the mobilisation during the preparation phase. A relationship was observed between preparation and C4. In cases where significant pressure was applied to reduce preparation time, mobilisation time increased. The researcher’s point of view is this is an inappropriate trade-off, as lower-cost preparation time (off the critical path) is traded for very expensive mobilisation time (on the critical path).

Once the task is fully started, the actual work can (eventually) proceed with full attention. “Full” start refers to when all resources are fully engaged, in contrast with cases where key resources are not yet available, and available resources started with lesser work (for example in an attempt to demonstrate activity on the task).

## 5.2.2 Description and discussion of component $\gamma$

$\gamma$  refers to the time for executing the scope of work of the task, also called “touch-time”.  $\gamma$  is accepted as the major component of task duration and often the only component of duration referenced by project plans.

#### *Observations*

The task manager is responsible for  $\gamma$  and in practice it was found  $\gamma$  received the most attention from both the project manager and the task manager. The attention is warranted by the traditional definition of project duration,

$$Project\ Duration = \sum_{i=1}^N D_i$$

with the assumption that  $D_i \approx \gamma$ .

However, this assumption is challenged. Utilising work-study methods, stopwatches and observers with clipboards on eight industrial projects, it was observed that on average  $\gamma = 34\%$  of total task duration as presented in Figure 5-3. This result can be referenced to the academic literature on productivity in various environments, including nuclear and fossil fuel power stations (Liou & Borchering 1986) and construction (Thomas 2000).

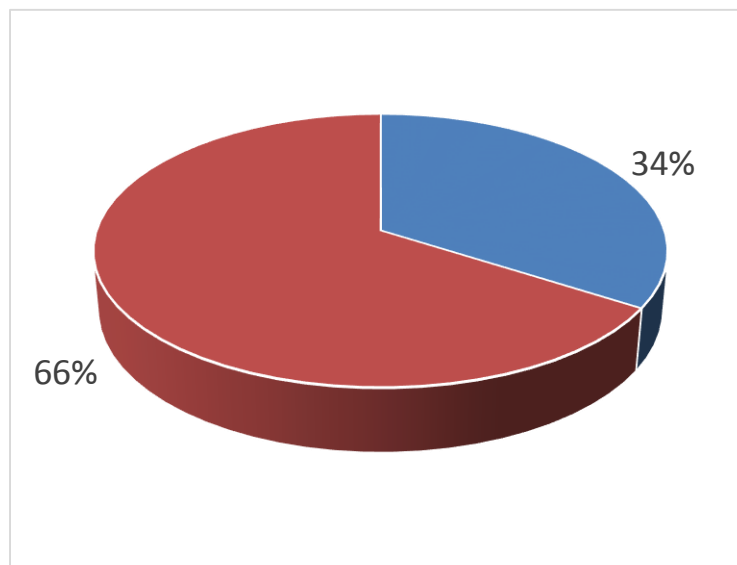


Figure 5-3: Touch-time compared to task duration.  $\gamma = 34\%$

Project duration can be reduced by reducing  $\gamma$ , and the typical effort is in fast-tracking the execution of the task e.g. weld faster, build faster, design faster or execute faster.

Management energy is focused by the project manager “on” the task manager, which, amongst other things leads to the typical adversarial relationship between the project manager and the task manager. The quality of this relationship further contributes towards an incentive to maintain and even expand the information asymmetry from both sides. Examples of

information asymmetry are observed when neither party shares newly identified opportunities for potential savings or achieved savings with each other.

Crushing is widely utilised as a methodology to reduce project duration (Rosenblatt, Meir J. Roll 1985; Abbasi, Ghaleb Y. Mukattash 2001; Gerk & Qassim 2008). The reduction of non-value adding effort and fast tracking presents its opportunities, benefits and challenges (Han *et al.* 2012; Howell 2003) while the benefits of fast tracking are challenged by Tighe (Tighe 1991).

It is, therefore, clear that  $\gamma$  is different from other components, requiring different measurements and controls though  $\gamma$  is dependent on at least the scope included in preparation.

However, once  $\gamma$  is completed, it does not necessarily mean that the task is reported complete or handed over.

### **5.2.3 Description and discussion of component $\phi$ (post- $\gamma$ delay on critical path)**

$\phi$  refers to the time delay from after completing the work to when completion is reported or to when handover is presented to the succeeding task.  $\phi$  is the responsibility of the task manager and assumed to be zero. Project duration is impacted when  $\phi > 0$ . Parkinson's law is one motivation for  $\phi > 0$ .

#### **5.2.3.1 Parkinson's Law**

Parkinson stated that work expands to fill the available time (Parkinson 1957). Gutierrez and Kouvelis studied the impact of Parkinson's law and developed a mathematical model for its implication in the project management domain. They noted that "*the elasticity of work in its demand on time (especially for activities requiring human involvement) is in many cases, as most project managers have experienced, a major cause of project delays*" (Gutierrez & Kouvelis 1991).

### 5.2.3.2 Incentives for delayed completion

A further contribution to  $\varphi$  is measurements and incentives that present unintended consequences, e.g. when late completion is incentivised by reducing remuneration or contract duration as a reward for early completion.

In addition, when historic durations are utilised as a baseline for future performance, delayed completion is incentivised.

Therefore, to reduce project duration,  $\varphi$  must be measured and managed differently.

*In addition to the three components of task duration  $D_i$ , additional task components are required to execute the task.*

**These components are not on the critical path, as presented in Figure 5-4.** The critical path is indicated in the customary red. (Presentation is not to scale).

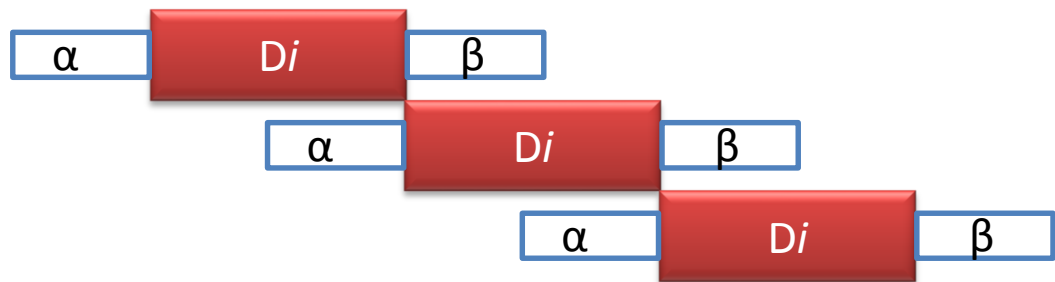


Figure 5-4: Demonstrating task components NOT on the critical path

**The task components not on the critical path, are typically preparation and close-out components as presented in Figure 5-4,**

**Where**

**$\alpha$  = Cumulative of all time requirements prior to starting  $D_i$  on the critical path. Refer section 5.2.4 for a detail description.**

**$\beta$  = Cumulative of all time requirements to complete the task post  $D_i$ . Refer section 5.2.5 for a detail description.**



#### 5.2.4 Description and discussion of component $\alpha$ (preparation)

$\alpha$  includes all aspects of preparation, including for example sourcing of materials, skills and resources, as well as finalising designs and approvals. CCPM refers to “full-kit” preparation.

##### *Observations*

$\alpha$ -time is often not included in the detailed project plan, therefore separate processes and lists are required to manage it.  $\alpha$  is the responsibility of the task manager and task managers often complain that they frequently have limited control to ensure preparation is completed in time.

Though  $\alpha$  is typically scheduled as late as possible prior to the task start date (in order to minimise waiting time between  $\alpha$  and  $D_i$ ), the challenge for  $\alpha$  is not to delay task start.

All project managers (with whom the researcher interacted over more than two decades) apportioned some level of blame to  $\alpha$ , for delayed completion.

The opportunity to reduce project duration by addressing preparation is two-fold. (1) Full-kit preparation must be completed prior to task start and must not encroach on the critical path. Preparation is acknowledged as important, though measurements are limited. A significant contribution was made by CCPM, which focuses significantly on completing full-kit timeously, utilising buffer penetration to demonstrate the impact on project duration.

A further opportunity to reduce project duration is based on (2) the understanding that the value of one day **on** the critical path is significantly more expensive than one day **off** the critical path. Since  $\alpha$  is not on the critical path, justification is available to review and potentially extend  $\alpha$ -time in favour of a reduction in  $\gamma$ -time.

This justification to extend  $\alpha$  time is in stark contrast to the experience of task managers, who report that management attention and performance incentives are related to early completion (also of preparation tasks).

Different measurements are therefore required for  $\alpha$ , as it impacts  $D_i$  though not a component of  $D_i$  or on the critical path.

### 5.2.5 Description and discussion of component $\beta$ (close-out)

$\beta$  refers to the time from handover to final close-out of the task, which includes, for example, the duties of quality assurance, documentation, debriefing and clean-up.

#### *Observations*

These duties are acknowledged as the responsibility of the task owner, though often neglected for several reasons. The two most frequent motivations reported were (1) specialised resources are in short supply, and the task owner's speciality might be required in succeeding tasks, and (2) this latter part of the task is often less interesting to the task resource than initiating or driving other tasks.

Furthermore, due to  $\beta$  not being on the critical path, de-scoping or reducing  $\beta$  is usually not perceived to have any effect on project duration.

Neglecting  $\beta$  impacts project quality assurance and the platform to embrace lessons learnt.  $\beta$  provides a significant opportunity to optimise the preparation and execution of future tasks through embracing the lessons learnt. Therefore, a task is influenced by all previous  $\beta$ -components, which all contribute to lessons learnt and optimising current task duration.

In summary,  $\beta$  impacts on the duration of all future tasks.  $\beta$  is different from other components and some level of interdependence exists, requiring unique measurements for  $\beta$ .

### 5.2.6 Summary of concept definitions

**In summary, the following components were developed, and they are different though interdependent.**

**$\gamma$  = Component of task duration  $D_i$  to execute the scope of work.**

**$\lambda$  = Component of task duration  $D_i$  before the start of  $\gamma$ .**

**$\varphi$  = Component of task duration  $D_i$  after completion of  $\gamma$ .**

**And equation 1 was stated as  $D_i = \lambda_i + \gamma_i + \varphi_i$**

Two components, which are not on the critical path, were added:

$\alpha$  = Cumulative of all time requirements prior to starting  $D_i$  on the critical path (refer section 5.2.4 for a detailed description).  $D_i$  is impacted on by how effectively and how comprehensively  $\alpha$  was executed.

$\beta$  = Cumulative of all time requirements to complete the task post  $D_i$ . Refer section 5.2.5 for a detail description.  $D_i$  is impacted by how much can be transferred from  $D_i$  to  $\beta$ -time, as well as how effective the lessons from previous tasks incorporated in executing  $D_i$ .  $D_i$  is therefore influenced by all previous  $\beta$  components.

### 5.3 Definitions of key relationships

$$Project\ Duration = \sum_{i=1}^N D_i$$

Where

$N$  = Number of tasks on critical path

$D_i$  = Duration of task  $i$  on the critical path

and

$$D_i = \lambda_i + \gamma_i + \varphi_i \quad \text{(Equation 1)}$$

To which is added

$$D_i = \lambda_i + \gamma_i + \varphi_i + f(\alpha_i, \beta'_i)$$

Where

$$\beta'_i = \sum_{j=1}^i \beta_j$$

Due to  $D_i$  being influenced by all previous components of  $\beta$

Which is simplified and further referenced as

$$D_i = f(\lambda_i, \gamma_i, \varphi_i, \alpha_i, \beta_i') \quad \text{(Equation 2)}$$

## 5.4 Definition of domain and limitations

TOM-P is specifically relevant and applicable for time-critical projects.

TOM-P has limited application in project environments where the importance of on-time completion is secondary to cost saving or resource availability, as well as where strategic decisions (or lack thereof) are delaying project execution. An example might be the decommissioning of the German nuclear power generation fleet. Although a timeline has been established, there might be a limited commercial incentive to aggressively drive completion of the projects towards early completion.

Further conditions which bound the implementation domain of TOM-P include the existence of barriers to early delivery. These are often “hidden” and can be the unintended consequences of incentives. Examples include (1) reduced earnings for early completion, (2) utilising early completion as baseline for future negotiations, (3) rewarding “emergency firefighting” towards the end of the project and (4) not approving the required resources indicated by  $\alpha$  and  $\beta$ .

## 5.5 Predictive claims

**TOM-P provides the understanding to utilise differentiated measurements in order to shorten project duration.**

Conventional progress measurements focus on reducing the duration of all tasks in order to complete the project on time, concentrating on  $\gamma$ -time (executing the task scope).

TOM-P reaffirms that

$$\text{Project Duration} = \sum_{i=1}^N D_i$$

Where

$$D_i = \lambda_i + \gamma_i + \varphi_i \quad \text{(Equation 1)}$$

**TOM-P added equation 2, and the difference between the two equations introduces the opportunity for differentiated measurements.**

$$D_i = f(\lambda_i, \gamma_i, \varphi_i, \alpha_i, \beta_i') \quad \text{(Equation 2)}$$

**The differentiated measurements suggested by TOM-P also leverage the Pareto concept, proposing that measurement addresses those few components which provide the maximum benefit.**

**Since  $\alpha$  and  $\beta$  are not included in equation 1, differentiated measurements provide opportunities to transfer time (and scope) from  $D_i$  to  $\alpha_i$  and  $\beta_i$  (i.e. from on critical path to off the critical path)**

***Prediction 1:***

Utilising TOM-P, we predict that by focusing differentiated measurements on  $\alpha$ ,  $\beta$ ,  $\lambda$  and  $\varphi$ -time (and not  $\gamma$ ), project duration will reduce.

Therefore,

if  $\lambda$  and  $\varphi$  are reduced by focusing measurements on reducing handover, non-value adding time, student syndrome and the effect of Parkinson's law and

$\alpha$ -time and  $\beta$ -time are only measured in relation to how it contributes to reducing  $D_i$  (even if it requires extension of  $\alpha$  and  $\beta$ )

then project duration will be reduced.

(treating  $D_i$  in effect like a symptom, not the cause).

In projects where  $D_i \gg \gamma$  (e.g. task duration is much larger than touch-time), the effect will be more significant than in projects where  $D_i \approx \gamma$ .

Once  $D_i \approx \gamma$  and the contributions of  $\alpha$  and  $\beta$  have been maximised, i.e. preparation cannot be leveraged further and maximum value has been derived from lessons learnt, then further reduction of  $D_i$  will be dependent on reducing  $\gamma$  (utilising existing PM knowledge, including crashing).

### *How are TOM-P measurements different?*

Initiatives to remove the effects of non-value adding time, student syndrome and Parkinson's law to reduce project duration are not new. Both CPM and CCPM literature refer to initiatives in this regard.

Both CPM and CCPM contributed that all **tasks are not the same** and focus is required on the appropriate task, which is defined as the critical path by CPM, and by CCPM as the task causing the largest buffer penetration.

TOM-P contributes new and more detailed understanding of task time by decomposing task duration. These task components are both different and interdependent. TOM-P provides the unique understanding on how differentiated measurements are utilised to reduce task and project duration, supporting both CPM and CCPM. The TOM-P equations provide unique guidance on how to identify and develop different progress measurement questions for each component. It provides a new degree of clarity for actionable opportunities by CCPM project managers who is driving projects based on buffer penetration by measuring the remaining duration of tasks.

In addition, utilising the understanding from organisational control, TOM-P provides opportunities to improve the project management relationships.

It is predicted that the transfer of focus from  $\gamma$ -time to the other components will also contribute to the improved relationship between the project manager and task owner. Improved relationship will contribute to reduced information asymmetry, which will furthermore improve project management decision-making.

The combination of reducing task duration and improving project management relationships is predicted to have a significant impact on improving project success, specifically reducing project duration and reducing due date risk.

## 5.6 Discussion of TOM-P

This section discusses the compliance of TOM-P in terms of the requirements for scientific knowledge and theory-building as documented in the academic literature (Reynolds 1976; Koskela & Howell 2002; Choi & Wacker 2011; Quine & Ullian 1980; Amundson 1998).

### 5.6.1 Reynolds

Reynolds stated a set of five requirements for scientific knowledge to provide value. These requirements, as well as the compliance of TOM-P, is summarised (Reynolds 1976).

Reynolds states that scientific knowledge must provide a typology, a method of organising and categorising things. TOM-P describes the identification and categorisation of task components in section 5.2 by defining the task components. This new typology provides opportunities for a new level of focus and communication by the project management role players.

Scientific knowledge must also provide predictions of future events. The predictive claims of TOM-P are presented in section 5.4.

Furthermore, Reynolds requires scientific knowledge to explain past events. It must provide *a sense of understanding about what causes events*. The identification and discussions of individual components in section 5.2 provide explanations of past events, specifically providing additional insight into the motivations for late completion of tasks and projects.

In the fifth position, Reynolds states that scientific knowledge must provide the potential to control future events. The relationships underlying TOM-P, as summarised in section 5.3 and the predictive claims presented in section 5.4 provide measurements and controls to influence future projects.

In summary, TOM-P complies with the requirements stated by Reynolds for scientific knowledge to provide value.

The value provided by TOM-P is demonstrated in the validation case studies as reported in Chapter 6.

## 5.6.2 Koskela

Koskela defined the six roles of a theory. These six roles, as well as the compliance of TOM-P, are summarised below (Koskela & Howell 2002).

The first role of a theory is to provide an explanation of observed behaviour and contribute to understanding. This is similar to the requirement by Reynolds for scientific knowledge to explain past events. As mentioned, the identification and discussions of individual components in section 5.2 provide explanations of observed behaviour and it contributes to the understanding of past events.

Koskela further states that a theory must provide a prediction of future behaviour. Similar to complying with the requirement by Reynolds, the predictive claims of TOM-P is summarised in section 5.4.

The third role of theory, according to Koskela, is to provide the basis for developing tools which can be utilised to analyse, design and control events. The relationships underlying TOM-P as defined in section 5.3 and the predictive claims presented in section 5.4 provide measurements to analyse, design and control future projects. It provides a new level of understanding to project managers on where to focus when managing time critical projects.

A theory must also provide the basis for a common language through which co-operation is enabled. The identification and isolation of the underlying components in TOM-P as described in section 5.2, provide a common language between the project manager and task owner to improve cooperation. In addition, increased cooperation contributes to the improvement of the relationship the relationship and reduce information asymmetry.

In the fourth position, Koskela defines the role of theory to give direction in identifying opportunities for further progress. Several opportunities for further progress were identified and were summarised in chapter 7.

According to Koskela, theory is instrumental in teaching. As a condensed piece of knowledge, the theory must empower novices to do the things that formerly only experts could do. TOM-P provides a concise understanding of



focused measurement and progress questions which novice project managers may utilise effectively when they manage time-critical projects.

In summary, TOM-P complies with the role requirements for theory as stated by Koskela.

### **5.6.3 Choi and Wacker**

Choi and Wacker summarised the characteristics of good theory building in the three traits of uniqueness, fecundity and integration (Choi & Wacker 2011).

Uniqueness refers to the precision of definitions of constructs under clearly delineated conceptual boundaries. The definition of constructs are summarised in section 5.2.6 and the domain limitations for application of TOM-P is delineated in section 5.4. These definitions are concise and unique.

Fecundity refers to the *richness of new areas to explore*, which are discussed in Chapter 7.

Integration conceptually connects multiple theories together for a purpose. TOM-P integrates knowledge from the project management domain (CPM, CCPM) with theories from the metrology and organisational control domains. The purpose of TOM-P and integration of knowledge domains is to improve the success of time critical projects being delivered on time.

In summary, TOM-P demonstrates the characteristics of good theory building based on the research of Choi and Wacker.

### **5.6.4 Quine and Ullian**

Quine and Ullian contribute the qualities of “good” theory, which they defined to include uniqueness, parsimony, conservation, generalizability, fecundity, internal consistency and empirical riskiness (Quine & Ullian 1980; Klemke *et al.* 1998). Each of these is briefly discussed below as well as the extent to which TOM-P complies to these qualities of good theory.

TOM-P **unique** in the understanding it provides to create differentiated measurements of task components. TOM-P supports CPM and CCPM project management by providing a unique additional theory to improve task progress measurements (during time critical projects).

**Parsimony** refers to simplicity. The fewer the assumptions and the simpler the explanation, the better the theory. TOM-P is essentially described by the difference between two equations and one boundary condition.

**Conservatism** requires that a current theory cannot be replaced unless the new theory is superior in its virtues. When a new theory is proposed there must be good reason to believe all other theories are lacking in some virtue. TOM-P conserves CPM and CCPM theories and provides additional measurement theory to improve management focus. Current theories do not provide sufficient support to successfully complete time-critical projects, and TOM-P contributes to this gap in project management knowledge.

A better theory is identified by the variety and the extent of areas that the theory can be applied to, so-called **generalisability**. The researcher has applied TOM-P in a variety of time-critical projects and industries, but no knowledge is yet documented on its application outside the domain of time critical projects.

**Fecundity** refers to the fertility of a theory. A good theory is fertile in generating new models and hypotheses. The further exploration areas are discussed in Chapter 7.

**Internal consistency** requires a theory to identify all the relationships and provide adequate explanations. Wacker writes that internal consistency means that the theory logically explains the relationship between variables. The more logically the theory explains the variables and predicts the subsequent events, the better the theory is. This internal consistency virtue means that the theory's entities and relationships must be internally compatible using symbolic logic or mathematics. This internal consistency means that the concepts and relationships are logically compatible with each other. Internal consistency of TOM-P is supported by the logical deduction

and description of the task components in section 5.2 as well as relationships described in section 5.3.

**Empirical riskiness** refers to the refutation possibility. A good theory must be refutable, and an empirical test of a theory should be risky. Popper stated that *every good theory has at least one prohibition; it prohibits certain things from happening* (Popper 1961). The essence of TOM-P is summarised into two equations. Should either of these two equations be proven incorrect, TOM-P is refuted and to be replaced by a better theory.

At some stage any theory, even “good” theories, are proven invalid and replaced by better theory. A “good” theory is easily refutable and does not lead research astray or hinders progress in scientific knowledge development (Wacker 1998), or a Popper stated: *A theory which is not refutable by any conceivable event is non-scientific. Irrefutability is not a virtue of a theory (as people often think), but a vice* (Popper 1961).

#### 5.6.5 Amundson

Theory also frames how one views a phenomenon. This cognitive framing approach was described by Amundson and involves three steps (1) specifying and defining concepts, (2) prioritising of the key concepts and (3) specifying the relationships between the main concepts (Amundson 1998).

Though seen from a different approach, these three steps are similar to the requirements stated above and TOM-P complies by defining the key concepts, defining the key relationships and describing predictive claims.

### 5.7 Conclusion

Chapter 5 summarises the development of the theory of measurement for projects.

It systematically documents the original contribution of this research and summarises its key contributions and differentiating factors from current knowledge.

TOM-P was analysed in terms of acknowledged requirements for good theory. TOM-P complies with these requirements for good theory and

provides a basis for significant improvement in on-time completion of time critical projects. The application of TOM-P and validation of each virtue is described in chapter 6.

TOM-P provides additional theory to support both conventional and critical chain project management. The additional theory, specifically applicable in time critical projects, provides for differentiated measurements of task components, to achieve significant gains in project duration.

The value of TOM-P is directly related to its ability to support project managers, who manage time critical projects, to complete these projects early.

The particular focus of this research was defined as the **early or on-time completion of time-critical projects**, i.e. where the strategy of the organisation is at stake if projects are not completed in time. Furthermore, early completion of time critical and strategic projects can be of significant monetary value to organisations and can be used as a strategic weapon in a competitive business environment. TOM-P provides theory to support project managers and organisations in managing time critical projects more successfully.

The objectives of this study were defined as (1) To establish a theory of measurement for project time measurement, and (2) To validate the theory through empirical testing.

It is held by this research that differentiated measurements of task progress, based on TOM-P, will significantly reduce project duration. This benefit of reduced project duration is specifically valuable for time-critical projects. However, talk is cheap and chapter 6 provides a summary report of a validation study utilising 84 projects to demonstrate the virtue of TOM-P.

## 6 Validation of TOM-P through empirical studies

### 6.1 Introduction

Chapter 6 reports on a validation study to evaluate whether TOM-P addresses the research problem successfully. Empirical research findings from eighteen test projects and 66 control projects case study projects were utilised to evaluate  $H_2$  in qualitative and quantitative terms. Unique progress measurement questions, based on the understanding provided by TOM-P, were implemented on the test projects and the early completion of all eighteen test projects demonstrates support for the hypotheses.

$H_2$  states that implementing a measurement methodology based on the TOM-P reduces project duration (compared to not implementing the measurement methodology based on the TOM-P).

### 6.2 Approach for validation study

The validation study was executed between 2012 and 2014 on engineering management projects. A primary selection criterion was time-critical projects with extensive current control group data.

84 similar projects were identified of which 25 projects had previously been completed. The remaining 59 projects were executed in three groups of eighteen, nineteen and 22 by three independent project teams. The project teams were co-located in geography and time. The validation case study projects are summarised in Table 6-1.

N	84 projects
Control group	Control group 1 (CG1) of 25 projects completed in the prior year to the test cases. Control group 2 (CG2) of 22 projects executed by the same team as CG1 Control group 3 (CG3) of 19 projects
Test Group	18 projects executed by the test group

Table 6-1: Summary of validation study cases

The project sponsor requested the project to be completed “as soon as possible” as they were already late in terms of their commitment to the larger project portfolio. No incentives were available for early completion while all project teams were of similar size and similar qualifications.

All three project teams were structured with a team director reporting to the sponsor. Team leaders were appointed for each project who reported to the team director. Project resources for each project reported to the team leader, as depicted in Figure 6-1.

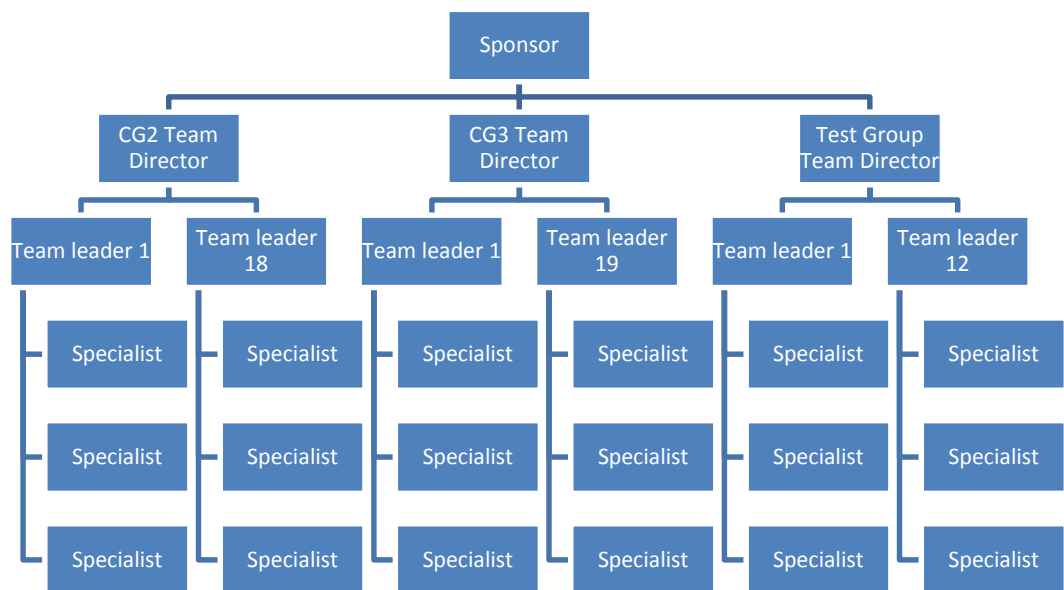


Figure 6-1: Organisational structure for project teams

Weekly progress meetings were conducted with the primary objective of “ensuring” each team will complete on the relevant due date.

### 6.3 Control group results

All control group projects were planned by utilising a Gantt chart and a standard set of project tasks (ranging from 20-40 tasks), as mandated by the sponsor. Project task progress was initially measured as percentage complete on all tasks and later reduced to a commitment to complete on the due date (“As long as you confirm you will be complete on the due date, I do not want to know how far you are today”).

Executive approval meetings were conducted approximately every month, which resulted in projects being finalised in batches. The results of the control projects are summarised below.

### **Control Group 1**

CG1 was completed in the prior year with all 25 projects completed in less than 60 weeks with an average of 57,2 weeks as presented in Table 6-2 below.

<b>Project ID</b>	<b>Group ID</b>	<b>Project duration</b>
P1	Control Group 1	54 weeks
P2	Control Group 1	54 weeks
P3	Control Group 1	54 weeks
P4	Control Group 1	54 weeks
P5	Control Group 1	54 weeks
P6	Control Group 1	54 weeks
P7	Control Group 1	54 weeks
P8	Control Group 1	54 weeks
P9	Control Group 1	54 weeks
P10	Control Group 1	59 weeks
P11	Control Group 1	59 weeks
P12	Control Group 1	59 weeks
P13	Control Group 1	59 weeks
P14	Control Group 1	59 weeks
P15	Control Group 1	59 weeks
P16	Control Group 1	59 weeks
P17	Control Group 1	59 weeks
P18	Control Group 1	59 weeks
P19	Control Group 1	59 weeks
P20	Control Group 1	59 weeks
P21	Control Group 1	59 weeks
P22	Control Group 1	59 weeks
P23	Control Group 1	59 weeks
P24	Control Group 1	59 weeks
P25	Control Group 1	59 weeks

Table 6-2: Validation study Control group 1 data

## Control Group 2

CG2 was executed by the same resource and management team as CG1, concurrent to the execution of CG3 and the test projects. The 22 projects were completed in an average duration of 38,4 weeks as presented in Table 6-3 below.

Project ID	Group ID	Project duration
P26	Control Group 2	37 weeks
P27	Control Group 2	37 weeks
P28	Control Group 2	37 weeks
P29	Control Group 2	37 weeks
P30	Control Group 2	37 weeks
P31	Control Group 2	37 weeks
P32	Control Group 2	37 weeks
P33	Control Group 2	37 weeks
P34	Control Group 2	37 weeks
P35	Control Group 2	37 weeks
P36	Control Group 2	37 weeks
P37	Control Group 2	37 weeks
P38	Control Group 2	37 weeks
P39	Control Group 2	37 weeks
P40	Control Group 2	37 weeks
P41	Control Group 2	37 weeks
P42	Control Group 2	42 weeks
P43	Control Group 2	42 weeks
P44	Control Group 2	42 weeks
P45	Control Group 2	42 weeks
P46	Control Group 2	42 weeks
P47	Control Group 2	42 weeks

Table 6-3: Validation study Control group 2 data



### **Control Group 3**

CG3 was executed by a separate independent team. The nineteen projects were completed in durations ranging from 60 to 85 weeks, with an average of 70,3 weeks as presented in Table 6-4 below.

<b>Project ID</b>	<b>Group ID</b>	<b>Project duration</b>
P48	Control Group 3	60 weeks
P49	Control Group 3	60 weeks
P50	Control Group 3	60 weeks
P51	Control Group 3	60 weeks
P52	Control Group 3	60 weeks
P53	Control Group 3	60 weeks
P54	Control Group 3	72 weeks
P55	Control Group 3	72 weeks
P56	Control Group 3	72 weeks
P57	Control Group 3	72 weeks
P58	Control Group 3	72 weeks
P59	Control Group 3	72 weeks
P60	Control Group 3	72 weeks
P61	Control Group 3	72 weeks
P62	Control Group 3	72 weeks
P63	Control Group 3	72 weeks
P64	Control Group 3	85 weeks
P65	Control Group 3	85 weeks
P66	Control Group 3	85 weeks

**Table 6-4: Validation study Control group 3 data**

The combined results of all control group projects are presented in Figure 6-2

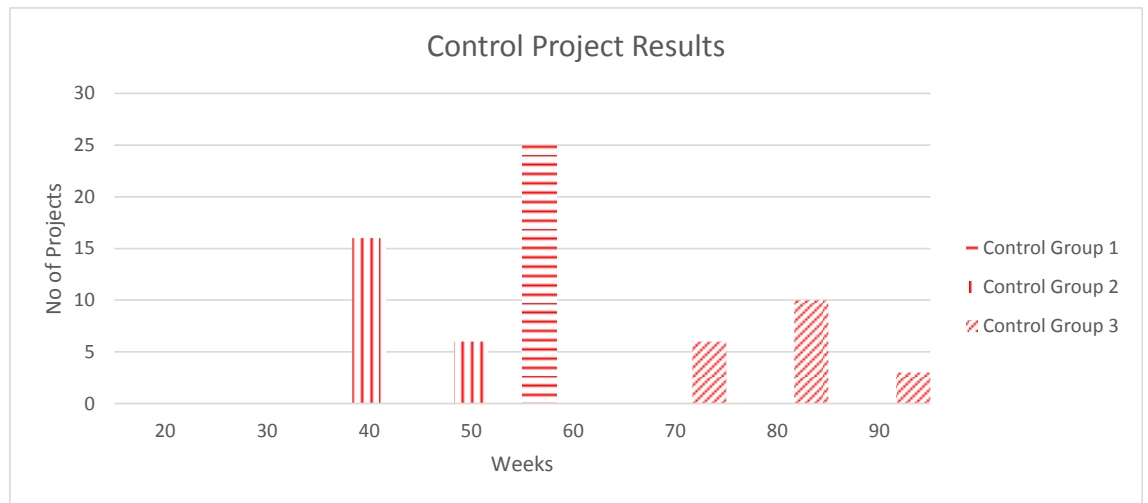


Figure 6-2: Control group results

The timeline underlying Figure 6-2 provides additional information.

- CG1 was executed first, with an average of 57,2 weeks.
- CG2 followed, utilising the same resource team as CG1, which reduced the average duration from 57,2 weeks to 38,4 weeks. The team attributed this reduction to the benefits achieved from the learning curve of CG1.
- The resource team delivering CG3 was new and did not have the benefit of any prior learning curve. CG2 and CG3 started at the same time.
- The average of 70,3 weeks achieved by CG3 was investigated but no significant difference in terms of difficulty or scope of work could be observed between the three sets of control projects.
- The team from CG1 made the comment that the average of about 70 weeks was no surprise to them, as it coincided with their pre-learning curve expectations.

## 6.4 Measurement methodology for the test projects

The test projects were planned utilising only a logic network. The series of preceding and succeeding tasks were mapped visually on a wall and no dates were allocated to task start or completion. Combined daily project progress meetings were conducted with all test project teams. The progress meetings focused on the project progress measurements designed from the understanding provided by TOM-P.

The measurements are summarised as follows:

### *Measurement of $\gamma$ -time*

“What information or resources do you need to eliminate delays on your task and to enable early handover?”

From when should the succeeding task be ready to receive an early handover? (No commitment is required, this is just an early warning system). This question is similar to the utilisation of remaining duration by CCPM.

No commitments for completion dates were requested or measured, nor any estimates of percentage complete.

For the case study purpose, there was specifically no attention or measurement to expedite  $\gamma$ . This includes any demands or measurements to design faster, build faster or asking teams to work harder.

### *Measurement of $\lambda$ and $\phi$ -time*

The daily project progress meetings endeavoured to remove multi-tasking and by focusing on  $\gamma$ -time progress daily, the occurrence of student syndrome was limited to units of hours.

By involving both preceding and succeeding task managers in the daily meeting, handover delays were limited, through the progress question to the succeeding task manager: “What is the minimum still to be done before you will accept handover?”

With no committed dates to comply with and the progress question related to handover as stated above, Parkinson-related delays were all but eliminated.

### ***Measurement of $\alpha$ -time***

TOM-P provides guidance for a measurement of  $\alpha$ -time through the trade-off surfaced in the difference between the two equations:

$$D_i = \lambda_i + \gamma_i + \varphi_i \quad (\text{Equation 1})$$

$$D_i = f(\lambda_i, \gamma_i, \varphi_i, \alpha_i, \beta_i) \quad (\text{Equation 2})$$

The following progress measurement for  $\alpha$ -time was implemented in the test projects: “What additional work can you do during preparation time ( $\alpha$ -time) which will reduce  $\gamma$ -time?”

Only in a very few cases was it necessary to execute a cost-benefit study to evaluate whether the trade-off benefit was positive.

### ***Measurement of $\beta$ -time***

Measurement of  $\beta$ -time was focused on the widespread absorption of lessons learnt by the project teams, driven by the daily progress question: “How would anyone do something similar faster next time?”

In addition,  $\beta$  provides an opportunity to reduce  $\gamma$ -time through the progress question: “What can be transferred to  $\beta$  to reduce  $\gamma$  and enable early handover?”

## 6.5 Results from test projects

The set of eighteen test-case projects was completed in two series.

Series 1 comprised thirteen projects and was completed in two batches. The first batch was completed in week 23 and the second batch was completed in week 28, with an average of 24,9 weeks for the test group.

Series 2 was executed as an extension of the original contracted assignment, and the five projects were completed in ten weeks.

The results of the eighteen test projects are presented in Figure 6-3 on the same x-axis scale as the control group projects.

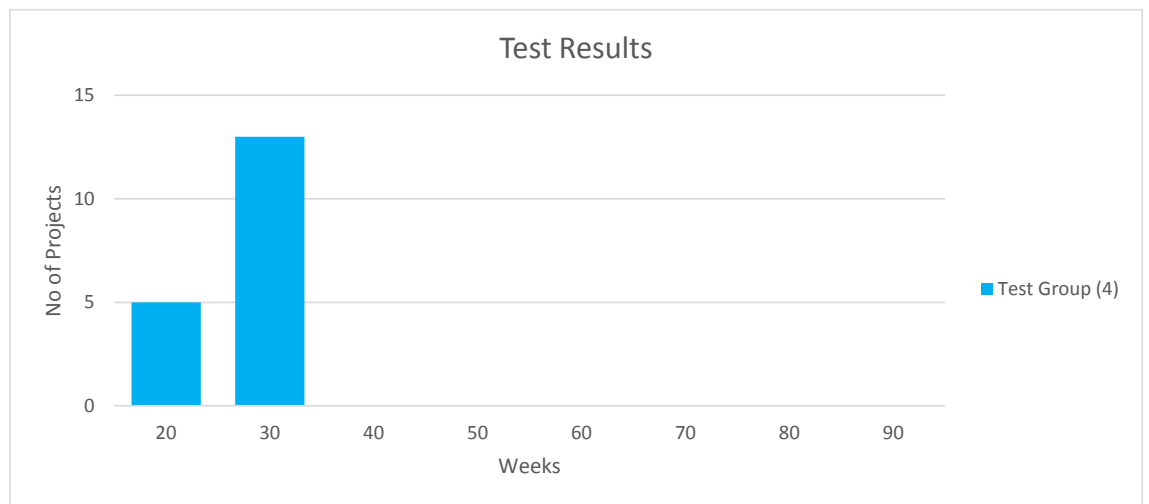


Figure 6-3: Test project results

The results for the validation study test projects are presented in Table 6-5.

<b>Project ID</b>	<b>Group ID</b>	<b>Project duration</b>
P67	Test Group	23 weeks
P68	Test Group	23 weeks
P69	Test Group	23 weeks
P70	Test Group	23 weeks
P71	Test Group	23 weeks
P72	Test Group	23 weeks
P73	Test Group	23 weeks
P74	Test Group	23 weeks
P75	Test Group	28 weeks
P76	Test Group	28 weeks
P77	Test Group	28 weeks
P78	Test Group	28 weeks
P79	Test Group	28 weeks
P80	Test Group	10 weeks
P81	Test Group	10 weeks
P82	Test Group	10 weeks
P83	Test Group	10 weeks
P84	Test Group	10 weeks

Table 6-5: Validation study Test project results

## 6.6 Analysis of validation study results to evaluate $H_1$

### 6.6.1 Summary of results

The results of the validation study are presented in Figure 6-4 and summarised in Table 6-6.

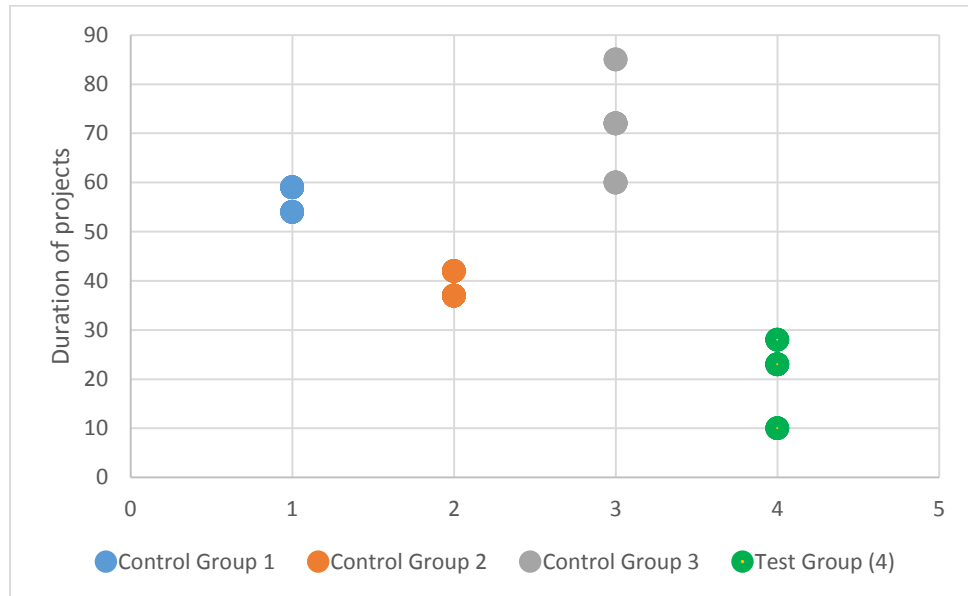


Figure 6-4 Results of validation study

	Control Projects summary	Control Group 1	Control Group 2	Control Group 3	Test projects	Total
<b>n</b>	66	25	22	19	18	84
<b>Mean</b>	54,7	57,2	38,4	70,3	24,9	47,4
<b>Sdev</b>	13,6	2,4	2,2	8,3	7,0	18,7

Table 6-6: Summary of statistical data from validation study

The average duration of the test projects (24,9 weeks) in comparison with the average control project duration (54,7 weeks) also demonstrates initial support for  $H_2$

### 6.6.2 Evaluation of association

The correlation analysis of the test and control project data utilised the same statistical process as the scoping study to accommodate the combination of quantitative and nominal results data. The point-biserial correlation coefficient is a special case of Pearson in which one variable is quantitative and the other nominal.

The point-biserial correlation coefficient was calculated as  $r_{pb} = 0,74$  with  $t = -10,1$  (degrees of freedom = 82) (P two-tailed  $< 1 \times 10^{-4}$ )

Hypothesis  $H_1$ , stating that there is an association between project task time measurement methodology and project duration, was supported.

### 6.6.3 Evaluation of independence

The Pearson's Chi-square test for independence analyses categorised data and evaluates the null hypothesis. For the purposes of the Chi-square test, the data from the validation study are categorised as detailed in Table 6-7.

	Control Projects	Test Projects
Duration longer than 30 weeks	66 Projects	0 projects
Duration shorter than 30 weeks	0 projects	18 projects

Table 6-7: Data from validation study categorised for Chi-square test

From the data above, the Chi-square statistic was calculated as  $\chi^2 = 84$ .

The probability of independence, the P-value, was calculated to be  $P = 0$  at confidence level  $p < 0.01$  which strongly supported the rejection of the null hypothesis.

However, as previously noted during the analysis of the scoping study, the chi-square test was challenged when the data sample included small frequencies (e.g.  $< 5$ ) and additional tests were performed.

The effect size  $w = \sqrt{\frac{\chi^2}{n}}$ , where  $\chi^2$  is the Chi-square statistic and  $n$  the sample size was calculated. For the validation study  $\chi^2 = 84$  and  $n=84$ , resulting in  $w = 1$ .



The Yates correction is calculated to be  $\chi^2_{Yates} = 80$  and the Fisher exact test produces a result of  $P < 10^{-3}$ , both supporting the conclusion from the Chi-squared test, that the null hypothesis, which states that there is no correlation between MM and project duration, is rejected.

Utilising the paired t-test statistical evaluation, the two-tailed P value  $< 10^{-3}$ , ( $t=10$  and  $df=82$ ) supporting the previous results that the difference between the control projects and the test projects is statistically significant.

*In summary hypothesis  $H_1$  was supported and the null hypothesis  $H_{1.0}$  was rejected*

## **6.7 Evaluation of $H_2$**

$H_2$  was stated as: Implementing a measurement methodology based on the TOM-P reduces project duration (compared to not implementing the measurement methodology based on the TOM-P).

The correlation of 0.79 during the scoping study and the correlation of 0.74 during the validation study did not provide motivation to accept the  $H_2$ . Correlation does not prove causality.

Two approaches are presented below to justify the acceptance of  $H_2$ , being (1) Hill's criteria for causation and (2) logical elimination of confounding factors.

### **6.7.1 Hill's criteria for causation**

Sir Bradford Hill defined eight criteria to consider when evaluating whether a particular relationship is due to causation (Hill 1965). Hill proposed these conditions in the context of medical science, though his criteria have found wide application in social sciences. Considering organisational control as a component of project management, the utilisation of Hill's criteria is justified in this research. The criteria list is summarised as (1) strength, (2) consistency, (3) specificity, (4) temporality, (5) biological gradient, (6) plausibility, (7) coherence, (8) experiment and (9) analogy. These criteria are further discussed with reference to the validation study.

Hill lists the strength of the association as primary parameter and suggests that a stronger correlation provides an increased indication of causality.

- With the correlation of MM to project duration at 0.79 and 0.74 from the scoping and validation studies respectively, substantial support for causality is indicated. The strength of correlation is however not sufficient.

When a relationship is repeatedly observed under different circumstances and at different times, potential causality is indicated. Consistency further relates to the definition of causality by *Oxford Dictionary* as the “**universal** operation of cause and effect as a belief”.

- The results from the application of TOM-P is consistent between the scoping study and the validation study. These two studies were executed by different teams, in different industries and different decades, leading to further support for causality between MM and project duration.
- These limited case studies, however, do not prove universality and further research is required.

If the association between parameters is limited to specific instances and there is no other association, the argument favours causation. Hill also notes that the importance of specificity should not be over-emphasised. Specificity is also visible when the magnitude of the independent variable is changed, and a corresponding variance is observed in the dependent parameter when all external parameters are constant. It is usually difficult to isolate experiments to single variables and *if specificity exists we may be able to draw conclusions without hesitation, if it is not apparent, we are not necessarily left sitting irresolutely on the fence.*

- It is difficult to deduce specificity unambiguously when MM cannot be “increased” to evaluate a commensurate change in project duration. In addition, the case studies for both the scoping study and the validation study were executed in the

real life organisations.

Fortunately, further criteria can be utilised to evaluate causality.

Temporality considers time. The cause must precede the result.

- Measurement precede control according to the cybernetic control model, and therefore the deduction is made that measurement effects precede control effects.

Biological gradient refers to the dose-response relationship. If increased doses result in improved responses, further support for causality can be inferred. Hill states that *the difficulty is often to secure some satisfactory quantitative measure of the environment which will permit us to explore this dose response.*

- In the project management domain, particularly considering the measurement methodology, it is difficult to evaluate an “increased” application of MM.

The relationship under investigation should be plausible from current scientific knowledge. There needs to be a theoretical basis for postulating the causal relationship.

- The plausibility of the how MM contributes to reducing project duration is fully described in the development of TOM-P, through the definition of concepts and relationships. The description of TOM-P utilises the combination of the existing equation 1 combined with the new equation 2 to demonstrate how differentiated measurements contribute to reducing project duration.

The cause-and-effect interpretation should not seriously conflict with the generally known facts and should be compatible with existing theory and knowledge.

- Both plausibility and coherence rely on compatibility with existing scientific knowledge. Galileo’s view of the solar system

was neither plausible nor coherent with current knowledge of the day.

- A reduced version of coherence is defined by stating that the causal relationship must be plausibly explicable when utilising existing knowledge.
- The causal relationship between MM and project duration postulated by TOM-P is explained utilising current project management knowledge and the detail descriptions of concepts and relationships is coherent with existing project management knowledge.

Hill states that experimental results potentially reveal the strongest support for any causation hypothesis. Experiments should be designed to identify the effect with and without the independent parameter, or control groups can be utilised.

- The scoping study and the validation study provide extensive experimental results which demonstrate the effect of executing projects with and without the implementation of new MM based on TOM-P.
- Section 6.7.2 further discusses the structured exclusion of confounding parameters during the validation study.

The analogy criteria relate to the consideration of similar factors, especially the consideration of alternative explanations or the existence of confounding parameters.

- The research design attempted to identify and neutralise confounding parameters by e.g. conducting control and test projects concurrently. Further details are described in the sections 6.7.2 and 6.8.

## Summary

Hill added that even though these nine criteria could indicate causation, it could not prove it. Several researchers subsequently contributed to Hill's disclaimer that the criteria are insufficient to deduce causation (Phillips & Goodman 2006; Höfler 2005). Logical deduction, experimental exclusion of confounding variables and the demonstration of common sense is required to motivate a causal relationship.

### 6.7.2 Logical elimination of confounding factors

The existence of confounding factors challenges the validity of research and integrity of conclusions. To evaluate  $H_2$ , the measures implemented during experimental design as well as the post-facto verification processes, must be documented and evaluated.

Verification is the process of checking, confirming, making sure, and being certain. In qualitative research, verification refers to the mechanisms used during the process of research to incrementally contribute to ensuring reliability and validity and, thus, the rigour of a study (Morse *et al.* 2008).

The challenges to reliability and validity require the systematic identification and exclusion of confounding parameters. The categorisation of confounding parameters into four groups follows the research lead by Campbell and Yin (Campbell *et al.* 1963; Yin 2013).

- Group 1 relates to factors where the lapse of time is relevant.
- Group 2 refers to factors where selection impacts validity.
- Group 3 relates to factors significantly influenced by individual perceptions and changes in human performance during the experiment.

#### 6.7.2.1 Confounding parameters related to the lapse of time

Time lapse might impact reliability and experimental rigour as external events that occur between the first and the second measurement might influence the result.

- The experimental design for the validation study included the utilisation of concurrent case studies for control projects and test projects, which is in contrast to the scoping study where sequential projects were utilised.
- The potential of external influences changing over time and influencing the results was reconsidered on the completion of the scoping study. Experimental design therefore excluded the lapse of time as confounding parameter during the validation study. The results of the scoping study and the validation study were similar, and it is deduced that the lapse of time did not have an effect on the results of the scoping study.

Maturation can impact empirical results. It refers to processes that change as a function of time. Where the experimental duration is a few years, most participants would probably change performance regardless of treatment.

- The scoping study was conducted over three years and the validation study was completed in less than two years.
- An improvement of performance was observed during the experimental procedures, which is expected to have reduced the margin between test and control groups to a limited degree.
- The experimental design for the validation study utilised concurrent test and control projects to eliminate the effect of maturation. It is deduced that maturation did not influence the validation study.

Multiple testing can impact empirical results, as prior knowledge of evaluation questions could influence test results.

- The experimental design required participants to have prior knowledge of the measurement methodology as well as the outcome to be measured (i.e. project duration and on-time completion of the project). Furthermore, this research utilised only quantitative experimental results (project duration). The quantitative results were isolated from any influence by prior

knowledge of evaluation questions. It is deduced that multiple testing did not influence the validation study.

Mortality refers to the loss of test subjects during the experiment that may impact the results, e.g. “Those who stayed in the project all the way to the end may be more motivated to learn and thus achieved higher performance.”

- The experimental design for this research did not include mortality. The design of the project execution environment also did not include an opt-out option. All projects were completed and it is deduced that mortality did not have an effect on the scoping study or the validation study.

#### 6.7.2.2 **Confounding factors related to selection parameters**

When instruments or observers change during experiments, it might impact the results.

- With experiments of this size, it is inevitable that observers will change during the study. Due to several projects being executed in parallel, multiple observers had to contribute to the study. The experimental design targeted outcomes measurements which would be largely independent of instrument and observer. The primary outcomes measurement utilised was on-time completion of the project, quantified as the number of days early or late. This standardised instrument limited the subjectivity of observers to influence empirical results. Relative objectivity was therefore achieved through design rigour and it is deduced that neither changing instruments nor observers influenced project results.

If the selection of test subjects for either the test group or the control group is not randomised, the selection process can jeopardise the reliability of results.

- The experimental design for both the scoping study and validation study utilised a third party, the respective project sponsors, to allocate the projects.

- For the scoping study, the selection of test projects were announced, but for the validation study, the experimental design utilised a blind allocation of test projects.
- In both studies, project resource teams were allocated post identification and allocation of projects.
- In addition, due to all 84 projects in the validation study being similar in nature and 66 projects used as control group, the pseudo-random allocation and large control group supports reliability.

Regression is caused by selecting test subjects on the basis of extreme scores, e.g. any four worst projects will show improvement after treatment.

- The scoping study provided initial support for this research and was potentially subject to the influence of extreme results due to the small sample.
- The experimental design for the validation study therefore required a larger sample of both test and control projects.
- The relatively large sample size of eighteen test projects and 66 control projects, which were independently allocated, provides some assurance that project groups were not selected based on any levels of extreme difficulty. The blind allocation of projects and project resources further reduced the potential influence of extreme poor performance or unique level of skills.

### 6.7.2.3 **Confounding parameters related to perceptions**

Factors influenced by individual perceptions or changes in human performance during the experiment can influence experimental results and challenge the validity of conclusions.

The John Henry effect is one such influence. It refers to situations where a control group unexpectedly outperforms the test group (Saretsky 1972). John Henry was a drill operator who outperformed a machine under an



experimental setting because he was aware that his performance was compared with that of a machine. (He unfortunately also died afterwards due to exhaustion.)

- The experimental design included limited monitoring of control projects during the scoping study. Due to the co-location of test and control projects during the validation study, extensive monitoring of control projects was possible.
- No change in performance was observed during the scoping study and although limited diffusion was observed during the validation study, the changes did not materialise into significant effects. The diffusion also resulted from the competitive nature of teams when co-located and working on similar projects.
- The observation of only marginal diffusion was unexpected. In the context of time-critical projects, and significant strategic importance was attached to on-time completion by a project team. For the project team then to maintain operational processes which proved less effective than available and visible alternatives, is “interesting” (and requires further research on the diffusion of improvement methodologies).
- It is deduced that the John Henry effect did not influence the validation study results.

Where participants behave differently simply due to them being included in a study, it is referred to as the Hawthorne effect (Howard 1982). This refers to a classic study at the Hawthorne Western Electric company plant in Illinois, USA where workers improved their output regardless of the working and lighting conditions.

- Adapting the experimental design for the scoping study to structurally exclude the Hawthorne effect was one of the most difficult to address. By utilising different management and resource teams on the various test projects and initial random allocation of test projects, attempts were made to address the

Hawthorne effect. There is, however, no significant support that this effect was eliminated.

- The experimental design for the validation study was therefore adjusted to further address the Hawthorne effect. The relatively large sample size and blind allocation of test projects, resources and teams contributed to reducing the influence of this effect. Interim results of project progress obviously demonstrated significant variances in team performance, making visible the allocation of test projects and eliminating the benefit of blind allocation. Reliance is therefore significantly on the large sample size to reduce the potential Hawthorne effect during the validation study.
- The Hawthorne effect had a secondary impact on the results. The last five test projects, which were completed in ten weeks, were executed by the “best” team. The results are expected to include some influence from the Hawthorne effect.

In test and control groups where incentives differ, the compensatory rivalry may cause additional effort from the team who perceives to receive more advantageous treatment. As a result, performance might be impacted by additional effort, rather than by the independent variable (or demoralisation could impact the alternate group).

- The experimental design for the scoping study included projects where large groups of people were involved (>1000). Movement of personnel between projects could not feasibly be stopped or excluded. However, all participants were subject to standard employment and incentive regulations, and no differentiation existed between test and control projects.
- During the validation study, teams were on different remuneration scales, but no incentive system was available to the test team and no differentiated effort was expected or observed.

- As mentioned, the last five test projects are suspected to have received additional effort from the project team due to their nomination as “best” team. The incentives were not monetary, but the recognition as “best” team and expectations of excellent performance undoubtedly boosted performance. Fortunately, the margin between test and control projects is sufficiently large to negate the exceptional performance of the last five test projects.

The Rosenthal or Pygmalion effect refers to cases where researcher expectations influence the participant's behaviour (a type of self-fulfilling prophecy.)

- The researcher was obviously biased based on prior successful results and involvement in this research.
- The experimental design for the scoping study therefore deliberately utilised both different project teams and project sites. In addition, the researcher was not full-time involved nor part of the management team, enabling relative independent execution from researcher bias.
- The researcher was involved with the validation projects and reliance to reduce the Pygmalion effect vested in the relatively large number of test projects
- The researcher had limited interaction with the test team executing the last five test projects.

Response shift bias refers to experiments where the experiment influences the participant's awareness and perception of a measured attribute.

- The experimental design for both the scoping study and validation study included initiatives to influence the participants' perception and behaviour related to on-time completion of projects.

- However, participant perceptions were not evaluated and only quantitative results were utilised to assess outcomes.

### 6.7.3 Summary on $H_2$

The summary presented above demonstrates the significant attention given to experimental design in order to eliminate or reduce potential confounding parameters.

It is acknowledged that the presentation and analyses in the sections above do not prove causality. However, by removing all known possible confounding parameters, and by complying with Hill's criteria, support for the causal relationship is strengthened.

$H_2$  was stated as: Implementing a measurement methodology based on the TOM-P reduces project duration (compared to not implementing the measurement methodology based on the TOM-P).

$H_{2,0}$  was stated as: Implementing a measurement methodology based on the TOM-P *does not* reduce project duration.

From the analysis above, it is resolved that the validation study results supported  $H_2$  and rejected  $H_{2,0}$

## 6.8 Validity and reliability of research

*Without rigor, research is worthless, becomes fiction and loses its utility.* (Morse *et al.* 2008). Verification, therefore, needs to confirm the rigour, providing assurance of data and process integrity. Verification was defined by Morse as the mechanisms used during research *to incrementally contribute to ensuring reliability and validity and, thus, the rigour of a study* (Morse *et al.* 2008).

The reference to “incrementally” refers to Morse’s view that qualitative research is more of an iterative nature, rather than linear. *A good qualitative researcher moves back and forth between design and implementation to ensure congruence among question formulation, literature, recruitment, data collection strategies, and analysis* (Morse *et al.* 2008).

The incremental approach utilised in this research is demonstrated by the experimental design that included first a scoping study and later the validation study, modelled on the Wallace process (refer to Chapter 3 for details).

The detailed description of the experimental design in Chapter 3 provides a background to the rigour of this research. The reliability and validity of the research are further supported by the extensive attention to addressing potential confounding parameters during the design and execution of the validation study, as presented in section 6.7.2.

Morse contributes extensively to the importance of designing for reliability and validity, rather than strategies for evaluating trustworthiness and utility which are implemented once a study is completed (Morse *et al.* 2008). This research followed the recommendation of Morse as far as possible, though unexpected events in the context of real-life projects required research responsiveness and flexibility.

The four criteria commonly used to assess the validity and reliability of case study research are primarily (1) internal validity and (2) construct validity and secondly (3) external validity and (4) reliability (Campbell *et al.* 1963; Gibbert *et al.* 2008; Gibbert & Ruigrok 2010). In order to motivate the validity and reliability of this research, these four criteria are discussed in the following sections, with references to sections in this document rather than duplication of content.

### **6.8.1 Internal validity**

Internal validity or logical validity refers to the causal relationship between variables and results (Cook & Campbell 1979; Yin 2013; Gibbert *et al.* 2008; Gibbert & Ruigrok 2010). The requirement is that sufficiently plausible and logical reasoning is presented to defend the research conclusions. Silverman describes “anecdotalism” when selecting a few well-chosen samples (Silverman 2013), in contrast to a critical investigation of all data. This is aligned with Popper’s process to systematically falsify alternative explanations and to exclude spurious correlations and confounding parameters (Popper 1961).

Three strategies to ensure internal validity was suggested, viz. a well-designed research framework, analogy and triangulation.

A **research framework** should be designed to demonstrate the logical deduction of the dependent variable from the independent variable, and not a confounding or spurious third variable (Gibbert & Ruigrok 2010). Yin supplements this view by considering to what extent the research framework was explicitly based on academic research, and detailed descriptions used to explain the relationships between variables and results.

- This research utilised a research framework, modelled on the Wallace process, as described in Chapter 3.
- The identification and systematic elimination of confounding variables were described in section 6.7.2.

Utilising analogy, research data should be compared with predicted patterns or prior research.

- Significant prior research of project success, and specifically the late completion of projects, is available and referenced in chapters 1 and 2.
- The difference between touch time and task duration is discussed in CCPM documentation, but no quantitative indications or empirical results could be sourced. There is limited academic research literature on the implementation of CCPM (Steyn 2002; McKay & Morton 1998).
- Previous research (Liou & Borcharding 1986; Thomas 2000) aligns with the results of the scoping study and the validation study.

Triangulation requires the researcher to compare results from multiple sources and perspectives. Multiple datasets contribute significantly towards reliability. Gibbert writes “*authors are encouraged to report different theoretical lenses and bodies of literature used, either as research*

frameworks to guide data gathering and analysis or as means to interpret finding” (Gibbert & Ruigrok 2010)

- The experimental design of the scoping study utilised five separate projects that contributed significant value for inter-project comparisons as well as intra-project comparisons. Further investigations and further empirical results were required during the scoping study after project B4 was unexpectedly completed late.
- The definition of theoretical concepts in section 5.2 was developed using existing project management knowledge and terminology.
- The most extensive triangulation of results was available from the validation study where eighteen different case studies were evaluated.
- The results of the scoping study and the results from the validation study were also consistent as discussed in section 6.6.
- The validity of the research findings was further enhanced by the consistency between the correlation results from the scoping study and the validation study (refer Table 6-8).

<b>Association of MM and project duration</b>	<b>Scoping study</b>	<b>Validation study</b>
$r_{pb}$	0,79	0,74
t	3,82	10,1
df	9	82
P two-tailed	$4 \times 10^{-3}$	$<1 \times 10^{-4}$
Effect size $w$	0,83	1

Table 6-8: Summary of results to demonstrate consistency

- The evaluation of independence utilising the data from the two studies, which supports the rejection of the null hypothesis, also presented similar confidence levels in the rejecting the null hypothesis (refer Table 6-9).

Evaluation of independence	Scoping study	Validation study
$\chi^2$	7,5	84
P	$6 \times 10^{-3}$	0
p	<0.01	<0.01
$\chi^2_{Yates}$	5	80

Table 6-9: Summary of independence test results

### 6.8.2 Construct validity

Construct validity refers to the extent to which a study investigates what it claims to investigate and particularly the experimental procedure to collect data rather than using subjective judgements. Data triangulation as well as a clearly defined experimental procedure, which allows the reader to reconstruct the research process, supports construct validity (Gibbert & Ruigrok 2010; Yin 2013).

- This research addresses time-critical projects and measurement theory to improve the on-time completion of projects. In order not to rely on subjective judgements, the research specifically utilised project duration as an objective parameter for project success, rather than questionnaires to capture the subject of views of project role players.
- Data triangulation between projects, case studies, prior research and an independent survey was presented in section 6.8.1 above.
- The experimental design was presented in Chapter 3. Further clarification for the scoping study was presented in Chapter 4 and in Chapter 6 for the validation study. These details provide support to reconstruct this research in a different context.



### 6.8.3 External validity

*“External validity or generalisability is grounded in the intuitive belief that theories must be shown to account for phenomena not only in the setting in which they are studied, but also in other settings”* (Gibbert & Ruigrok 2010).

In this research, case studies are utilised and Yin notes that neither single nor multiple case studies allow for statistical generalisation to the broader population (Yin 2013). However, this does not mean that case studies do not support generalizability or external validity. Generalisation can extend on a statistical basis or, as methodologists hold, generalisation from empirical observations to theory rather than a population (Yin 2013). Case studies can be a starting point for theory development and Eisenhardt suggests that a cross-case analysis involving four to ten case studies may provide a good basis for analytical generalisation (Eisenhardt 1989b). The Eisenhardt cross-case analysis approach provides the basis for generalisation utilised in this research.

Threats to external validity compromise our confidence in stating whether the study’s results apply to other environments. Factors that jeopardise external validity include:

Interaction effects of selection biases and the experimental treatment or variable, for example, when some selection factor interacts with the experimental treatment in a way that would not be the case if the groups were randomly selected.

- The experimental design of the scoping study included the allocation of the projects by the project owner, independent of the researcher.
- No interaction effect was observed in the scoping study, but in a further attempt to reduce the possible existence of any interaction effects, the validation study utilised a blind allocation process for projects and resources.

Reactive effects of experimental arrangements are also considered. It would be difficult to generalise to non-experimental settings if the effect was attributable to the experimental arrangement of the research.

- The experimental design for both the scoping study and the validation study utilised real-life case studies as a research platform, limiting the potential reactive effects of experimental arrangements.

The Hawthorne effect is an effect that is due simply to the fact that subjects know that they are participating in an experiment.

- Discussed in detail in section 6.7.2.3

Multiple-treatment interference: When the same subjects receive two or more treatments, there may be a carryover effect between treatments such that the results cannot be generalised to single treatments.

- Discussed in detail in section 6.7.2.1

#### **6.8.4 Reliability**

Reliability refers to the absence of random error which enables the reader to conclude with the same insights, should they conduct a similar study (Gibbert & Ruigrok 2010). Silverman also refers to “*low-interference descriptors*” for data entities and results (Silverman 2013) as the inevitable existence of researcher bias can challenge the reliability of research findings.

- As mentioned previously, the experimental design for both the scoping study and the validation study utilised objective variables as data entities for research.
- Project duration is a low interference descriptor as proposed by Silverman and MM was a binary parameter. Either the new measurement theory was utilised or not, leaving limited opportunity for subjective bias when recording data points.

## 6.9 Conclusion from validation study

The validation study evaluated  $H_1$  and  $H_2$  utilising 84 similar projects, of which 66 were control projects and 18 test projects.

### $H_1$

$H_1$  : There is an association between project task time measurement methodology and project duration.

$H_1$  was supported by a correlation coefficient of  $r_{pb} = 0,74$  and an effect size of  $w = 1$ .  $H_{1,0}$  was rejected at a statistical significance level of  $< 10^{-3}$ .

### $H_2$

$H_2$  : Implementing a measurement methodology based on the TOM-P reduces project duration (compared to not implementing the measurement methodology based on the TOM-P).

Extensive descriptions were provided to demonstrate how confounding parameters were considered and eliminated during the design and execution of the validation study.

From the research data available  $H_2$  was supported and the null hypothesis  $H_{2,0}$  rejected.

Significant attention was given to research rigour during the design and execution phases to support the reliability and validity of research findings. The detail on how this research addressed internal validity, construct validity, external validity and reliability was presented, based on acknowledged academic literature.

In conclusion, the validation study successfully demonstrated the validity of the theory as well as the value to managing time-critical projects, leading to the conclusion of the study.

## 7 Conclusion

Projects and project management are fundamental to human and business activity. Both strategy and strategic benefits are delivered through the successful implementation of projects.

With project success this important, it is unfortunate that project success is not as consistent as one would prefer. The alarming statistics on project success, as well as many high-profile project failures, cause significant concern. Steyn agrees that "*the implications of overspending ... and late delivery ... can hardly be overemphasised*" (Steyn 2009).

Several authors are criticising the traditional approach to project management. The assumption of predictability, which in turn over-emphasises planning, is ineffective for managing dynamic projects with high levels of complexity and uncertainty (Kapsali 2013; Söderlund 2004; Sebaux *et al.* 2011; Cullen & Parker 2015)

### 7.1 Thesis

This research focused on time-critical projects, i.e. where the strategy of the organisation is at stake if projects are not completed in time. Execution management (specifically improvements in measurement) is addressed in preference to improvements in planning and estimation accuracy.

The objectives of this study were to develop a theory of measurement for project time measurement and to validate the theory through empirical testing.

Two hypotheses were postulated to evaluate the empirical findings.

**$H_1$**  : There is an association between project task time measurement methodology and project duration, with corresponding  **$H_{1,0}$**  that there is no association between project task time measurement methodology and project duration.

**$H_2$**  : Implementing a measurement methodology based on the TOM-P reduces project duration (compared to not implementing the measurement

methodology based on the TOM-P) and null hypothesis  $H_{2,0}$  : Implementing a measurement methodology based on the TOM-P *does not* reduce project duration.

## 7.2 Achievement of research objectives

The theory of measurement for projects was developed and the experimental design was modelled on the Wallace process for theory building. The scoping study was executed to support conceptualisation and to evaluate the viability of the theory.

The theory of measurement for projects was shown to comply with the four basic requirements for a theory: (1) definitions of concepts, (2) definition of domain and limitations, (3) definitions of key relationships, and (4) predictive claims. TOM-P was also evaluated in terms of the requirements for scientific knowledge and theory building as documented in the academic literature (Reynolds 1976; Koskela & Howell 2002; Choi & Wacker 2011; Quine & Ullian 1980; Amundson 1998).

The validation study was executed to evaluate the two hypotheses. A portfolio of 84 engineering management projects was selected for the validation study with eighteen test projects and 66 control projects.

The findings from the validation study were consistent with the results of the scoping study. A significant correlation between measurement methodology and project duration was reported. Scoping Study  $r_{pb} = 0,79$  and Validation Study  $r_{pb} = 0,74$ . In both cases the null hypothesis was rejected at a statistical significance level of  $< 10^{-3}$ .

To support the evaluation of  $H_2$ , acknowledged criteria Hill's criteria for causation were referenced and extensive descriptions were provided to demonstrate how confounding parameters were considered and eliminated.

Significant attention was given to research rigour during the design and execution phases to support the reliability and validity of research findings. Internal validity, construct validity, external validity and reliability were addressed based on acknowledged academic literature.

### 7.3 Original contribution

TOM-P and this research contribute a unique understanding of the effect of project measurements on project success, specifically the measurement of time on project duration.

The author's original contribution to the science of project and engineering management is systematically documented, according to acknowledged theory building requirements, and is contained in the theory of measurement for projects (TOM-P) and its validation.

The review of the academic literature demonstrated the shortage of research on project measurement, specifically the interchange between project management, measurements and organisational control. The development of TOM-P, in the confluence of these three knowledge areas, is a unique contribution to project and engineering management.

TOM-P provides the theoretical basis for an appropriately differentiated measurement methodology of task components to reduce project durations.

TOM-P reaffirms that

$$Project\ Duration = \sum_{i=1}^N D_i$$

Where

$$D_i = \lambda_i + \gamma_i + \varphi_i \quad (\text{Equation 1})$$

And added

$$D_i = f(\lambda_i, \gamma_i, \varphi_i, \alpha_i, \beta_i') \quad (\text{Equation 2})$$

The difference between the two equations introduced the opportunity for differentiated measurements. For example, although  $D_i$  is affected by  $\alpha$  and  $\beta$ , they are not included in equation 1, demonstrating the opportunities to transfer time (and scope) from  $D_i$  to  $\alpha$  and  $\beta$  (i.e. from **on** critical path to **off** the critical path). Furthermore, until  $D_i \approx \gamma$  measurement focus on  $\varphi$  and  $\lambda$

provided significant opportunities to reduce project duration, prior to measurement focus on  $\gamma$ .

In addition, TOM-P was evaluated and validated by the validation study, confirming the unique and valuable contribution to project and engineering management knowledge.

Differentiated measurements based on TOM-P were applied in the validation test projects, and it was demonstrated that by focusing MM on  $\lambda$  and  $\phi$ , project duration was significantly reduced. Furthermore,  $\alpha$ -time and  $\beta$ -time was only measured in relation to how it contributed to reducing  $D_i$

The results were significant reductions in project duration of the eighteen test cases, compared to the 66 control projects, demonstrating support for Hypothesis 2.

## **7.4 Recommendations for further research**

This research was executed in environments where touch time was significantly less than task duration. Further research in case studies where touch time is closely related to task duration would add value.

Further research is also required to remodel the progress measurements based on TOM-P utilised in this research for utilisation in information systems, and for roll-up in programme and portfolio environments.

Further research opportunities which will provide valuable contributions relate to the integration of the knowledge domains of project management, measurements and organisational control. For example (1) the utilisation of clan vs. behaviour control in project management, (2) how innovations e.g. measurement methodology, are diffused into project management practice, and (3) how management reaction to progress reports today influence the data quality and data integrity of progress reports tomorrow.

## **7.5 Closing remarks**

The journey to develop the theory of measurements for projects, as well as the extensive validation study, was both exhilarating and tiresome.

The very positive results achieved during the scoping study provided much encouragement to completing the theory development and the validation study. The powerful contribution of TOM-P was visible very early in the validation study when progress reports displayed considerable differences between test project and control project progress.

TOM-P provides a contribution to project management and engineering knowledge when managing time-critical projects, supporting both conventional CPM as well as CCPM project management methodologies.

I herewith respectfully submit my contribution to stem the tide of late projects



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