A SYSTEMS APPROACH TO RESOURCE PLANNING IN NEW PRODUCT DEVELOPMENT

By

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This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

Date:

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"If I have seen a little further it is by standing on the shoulders of giants."

Isaac Newton (1676)

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Contents

ABSTRACT

This thesis documents the novel application of Design of Experiments (Design of Experiments) to the predictive modelling of resource demand information in New Product Development (NPD).

Resource information is a fundamental problem across resource planning processes. No matter what tools are used to re-organise and manage the data, the essential success of the planning process lies in the data quality. The thesis begins by exploring the current resource information generation process before setting out criteria by which "good" resource data can be defined: accuracy, timeliness, consistency and transparency. It is at this juncture that the decision is taken to invest research effort in developing a predictive resource information model.

Several modelling approaches are considered with little success owing to a shortage of past-project data. Resultantly, a novel approach is developed. The approach is verified through internal repetition, external repetition and comparison with a limited pool of past project data before being successfully implemented in the sponsoring company. The novel approach involves using Design of Experiments to model the tacit, process of estimating resource using hypothetical project scenarios in place of experiments.

The outcome of the thesis is a process by which the tacit considerations of estimators can be modelled. Practically this translates to a useable and tested process for the development of a new approach to generating timely, accurate, consistent and transparent resource-demand-per-project information for industry leading to enhanced portfolio planning capability and resource utilisation.

CONTRIBUTION STATEMENT

The content of this thesis provides evidence for the advancement of knowledge in three areas.

CONTRIBUTION 1:

The development of a process for applying Design of Experiments (Design of Experiments) to modelling the tacit considerations used by managers in making resource estimations.

CONTRIBUTION 2:

Design of Experiments is applied in a novel way to develop a predictive model of resource demand per project. The novel method features estimations rather than actual data and hypothetical project scenarios in place of experiments.

CONTRIBUTION 3:

This research demonstrates that modelling the correlation between project characteristics and resource demand is a valid way to create a predictive planning model.

1.0 INTRODUCTION

"The quest for certainty blocks the search for meaning. Uncertainty is the very condition to impel man to unfold his powers"

Erich Formm

As an organization's portfolio develops, demands on resources become an increasingly complex problem to manage. With resources being distributed and shared across the portfolio, their availability as a result becomes increasingly dynamic and uncertain. At a project level, resource requirements mimic the rugged product development landscape: capacity and demand are unpredictable as development teams search alternatives to find value (Baldwin and Clark 2000). Due to the unique nature of each project, defining resource requirements in New Product Development (NPD) remains an exploratory exercise rather than an observable and exact science (Repenning 2001 Atkinson, Crawford *et al.,* 2006; De Weck and Eckert 2007). If decisions are made in a traditional, ad-hoc manner the added value to the organisation in delivering the portfolio becomes dependent upon the validity of assumptions. This could result in decisions being made that cannot be delivered, ineffectual project teams, poor quality execution and neglect of critical tasks, often due to lack of time and people rather than ignorance or lack of willingness (Cooper 2006). Poor understanding of fundamental problem drivers forces managers at all levels to adopt a generic notion of "balance" and base importance on intuition and heuristics (Anderson Jr and Joglekar 2005). Heuristics and estimates based on assumptions can, in fact, exaggerate the uncertainty inherent in NPD planning (Gino and Pisano 2006). Broadly speaking, resource planning in NPD is an interesting problem to study due to three inter-related facets: **Uncertainty**, **Complexity** and **Human issues.**

1.1 NPD PLANNING UNCERTAINTY

Resource planning in a NPD environment differs from other planning environments in that it is inherently characterized by uncertainty (Anderson and Joglekar 2005; Atkinson *et al.*. 2006; Pich, Loch and De Meyer 2002; Hastings and McManus 2004). Traditional planning environments tend to 'freeze' requirements early thus giving clear guidelines as to what must be achieved (de Weck *et al.* 2007; Earl, Eckert and Clarkson 2005). It is not uncertainty itself that is desirable but the innovation from which it emerges. The uncertainty most central to NPD (and perhaps less particular to other planning environments) is driven by the novelty and innovation fundamental to the process (Tatikonda and Rosenthal 2000; Sim and Duffy 2003).

Uncertainty can manifest itself in three ways:

1. Design is an exploratory process. The unravelling development terrain means the activities required, the activity sequence and activity duration, as well as the characteristics of the project, are changing. This has impact upon the resource requirements to complete each project phase and activity and thus affects the capability to predict resource demand and capacity (Anderson and Joglekar, 2005; Reinertsen 1999).
2. Uncertainty regarding the number of possible paths a project can take exacerbates the complexity of resource planning (Haffey 2007; Browning, Fricke and Negele 2006; Joglekar, Kulatilaka and Anderson Jr 2007). Austin *et al.* (2002) found that 90% of activities and deliverables could be anticipated *a priori* and the problem is in fact knowing what the '*unknown unknowns*' are and getting them into the plan.

3. Uncertainty about the nature and significance of factors affecting the capabilities and capacity of resources within functions as well as the significance of human factors such as political agendas and biases. Managing uncertainty to increase decision confidence tends to be biased towards understanding markets and products rather than the available human resources (Wernerfelt 1995, Wernerfelt 1984; Warren 1999; Collins 1995; Ainsworth 1995).

In a multi-project environment, the dynamically changing demand and capacity also becomes an overarching influential factor that must be understood. Inevitably, with all the possible parameters and interactions, the whole situation becomes extremely complex.

1.2 NPD PLANNING COMPLEXITY

Uncertainty about the inputs to each activity, the quantity of inputs and the interactions and coupling between inputs undoubtedly makes the product development process a complex one (Kim and Wilemon 2003).

Complexity is often cited as being the source of process improvement failure regardless of the type of process: From products (Repenning and Sterman 2002), to organisations (Park and Ungson 2001) to chemical plants (Venkatasubramanian, Rengaswamy *et al.* 2003). Ford and Sterman (2003b) describe the 'hallmark' of such failures as being disjointedness between the various elements of complexity and the mental models of the managers responsible. Cognitive processing research shows that the brain is arguably only capable of holding between seven plus or minus two objects in working memory (Miller 1956), constraining mental models to tight boundaries and short time horizons. Managers find it difficult to include interactions and feedback in such mental models, and consequently often act in a manner which is seemingly sensible from a local, short term perspective but in the long run leads to failure due to the inevitably flawed sense of complexity (Diehl and Sterman 1995; Sterman 1994).

There are several features of NPD that propagate complexity:

- The number of possible project activity combinations.
- The dynamic complexity of multiple projects: with concurrency, the number and frequency of information exchanges increases. (Clark and Fujimoto 1991; Krishnan and Ulrich 2001; Wheelwright and Clark 1992).
- Complexities due to the diversity of functional resources and their interactions in teams (Ford and Sterman 2003a).

Lévárdy and Browning (2009) describe the process of development as a kind of complex system which is more complex than the system/product it is producing. This is true for 3 reasons: (1) for each specification; or (2) determination of an emergent behaviour at least one action or decision is required in the NPD process (a one-to-many relationship). This greater number of one-to-many relationships (from both specification and determination of emergent behaviours) is further complicated by: (3) the greater number of inter-element connections.

Furthermore, when resources are associated with each activity or decision this can be linked to the resource plan. Resource planning involves multiple interdependencies between resources and activities; therefore it could be argued that resource planning is a far more complex process than either the product itself, or the process of developing the product. Reducing complexity is essential in product development resource planning because of the impact of resource demand and capacity information at multiple levels of planning (Anderson Jr and Joglekar 2005).

1.3 HUMAN ASPECTS OF NPD PLANNING

Human issues affecting planning can relate either to the properties of the resources and their capacity to work; such as skills and experience, or the properties of the work that influence the resource capacity, for example, the effect of overloading on morale. Additionally, estimation and assumption based planning allows political or personal agendas and biases to exist in the system. Such agendas are often myopic and non-compliant with the best long term interests of companies serving to defend the interests of individuals. Often untested assumptions are portrayed as factual to serve a purpose that might not be explicit (Janis 1982).

Human planning considerations can be broken down into those concerning either tangible or non-tangible aspects (Warren 2000). Characteristics and attributes associated with tangible resources include the cost efficiency associated with the resource, the number of resources available and, the skill levels associated with the resource. Tangible characteristics and their impact upon the NPD process and development teams are well documented in literature (Ward 1999; Coates *et al.* 2007; Farr-Wharton 2003; Odusami, Iyagba and Omirin 2003; Zika-Viktorsson, Sundström and Engwall 2006; Tether, 2005).

Non-tangible, indirect resources are those reflecting people's feelings or expectations about issues of personal concern. For example staff morale, reputation, or support from investors (Warren 2000). Other behaviours related with non-tangible resources include such things as 'blame culture', 'conspiracies of optimism', 'macho management' and 'management misdirection' (Sterman 2004). Such behaviours can propagate if knowledge and perceptions of uncertainty are inconsistently spread across a team (Chapman and Ward 2000, 2003). Atkinson, Crawford and Ward (2006) report that such behaviours reflect: an inability or unwillingness to recognize the difference between bad management and poor performance due to factors out with management control; good managers who apply proactive uncertainty management to reduce problems and; managers who are just ‘lucky’. In organizations experiencing such issues there is likely to be a lack of trust and feelings of vulnerability in terms of opening up about competencies and issues. Managers may ignore, hide or delay communications (Yassine *et al.* 2003); fail to recognize certain information in front of them due to organisational routines and filters (Henderson and Clark 1990); or distort data (something often referred to as gaming (Ford and Sterman 2003b)).

1.4 PRACTICE VERSES THEORY

Uncertainty, complexity and human factors are three inter-related difficulties that seem exaggerated in NPD in comparison to other planning environments. Literature theorises and philosophises over the academic aspects of each theme. However, very little is put into practice in industry. Despite the extensive recognition of the importance of getting resource planning in NPD “right” (Chao, Kavadias and Gaimon 2006; Kavadias and Chao 2007), industry is often reluctant to adopt the theoretical approaches proposed by academia despite the rigour of the analytical efforts (Loch and Kavadias 2002; Haque, Pawar and Barson 2000). There is a tendency for both industry and academia to focus upon the details of the system from a market and product perspective, rather than trying to strike a balance between the resources available and the business goals (O’Donnell and Duffy 2005; Lévárdy and Browning, 2009). The effects of this oversight are detrimental to organisational performance and competitiveness (Gino and Pisano, 2005; Hofer and Schendel, 1978; Wernerfelt 1995).

Each of the sources of confusion exists across levels of decision making (strategic, tactical and operational), permeating the full system. It is the author’s view that attempts to eradicate difficulties at one level, without consideration to the

Organisational design (e.g. Loch 2000) or interactions and dependencies between levels (Joglekar *et al.* 2007), cannot result in a practical solution. As the academic approaches merge with vaguely defined existing system elements and decisions, it is possible that unpredicted and often undesirable emergent system behaviours come to the fore. For example, a detailed theoretical formula for optimising portfolio management cannot work in practice when the information feeding the formula is flawed, or if the culture of the business is more conducive to decision making based upon intuition and "gut-feel". Efforts to implement such a measure could result in offended staff, lack of support for the initiative, lack of support for further initiatives, poor decision making, or at best, wasted resource. As a Systems Engineering Doctorate this thesis is concerned with the development of a practical and implementable solution to the NPD resource planning conundrum whilst, at the same time, offering a significant contribution to knowledge.

1.1 SCOPE OF THE RESEARCH: RESOURCE PLANNING

This research has been conducted in conjunction with DePuy Orthopaedics, a medical device development company; a franchise of Johnson and Johnson. The research project has been conducted over four years between October 2008 and October 2012. Approximately 75 % of the four years has been spent in DePuy R&D offices, Leeds and approximately 25% of the project time has been allocated to studying System's Engineering MSc modules at Loughborough University in addition to other research related courses at The University of Strathclyde.

DePuy are interested in better understanding and improving resource planning processes. They are bound by Food and Drug Administration (FDA) regulation to ensure that they use resources efficiently and effectively in all NPD activities.

The DePuy Worldwide Quality Policy (QSP-100000 Revision 5, Appendix 4) states the following:

"In accordance with the Johnson and Johnson credo and our company values, DePuy will strive to meet and exceed customers' needs with regard to our products and services.

We will strive to assure our customers' continued satisfaction by:

- ***Optimising our internal resources, both human and technological***
- *Building equal partnerships with suppliers*
- *Encouraging teamwork, employee empowerment and development*
- *Fostering an environment of continuous improvement and innovation.*

The successful attainment of this policy is the responsibility of all our employees. Management will ensure proper communication, understanding and periodic review of this policy."

This research project focuses on the process of optimising internal resources and specifically on the process of planning. This project is part of the process of DePuy moving towards optimising internal resources as is promised in the Quality Policy.

The scope of the research can be defined broadly in four dimensions. Firstly, in the broadest sense, the resource planning process is investigated. The other three dimensions are: The planning environment, the resource type, and the overarching methodological approach. Although these dimensions define the scope of the investigation, they focus on particularly complex instances of planning. The results will refer to, but should not be restricted to the specific problem explored: they may be applied to other planning environments or, other types of resources especially in simpler instances.

1.1.1 THE PLANNING ENVIRONMENT: NPD

The research focuses specifically on New Product Development resource planning as opposed to resource planning in other environments, for example: construction or civil engineering, defence, politics or retail. The uncertainty driven by the need for innovation in such an environment means that there are a unique set of issues perhaps more complex than those typically experienced in other planning contexts. The essence of NPD is the creation of something novel and undiscovered. This is not demonstrated in any other environment. The usual purpose of planning is to minimise uncertainty. The intrinsic link between the necessity of the innovation and uncertainty presents a uniquely complex planning environment.

1.1.2 THE OBSERVED RESOURCE: PEOPLE

With an abundance of projects they could profitably peruse, DePuy cannot simply start every project and employ new staff whimsically as and when required. Instead they seek to peruse the projects most in line with strategy whist utilising available resources most effectively. Johnson and Johnson adopt a strict and responsible approach to taking on new staff. Personnel availability is considered to be the main limiting factor in NPD.

A skilled workforce is critical to successful development work. Other types of resource cannot be substituted for knowledgeable development staff. Although information technology and prototyping technologies are used to aid designers, irrespective of whether or not they are more or less scarce, they are certainly less complex. We can be relatively sure about the productivity of a computer or the availability of prototyping technology however, human beings are somewhat less predictable especially when they are required to interact in a multi-project, team based environment.

1.1.3 THE METHODOLOGICAL APPROACH: SYSTEMS ENGINEERING

The environment of the research (both industrial and academic) has influenced the scope of this research not only in terms of terms of subject but also in terms of the methodological approach. The MSc Systems Engineering Modules completed concurrently with initial work provided a tool-kit ideally suited for addressing complex, multi-faceted research problems.

Rather than focusing on a specific problem aspect at the outset in a traditional reductionist manner, a large proportion of the effort invested in this work has been employed in adhering to systems engineering principles distilled to ensure that the most relevant issues were being addressed at each stage (verification), in a suitable and appropriate way (validation). The research has been designed to be relevant to industry and applicable in practice. The approach to the work has been engineered to fit within an existing system and the aim of the research is to enhance the existing system whilst contributing to new knowledge.

1.2 AIMS AND OBJECTIVES

The aim and objectives of the research are documented in this section. They are then reflected in Section 1.5 as they are laid out against the chapters in which their achievement is documented.

1.2.1 AIMS

The primary aim of this research is to significantly advance knowledge in the field of NPD resource planning. This will include an implementable component in the form of a new approach, tool and/or guidelines.

1.2.2 OBJECTIVES

To achieve the aim, the objectives of the research were identified to be:

- ✓ (O1) Develop a thorough understanding of the existing new product development resource planning process in DePuy and the associated opportunities for improvement
- ✓ (O2) Conduct a thorough and systematic review of NPD resource planning literature. Identify the key gaps in knowledge.
- ✓ (O3) Identify the key research opportunities in DePuy that are unresolved by reported research.
- ✓ (O4) Develop a research agenda based upon the achievements of O1- O3.
- ✓ (O5) Develop a systematic, triangulated and repeatable approach to addressing the key research issue(s).
- ✓ (O6) Employ the approach to addressing the research issues (s) in order to develop new knowledge and a new approach, tool or set of guidelines.
- ✓ (O7) Implement or, alternatively make recommendations regarding implementing the new knowledge generated through addressing the research issue (s).
- ✓ (O8) Evaluate the work in order to identify strengths and weaknesses, and areas for future work.

1.4 RESEARCH QUESTIONS

The initial research question established at the outset of the project was:

> **RQ 1: By adopting a systems engineering approach, can we reach an implementable, new approach to resource planning in NPD?**

Systems Engineering has proved to be a successful approach in addressing other multi-faceted or interdisciplinary problems, particularly in the fields of defence and aerospace. Given the plethora of NPD resource planning literature available and approaches from a range of isolated perspectives (focusing on specific planning levels or specific problem aspects without due consideration of system-wide impacts) and the unresolved nature of the planning, the research began with the concept to apply Systems Engineering principles as an alternative, logical approach to understanding the underlying problems.

A number of interesting potential means for addressing the initial research question emerged in the early stages of the project. The shortlist included opportunities that were highlighted as being unresolved by current research and identified through investigations in DePuy. With a system-wide view in mind, the issues were prioritised according to the impact a successful intervention could have on DePuy, and the potential to contribute to new knowledge. Although all items were given some consideration, the issue considered most significant was selected for further investigation and posed as the first research question to be addressed. With further investigations, this led to research question 2. The main research questions are:

> **RQ2: How can NPD organisations better understand resource demand per project?**

RQ3: Can we generate a predictive resource demand algorithm?

RQ2 emerged from RQ1. RQ2 led to advancement in procedural knowledge: Contribution 1 and Contribution 2 and lead to RQ3. RQ3 resulted in the third contribution to knowledge: evidence of correlations between project characteristics, resource demand and project phase duration.

1.5 THESIS STRUCTURE

The thesis is divided into three parts. The first part documents understanding of the aim, the development of the approach and the emergence of research questions. The second part records steps taken to address the research questions. Finally, the third section reflects upon and evaluates the research project. The overall structure is shown in Figure 1.

PART ONE: RESEARCH PROBLEM FORMALISATION (CHAPTER 2 AND CHAPTER 3)

This section describes the exploration of the NPD Planning system, the identification of and logic for selecting the research focus and the approach that will be taken to addressing the research objectives.

CHAPTER 2: METHODOLOGY

The methodology chapter provides an overview of the methodological considerations made throughout the project. A four stage (***Appreciation, Assessment, Analysis, and Action***) multiple-perspective (***material, personal, social***) approach relevant to the problem is detailed.

CHAPTER 3: A SYSTEMS APPROACH TO RESOURCE PLANNING IN NPD

Chapter 3 presents a review of literature from multiple-perspectives proposed in the approach section of Chapter 3 in order to develop problem ***Appreciation***. The literature is complemented by pertinent findings from investigations carried out within DePuy. A research gap offering synergistic, system-wide possibilities is identified.

The review of literature and investigations carried out within DePuy lead to RQ1 and RQ2 and a set of requirements for process improvement.

PART TWO: DEVELOPMENT OF A PREDICTIVE RESOURCE PLANNING MODEL (CHAPTER 4 AND CHAPTER 5)

This section describes how the main contribution to knowledge has been achieved.

CHAPTER 4: ASSESSMENT OF PREDICTIVE MODELLING POSSIBILTIES

This chapter provides an assessment of existing approaches that could be applied to addressing the research question one and expands to consider the limitations of the environment (a shortage of past –project data) before setting out requirements for and describing the conceptual possibilities and details of new Design of Experiments based approach.

CHAPTER 5: APPLICATION OF DESIGN OF EXPERIMENTS

Chapter five lays out a procedure for applying Design of Experiments to creating a predictive resource demand model. The modelling process is applied through six internal and one external case-study. This chapter provides the main contribution to knowledge.

PART THREE: CONCLUSIONS (Chapter 6 AND CHAPTER 7)

This section assesses how well the aims and objectives have been met through the work carried out in previous chapters. We ask: is the new approach useable and implementable, and: how Design of Experiments it contribute to new knowledge?

CHAPTER 6: EVALUATION OF IMPLEMENTATION

This chapter describes the results of a usability study and integration activities. The mathematical model developed in Chapter 5 is converted to an implementable format.

CHAPTER 7: CONCLUSIONS

This chapter compares the research outcomes with the original aims and objectives. The contributions and quality of the work are discussed and opportunities for future research are presented.

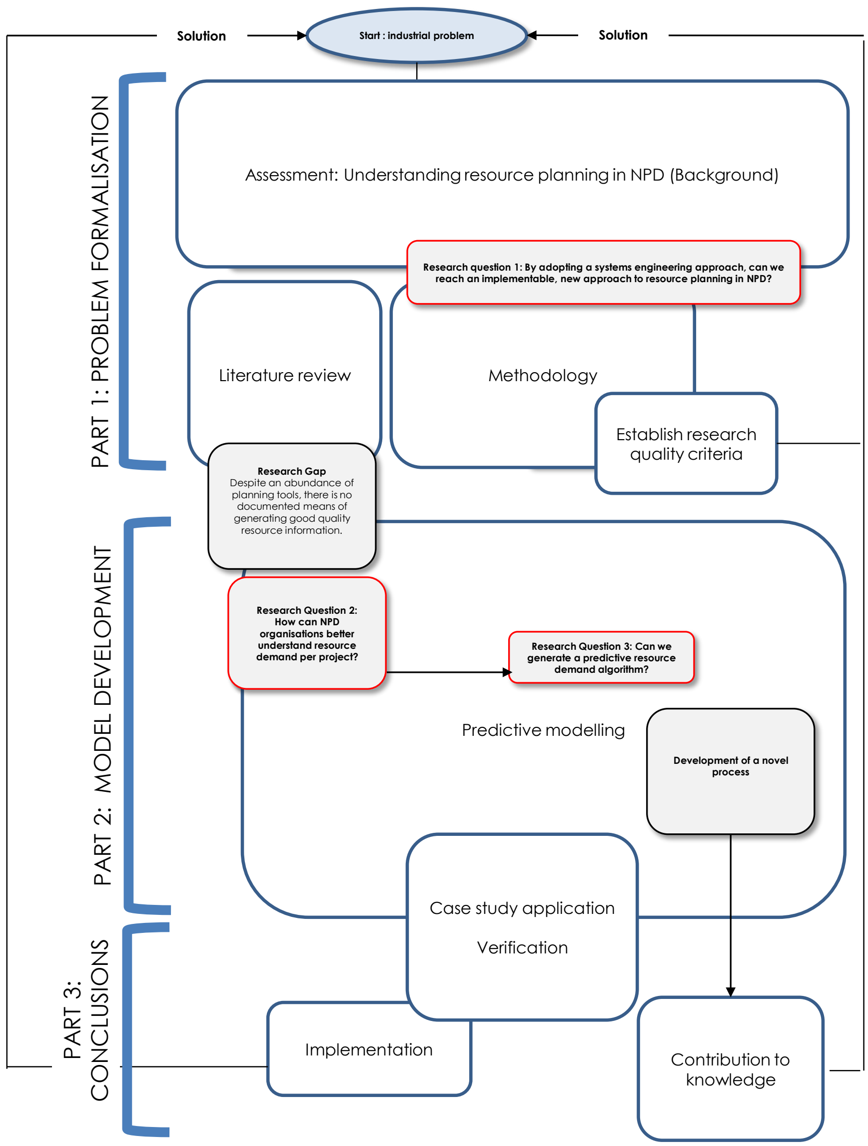


Figure 1- Thesis structure

2.0 METHODOLOGY

To provide context for the work that follows, Figure 2 presents an overview of the research activities and main stages. Fundamentally, the research splits into two stages: pre-modelling decision (problem appreciation and analysis) and post-modelling (assessment and action). The focus of the research switches quickly from understanding the nature of the problem to making a decision regarding which approach to take to addressing the problem over the remainder of the research.

The approach to taken to addressing the problem (i.e. predictive modelling) was chosen primarily as it offers significant practical benefits to industry. Existing modelling approaches are not suitable in this environment although the reasons why did not become clear until several unsuccessful modelling techniques had been tested. Hence the multiple methods employed in the second half. The main contribution of this work comes through the development and application of a new approach to predictive modelling.

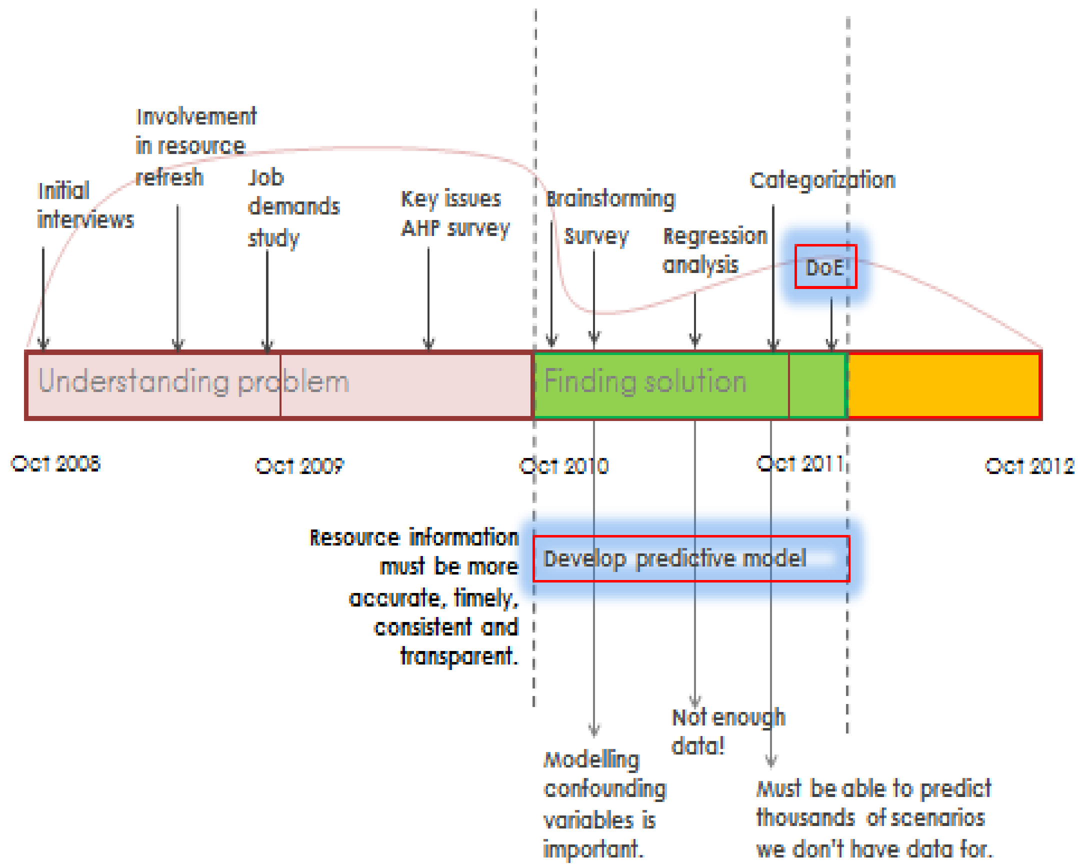


Figure 2 - Timeline for research project. Key milestones include establishing gap and setting direction of project to predictive model development and the realisation that Design of Experiments may provide a suitable approach.

2.1 METHODOLOGICAL CONSIDERATIONS

In the previous chapter we have outlined some of the theoretical and conceptual issues underpinning contemporary resource planning practices and research. Existing efforts and approaches stemming from a number of different methodological stand-points fail to provide a solution to NPD resource planning worthy of management confidence. A methodology is required that will allow us to intervene successfully to develop the current system. It is critical that we are able to include a variety of methodological standpoints without losing clarity and as we are exploring new and uncertain territory by taking such an approach, it is fundamental to success that we are able to verify and validate the process and the outcome.

Midgely (1990) proposes that in the real world the research question or problem is not chosen based upon a preferred methodology. Rather, the question is asked and the methodology chosen later. Different paradigms focus attention on different aspects of the situation and so multi-methodology is necessary to deal effectively with the full richness of the real world (Mingers and Brocklesby, 1996). Through this thesis we wish to demonstrate a significant contribution to new knowledge; the nature of the knowledge concerned is of fundamental importance. Understanding the nature of the knowledge helps in planning and conducting research that will yield interpretable and useful results associated with a tangible degree of credibility for a given set of objectives (Easterby Smith *et al.* 1991). Choosing methods to address the posed research question in an ad-hoc manner may or may not result in a useful conclusion and more importantly, the confidence and credibility associated with the methods used relative to the methods that *could have* been used would remain questionable.

Given the range of possible theoretical perspectives that could be taken and in order that this research process is repeatable and can be deemed thorough, it is necessary to set out and explain the perspective of the researcher, the assumptions and logic accompanying the cognitive processes supporting the choices made. Cotty (1998) argues that an inter-relationship exists between the theoretical stance adopted by a researcher, the methodology and methods used, and the researcher's perspective and the epistemological stance: each must be defined.

This first part of this chapter looks at the underpinning philosophy of research: the nature and significance of, and justification for the epistemological stance taken and the theoretical perspectives adopted by the researcher. The second part of the chapter describes how the aim of the research has guided methodological choice and the approach taken. The final section of the chapter describes the research methods used at each stage and the reasons behind choices made.

2.1 EPISTEMOLOGY

Before examining epistemology, it is useful to understand Ontology. Ontology is the study of being; *what is,* whereas epistemology is concerned with *what it means to know*. Two main Ontological traditions exist: ontology of becoming and ontology of being. In today's world reality is accepted as being made up of components of identifiable properties. This stable view of reality enables humankind to represent entities with words, symbols and concepts and allows us to focus upon outcomes and end points rather than perpetual change.

Knowledge, according to Habermas' theory of constitutive interests (see Finlayson, 2005), is geared towards serving particular human interests: our interest in prediction and control i.e. *technical interest*; our interest in developing inter-subjective meaning i.e. *practical interest* and; our interest in helping people free themselves through constraints imposed through power relations i.e. *emancipatory interest.*

Several different branches of epistemology exist. Key groupings are Objectivism, Constructivism and Subjectivism. Within each grouping are various schools of thought. Table 1 illustrates the links between epistemologies and this research.

Table 1 – Epistemologies and their applicability to this research

Epistemology	Interested in…	Reality is…	Associated theoretical perspectives	Applicability in this context.
Objectivism	Prediction and control, technical interest.	Singular. Out in the world waiting to be measured.	Positivist, realism.	Understanding the objective effects of the current resource planning system.
Constructivism	Inter-subjective meaning, practical interest.	Interpreted through classifications in the mind.	Interpretivism, symbolic interactionism.	Understanding how the resource planning system affects people ability to be productive.
Subjectivism	Helping people free themselves, emancipatory interest	Each individual's interpretation of reality is valid. Associated with a becoming ontology.	Phenomenology, post modernism.	Understanding how people feel about the resource planning system and how it affects them personally.

2.1.1 OBJECTIVISM

The Objectivist epistemology holds that reality exists independently of consciousness; that the truth is 'out there' waiting to be found. Research adopting this epistemology involves discovering this objective truth. This epistemology is closely linked to positivist and realist theoretical perspectives. Objectivism is linked with a *being* ontology.

2.1.2 CONSTRUCTIVISM

Constructivism takes the view that all knowledge is constructed rather than discovered. The truth and meaning do not exist in the world but are created through a subject's interactions with, and experiences of the world. The constructivist point of view is pragmatic and, similar to objectivism is also linked with a *being* ontology.

2.1.3 SUBJECTIVISM

For subjectivism, meaning or knowledge Design of Experiments not emerge from interactions but is imposed upon the world by the subject. Subjects construct meaning but not from interactions, they do so by internalising the world within their collective consciousness and through processes such as dreams and religious convictions.

Subjectivism is closely linked with postmodernism and a *becoming* ontology (Chia ,2002).

Given that existing research spans a broad range of views and that each epistemology could potentially be relevant, it is necessary to consider how they can be applied in tandem. Choosing one theoretical perspective at this stage could result in a narrow problem understanding; one that would be difficult to defend when confronted by other perspectives, and fundamentally one which may not be applicable in practice.

2.2 THE RESEARCH APPROACH

This research seeks to address an existing, practical problem: resource planning in NPD. This research problem has research potential: it is discussed to some extent in literature but several knowledge gaps exist. The aims and objectives of the research project (described in section 1.2) align with the essence of The Constructive Approach – to tie the problem and its solution with existing and growing theoretical knowledge. Through this thesis, we seek to demonstrate the nature of the problem, the novelty of the solution and the workings of the solution.

(Habermas 1984) argues that in any utterance intended for communication there are four claims: intelligibility, truthfulness, justification and sincerity. (Midgley 1990) proposes that intelligibility is a prerequisite for communication and the other three claims relate to three worlds: the objective external world, the normative social world and the individual's subjective internal world. (Midgley 1990) goes on to suggest that hard, quantitative methods pursue truth statements through modelling the external world; soft systems methods pursue rightness statements through debate and qualitative methods, and subjective Operational Research (OR) methods produce sincerity statements or a picture of an individual's unique perspective. (Flood and Jackson 1991) also draw upon

Habermas' (1984) theory of the knowledge constitutive interests: technical, practical and emancipatory, to describe three systems paradigms in support of each interest. (Flood and Jackson 1991) assert that hard systems methods support technical interests; soft systems methods support the practical interest, and critical systems methods support the emancipatory interest. Although these views or 'worlds' can be considered separately one at a time, in practice they are not separate from each other. Combining methods and developing a more complete 'systems view' is possible according to this logic. Table 2 demonstrates the relationships between the terminologies for various systems views. Our interaction with the world through each paradigm is illustrated in Figure 3.

Table 2 - World view and related paradigms

	Epistemology	Associated paradigms	Maxwell (2005)	Midgley (1990)	Mingers & Brocklesby (1997)
World view	Objectivism	Positivist, realist	Practical	External	Material
	Constructivism	Pragmatic	Intellectual	Social	Social
	Subjectivism	Post modernism	Personal	Internal	Personal

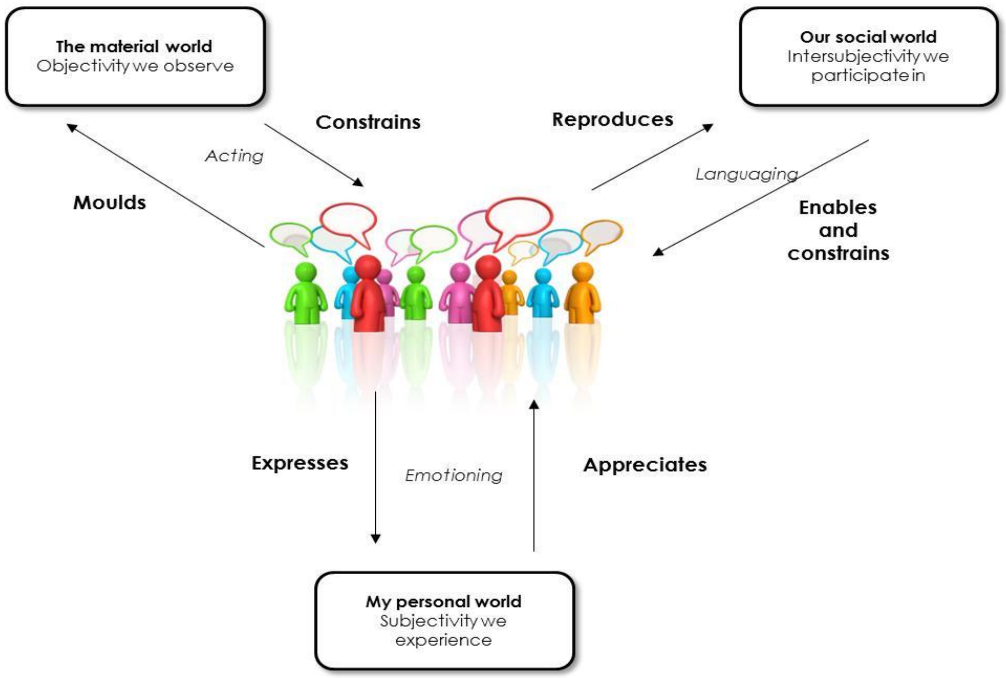


Figure 3 - The Three dimensions of problem situations. Adapted from Minger's and Brocklesby (1997)

Philosophically, systems thinking supports the views of Kant (Scruton 2001): we structure the world by means of already present innate ideas that we perceive the world through a filter unique to us although the source of a large proportion of these ideas comes from the outside world. Adopting a systems perspective not only allows researchers to view the world as a series of systems which can be engineered and understood (this would be a taking a systemic, "hard" view) but allows researchers to organise complex components of a system in a systematic way to explore the world as a learning system (the process of enquiry is systemic) (Checkland and Scholes 1999). This is illustrated in Figure 4 below.

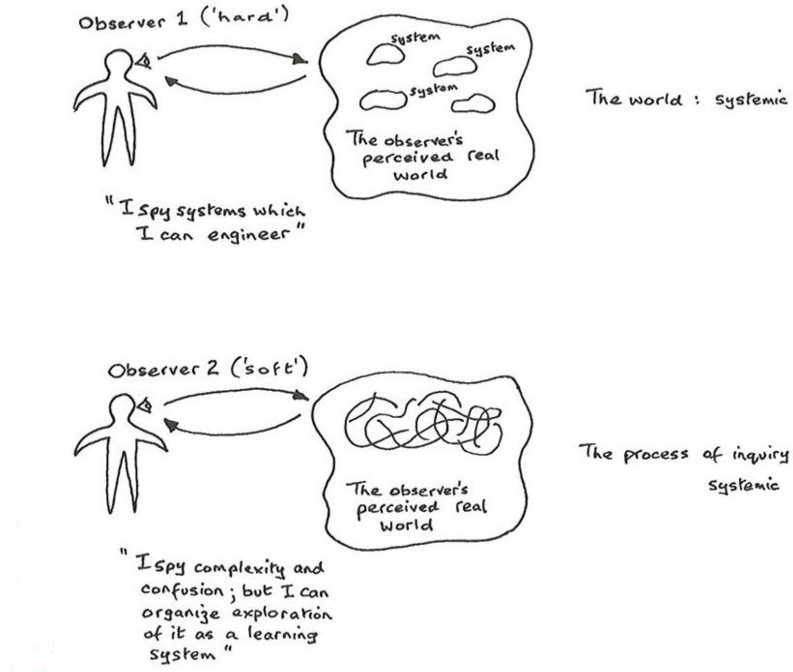


Figure 4 - The hard and soft systems stances. From Checkland and Scholes 1999

(Ford and Sterman 2003a) call for a more effective approach to development planning that echoes the holistic world view proposed by Midgley (1990):

"…*improving effectiveness of current development requires models that explicitly account for interactions and feedbacks among technical"* (material*), "organisational"* (social) *"and behavioural features*" (personal).

(Jackson 1982) stresses the importance of describing and modelling the real world rather than specifying and describing a solution or structuring the function the system is to perform.

This thesis employs a pragmatic approach and mixed methodologies. The merits of both positivism and Interpretivism are applied to different aspects of acquiring knowledge.

Shoe-horning what is essentially a social *and* empirical research problem into one view of the world would have been counter-productive and detrimental to the quality of the work. A single view of the world may expose certain aspects in brilliant detail (like a microscope) but, may be totally blind to others (microscope vs. a telescope). Employing only one paradigm is inevitably only gaining a limited view. In some instances a limited view may be sufficient but, in this instance where the goal of the research/ intervention is to produce an implementable global solution, it is critical for practical reasons that multiple views are considered.

By introducing multiple perspectives we can create a more robust understanding of the potential flaws in each perspective, and consequently a more robust understanding of the research area. Traditionally, researchers restrict themselves to methods aligning with a single paradigm or, more narrowly, one methodology. Over the past decade or so, multi-methodology or mixed methodology research has become more widely accepted as good practice; encouraging mixed or multiple views of the system undergoing research. Single multi-paradigm methodologies have been developed: System of Systems Methodology (Jackson, 1984), Total Systems Intervention (Flood, 1996) or, Soft Systems Methodology (Checkland, 2000) to name a few prominent examples. Mingers and Brocklesby (1997) argue that although such methodologies offer more flexibility than traditional single-paradigm approaches, a more desirable approach would be to combine several different methodologies (possibly from different paradigms) – a similar idea to the concept of *triangulation* applied in sociology.

The aim of this project is to develop a new approach to resource planning, to intervene with an actual rather than just a theoretical system. Intervention is not a discrete event but requires a process of events or a number of phases (Mingers and Brocklesby 1997). In order to map appropriate methodologies with phases, Mingers and Brocklesby (1997) derive four generic phases of an intervention with each phase posing different tasks and problems for the researcher specific to each research problem. The four phases are:

Appreciation of the problem situation as experienced by the agents involved.

Analysis of the underlying structure/ constraints generating the situation as experienced.

Assessment of the ways in which the situation could be other than it is; of the extent to which the constraints could be altered.

Action to bring about desirable changes.

Mingers and Brocklesby (1997) propose a framework for developing a multi-paradigm methodology based upon the four phases above and three different worlds: material, personal and social. A fully comprehensive intervention needs to be concerned with each of these views. An adapted version of Mingers and Brocklesby's four phase framework as described above is summarised in Table 3.

Table 3 - Mingers and Brocklesby's (1997) framework for mapping methodologies

	Appreciation of…	Analysis of…	Assessment of…	Action to…
Material	Physical circumstances	Underlying causal structure	Alternative physical and structural arrangements	Select and implement best alternative
Personal	Individual beliefs, meanings and emotions	Differing perceptions and personal rationality	Alternative conceptualisations and constructions	Generate accommodation and consensus
Social	Social practices, power relations	Distortions, conflicts, interests	Ways of altering existing structures	Generate empowerment and enlightenment

2.2.1 Verification and validation of the research outputs

One shortcoming of Mingers and Brocklesby's framework is that it Design of Experiments not include verification and validation of the system explicitly. Although the concurrent consideration of multiple systems paradigms could be equated to triangulation of research methods, there is no explicit simultaneous consideration of phases (other than in planning) and often in research (as in product development), the actual activities or event required will not become apparent until the preceding event has been completed.

According to ISO15288, a lifecycle describes "*the evolution of a System, product, service, project or any other human-made entity from conception through to retirement*". The aim of this research project is to develop a new approach to resource planning in NPD: a new tool (project), a set of guidelines or an improved process.

To develop a successful system, it is important to consider later stages of development early on (for example it is important to consider implementation or maintenance in the design stage). Failure to do so is likely to result in unexpected behaviors emerging. The more complex the system being developed, the more likely it is that unexpected or undesirable emergent behaviors will arise. The "Vee diagram" shown in Figure 5 below is a widely used illustration of a process that can be applied to the development of systems to help manage emergent behavior and, to aid the development of an implementable system that works in practice.

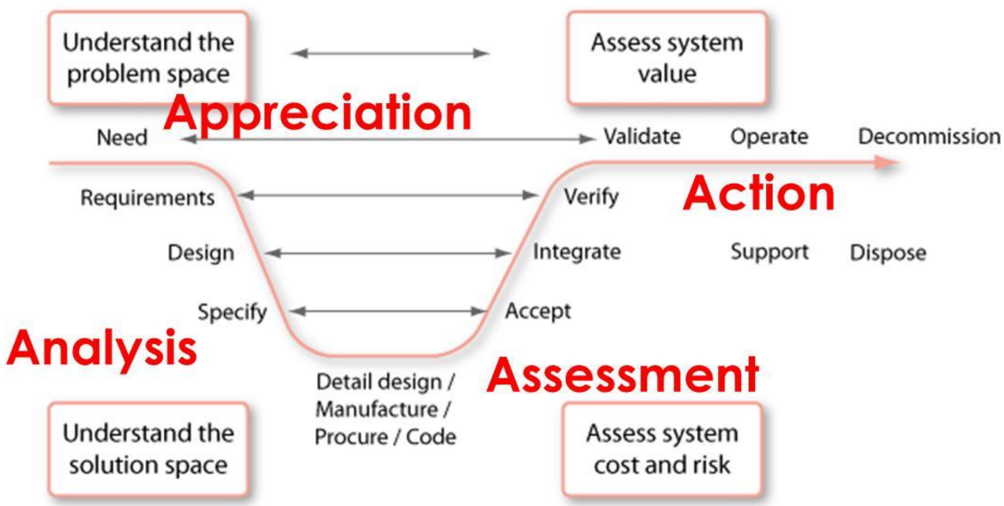


Figure 5 - The "System's Vee" from MOD Acquisition Operating Framework ISO15288 Enterprise Process: System Lifecycle Management. Adapted to include four stage framework.

The lines with arrows at each end that run across the model attempt to show the important links between left-hand and right-hand sides of the "Vee". For example – as the need is being defined, it is critical to think about how we will validate that the correct opportunity has been addressed: how will we know that the solution solves the issue? This will allow us to verify that we are indeed looking at the correct problem and to set expectations of the end results (perhaps in the form of a business case) before moving on to capture requirements.

By combining the "Systems Vee" and Minger's and Brocklesby's (1999) framework, we are able to develop a methodology suitable for developing a new, constructive systems approach to resource planning in NPD. Table 4 describes the approach as it was followed, including the research questions that resulted in specific actions or methods employed in subsequent phases.

2.2.2 Approach to research quality

In addition to verifying the deliverable, it is also important to make sure that the research process is valid and robust. Scandura &Williams (2000) state that "*Without rigor, relevance in management research cannot be claimed*". Yin (1994) sets out 4 criteria for robust case study research: ***construct validity, internal validity, external validity and reliability.*** A case study can be defined as "Research situations where the number of variables of interest far outstrips the number or data point" (Yin 1994 pg. 13). Whilst case studies may use quantitative data, a key difference with other research methods is that case studies do not attempt to control the context (Benbasat, Goldstein & Mead; Yin, 1994). Given that this research is in essence a case-study no matter the specific methods used, it seems appropriate that these factors are considered when designing the research and selecting methods.

Construct validity determines how well a test of experiment lives up to its claims: the extent to which the study relates to an accurate observation of reality (Denzin & Lincoln, 1994). It is possible that models underlying the qualitative (personal and social) aspects of this research may not be validated (Silverman, 2005 pg 212) as such models are not compatible with the idea that a true "fix" on reality can be reached by looking at it in different ways. A positivist research stance (perhaps supported by interpretivist and constructivist stances) is the best way to ensure construct validity. Methods such as triangulation of data sources, Denzin & Lincoln; Stake, 1995; Yin, 1994), provide a clear chain of evidence (Yin 1994, pg 104) and thick descriptions (Geertz, 2003).

Internal validity is the logical testing of the relationships between variables in the research. Based on ideas by Popper (1956), rather than trying to provide the hypothesis, the researcher can attempt to disprove all alternatives (Silverman, 2005). Techniques such as cross case analysis and open discussion regarding the assumptions can help establish internal validity. Deviant cases should also be included in the analysis of the hypothesis (Sliverman, 2005).

External validity refers to the generalizability of the research and can be supported through external case studies.

Reliability refers to the absence of random error, enabling subsequent researchers to arrive at the same insights if they conducted the study along the same steps again (Denzin & Lincoln, 1994).

The following must be considered when selecting research methods and analysis data:

- Cross-case studies (as opposed to single case studies).
- Including deviant cases (as opposed to selecting results congruent with the hypothesis).
- Triangulation of data.
- Careful documentation of methods and in-depth discussion of analysis.
- Positivist, qualitative data to support claims where possible.

Table 4 – Research Approach summary

Mingers and Brocklesby phases				Appreciation of…	RQ2.	Analysis of…	RQ.3.	Assessment of…	Action to…	Verify	Validate
Define scope, Understand existing system boundaries.	*Define methodological approach*	Consider validation	Material	What is the physical process for RP? How Design of Experiments this constrain and mould actions?	How can NPD organisations quantify resource demand per project?	What is the underlying causal structure?	Can we generate a predictive resource demand algorithm?	What are the alternative physical and structural arrangements for a model	Develop predictive model – Data gathering & Analysis	Verify the predictive model behaves in expected fashion.	Validate that the methodology and the methods have addressed the opportunity as anticipated
			Personal	How do people feel about RP process? How do they appreciate and express this?		How is this impacted by differing perceptions and personal rationality		What are the alternative conceptualisa tions and construction?			
			Social	How much influence do people have on RPP? How Design of Experiments this enable and constrain them?		Where are the distortions, conflicts, interests		How can a model alter existing social structures?			

2.3 RESEARCH METHODS

The process of research is like the process of design itself: the actual activities and events do not become completely clear until the preceding activity has been completed. None-the-less, several options were usually available. Although the actual activities, events, their outcomes and the logic that led to subsequent activities are documented in the following chapters of this thesis, here we provide an overview of the research path: a brief explanation of why the path taken was chosen and consideration of the alternative methods/ avenues. The methods referring to each stage presented in Table 4 are presented in Table 5.

Mingers and Brockles by (1997) suggest that a methodological approach is assigned to each of the cells in Table 4 although they do not advocate standardized methodologies but specific designs to each intervention. In this case, methods have been chosen from a System's Engineering Toolkit: an informal collection of methods primarily associated with managing and organising complexity and minimising uncertainty, (as opposed to just reducing effort required). A systems approach has already been assumed as we consider the problem for a variety of perspectives, concurrent to consideration of verification and validation.

Research methods are summarised in Table 5 at the end of section 2.3

2.3.1 APPRECIATION METHODS

The aim of appreciation is to generate a general and comprehensive understanding of the resource planning system with a view to identifying a key practical issue which aligns with a gap in knowledge. To do so, we explicitly adopt a range of perspectives. We explore each perspective through a **literature review** and through an **exploratory case**

study examining the NPD resource planning process as it exists in DePuy. The resource planning process is not a static system - it is subject to on-going improvement initiatives and changes independent of this research project. We examine the material, physical perspective by detailing process steps observed in DePuy and comparing with the process described in literature. This involved creating **flow charts** using standard symbols (www.wiley.com/college/busin/icmis/oakman/outline/chap05/slides/symbols.htm) as well as **Unified Modelling Language (UML) sequence diagrams** (http://en.wikipedia.org/wiki/Sequence_diagram). The flow charts and sequence diagrams were constructed by observing the process steps (some formally documented; others tacit). This allowed the documentation of what actually happened although didn't allow for the explicit description of a range of softer issues. Many of the softer issues relate to the process of generating estimations for resource requirements. Some of the softer issues emerged through the initial round of **interviews** with stakeholders across all levels of the business although further investigation was required. A literature review was used as a primary tool to investigate many of the softer issues; this was matched with **observations** in project team meetings and further interviews with portfolio planners, functional managers and project team members in DePuy. The researcher also **participated** in the process of gathering resource information for portfolio planning. The political aspects of the system were found to be closely related to the personal aspects. To formalise the political aspects a **Stakeholder Analysis** was conducted. In the early stages, **Analytical Hierarchy Process** (AHP) was used to establish feeling about which resource planning issues were most pertinent. The AHP results demonstrate the range of personal views and suggest a correlation between the stakeholder power position and their perception of which issues are most critical.

The appreciation methods used resulted in the identification of the primary research question: How can NPD organisations quantify resource demand per project? The research question addresses both a practical issue and a knowledge gap. The question is central to the resource planning process. Process mapping and the development of flow charts suggested that resolving this issue offered global, systems wide benefits as opposed to a local solution.

Through appreciation of the resource planning system in NPD and upon identification of a key issue, it was possible to begin to establish a set of requirements for improved resource demand information.

2.3.2 ANALYSIS METHODS

The initial requirements included timely, accurate, consistent and transparent resource estimations. An obvious option was to develop a predictive model for resource demand as this would be consistent and timely.

The aim of analysis from a material point of view is to establish the underlying causal structure. This provides an opportunity to address the first step in developing a predictive model: identifying something to correlate resource demand with. This involved **analysis of the literature** specific to other examples of predictive model methods (much of which is documented in the previous section). With no other reasonable alternative, *Project Characteristics* have been chosen although other options (Events & Activities and Product Characteristics) are discussed in terms of their merits and limitations.

From a personal point of view we explore which project characteristics are perceived to have an impact upon resource demand and how this differs per functional group and between managers within functional groups. To allow this understanding, we employed a **survey** constructed in Excel featuring a list of **brainstorm**ed characteristics and a drop down menu from which managers were asked to select high, medium or low in terms of how they felt each of the characteristic impacted resource demand per project. This highlighted the need to consider interactions between characteristics and confounding variables – another requirement of the predictive model.

The social and political effects of implementing a predictive model were considered, building upon the literature review and observations from practice. A predictive model and the data required to validate the model will result in a power shift within the organisation. Power lying in expert knowledge regarding resource requirements will be mitigated as it becomes public. Should a predictive model be implemented, estimations will no longer be in the hands of individuals. Even if the benefits can be clearly demonstrated it is something that may not be widely accepted by all.

Analysis and assessment methods were carried out in tandem. From a personal and social perspective both have been assessed together.

2.3.3 ASSESSMENT METHODS

The aim of assessment from a material point of view is to explore the alternative options for modelling and, how a predictive model would work in terms of the physical and structural arrangement within DePuy.

Firstly, a literature review was conducted to enable evaluation of predictive modelling methods. A **comparison matrix** was used to identify the methods that appeared most suitable given the requirements. Methods that initially appeared to satisfy the key criteria included **regression analysis**, **case-based categorisation** and **neural networking**. However, upon further investigation it became apparent that there was not sufficient past project data available to use statistical methods successfully and judgement based methods were sought. A **Design of Experiments**, estimation based approach was finally applied.

2.3.4 ACTION METHODS

Action involved the development of the model using Design of Experiments. Within the application of Design of Experiments, several methods were employed including a **survey** which required managers to estimate the resource requirements for a specific set of **scenarios** or experimental runs.

Design of Experiments (discussed more fully in section 4.6) allows an engineer or researcher to alter several variables simultaneously to develop an understanding of the overall design space (usually Design of Experiments is used to design a new process, as opposed to establish which factors are more influential and develop a predictive model. The key advantage of Design of Experiments is that it reveals interactions between variables where are other experimental/ predictive methods are only capable of examining the impact of each individual variable individually rather than establishing the confounding effects two or more variables interacting. A further advantage is the ability of the Design of Experiments approach to provide a broad understanding with relatively few experiments as opposed to the traditional experimental approach which requires changing one variable at a time.

Three **internal case studies** examine the application of Design of Experiments to resource planning in NPD. Each case study adds to understanding, extends experience and increases conviction about the application of the process (Stake, 2000). Although experimental design is being used and the process steps are semi-defined, the application is novel and required a combination of qualitative and quantitative methods. Three case studies have been used as opposed to just one as the single case study approach has not been universally accepted as reliable, objective and legitimate (Yin, 1994). Each case study models one of three functional groups: Project Management, Design and Regulatory.

In addition to internal case studies, an **external case study** was conducted as part of the validation process to help strengthen confidence in the applicability of Design of Experiments to predictive modelling of resource demand and project phase duration.

2.3.5 VERIFICATION AND VALIDATION METHODS

There are three aspects to verification and validation:

1. Verification and validation of the predictive models

2. Verification and validation of the process followed to develop the models

3. Validation of Design of Experiments predictive modelling as an improved approach

2.3.5.1 VERIFYING AND VALIDATING THE MODELS

Verification involved making sure that the model works in the manner it is designed to work. As the model was based upon estimations, verification involved making sure that the model was at least as accurate as the estimations made by managers. To do this data from past projects was collected. Original estimations recorded for past projects were compared with model predictions for the same projects.

The first stage of validating is to ensuring that the model not only reflects the estimations made by managers, but that it reflects what *actually* happens as closely as possible. To validate the model 'actual' project phase duration and resource demand data is required. In the main case study company, 'actual' data is only available for project phase duration. No actual data is available for resource demand. Therefore, in terms of accuracy only the duration aspect of the model could be validated.

The lack of resource data prompted the researcher to find an external company interested in modelling resource requirements per project. As well as presenting an opportunity to validate the process of developing the models through **external validation,** this allowed the researcher the opportunity to seek actual resource data and validate the ability of the model to predict resource demand in addition to project phase duration.

2.3.5.2 VERIFYNG AND VALIDATING THE PROCESS OF MODEL DEVELOPMENT

The process used to develop the models involved 'tuning' by adding and removing factors in order to inflate the R-sq. (adjusted) value. An assumption was made that models with higher R-Sq. values would offer improved predictability. This assumption is tested by comparing tuned and un-tuned models developed through the project management case study.

The second aspect of verifying and validating the process involved repetition through a total of four case studies. Six internal case studies and one external case study are documented in this thesis. Within each case study, the process of forming a predictive model based upon Design of Experiments is repeated for each stage gate phase, for both resource demand and project duration.

2.3.5.3 VALIDATION OF DESIGN OF EXPERIMENTS PREDICTIVE MODELLING: AN IMPROVED APPROACH

In addition to evaluating the accuracy of the models, it is also important to explore how well the developed solution addresses the original practical problem. To evaluate this, a series of interviews have been conducted with stakeholders. The purpose of the interviews is to conduct a usability test and collect responses to and opinions about the use of the solution. The stakeholders have been asked to assess the tool against the original criteria along a 1- 5 Likert scale. For comparison and as a datum, measures describing the current methods used have also been gathered. In addition to quantitative measures, stakeholders were also encouraged to discuss any practical, organisational, personal or cultural issues they felt may impede or affect acceptance of the tool within the business. An implementation plan detailing handover of the tool to DePuy has been developed based upon the results of the stakeholder analysis. The process of stakeholder evaluation has also been carried out in the external case study company. Evaluation of the appropriateness of the solution is documented in Chapter 6.

Table 5 – Research Methods

Mingers and Brocklesby phases			Appreciation of…	RQ1.	Analysis of…	RQ.2	Assessment of…	Action to…	Verify	Validate
Define scope, Understand existing system boundaries. *Define methodological approach*	Consider validation	Material	Literature review. Exploratory case study, UML sequence diagrams, flow charts, participation.	How can NPD organisations quantify resource demand per project?	Critical review of the literature – predictive modelling methods.	Can we generate a predictive resource demand algorithm	Comparison matrix.	Data gathering, regression analysis, categorisation trees, Design of Experiments. Create solution. Survey, scenarios. Case studies	Comparison with past project data. Replication of case studies. Replication of process within cases.	Stakeholder evaluation, usability testing, implementation plan.
		Personal	Interviews. Review of the literature, observations.		Survey, brainstorm		Survey - project characteristics impacting resource demand.			
		Social	Stakeholder Analysis. Analytical Hierarchy Process Review of the literature.		Stakeholder analysis.					

3.0 APPRECIATION OF RESOURCE PLANNING IN NPD

This section begins by exploring the broad issues associated with resource planning through a review of literature which guided and was guided by practice observed in DePuy. Rather than employ a conventional literature review process, the search strategy used to develop an understanding of the field has been largely informed by issues observed in practice. In some instances literature would highlight concepts which were compared to industrial practice for example the ideas about forming teams presented by Moffat (1998); King and Majchrzak (1996); (Farr-Wharton 2003) and Odusami *et al.* (2003), although interesting and perhaps valid were not relevant in this context. DePuy do not have the luxury of picking and choosing optimal teams from a large pool of available resource.

More often than not, practical issues guided the literature search. For example, the issues of managing work load was raised by an internal company survey (separate from the research work), this provoked a literature search for optimal work-loads and lead to the realisation that there was in fact a knowledge gap in this area.

Rather than presenting the investigative work as a series of isolated reviews the insights and observations are synthesised using a framework employed by Mingers and Brocklesby (1997) and the skeleton of a hierarchical planning process proposed by Anderson and Joglekar (2005) with a view to understanding the fundamental planning issues and research gaps.

Anderson and Joglekar's (2005) hierarchical planning framework has been chosen as a starting point for discussions (See Figure 6). The strength of the NPD planning model presented by Anderson and Joglekar is the simplicity of the view of the whole system, and the clarity it provides regarding the significance of resource information or, as they refer to it, the 4^{th} or "Infrastructure Level". The model negates some of the difficulties we have with managing the complexities of each individual level and allows us to think about resource planning in a way that encourages us to depart from the tendency to develop localised solutions (i.e. a tendency to develop solutions that suit one main stakeholder or group of stakeholders whilst neglecting synergies or detrimentally impacting the rest of the business). Accepting Anderson and Joglekars' model as a basis for discussions provides us with a clear and singular view of the components of the whole NPD planning system. We are then able to focus in on developing a global approach to the issue pertinent to all levels of the process and then having developed an approach, move back to a system wide view in order to ensure that a global rather than local solution has been developed.

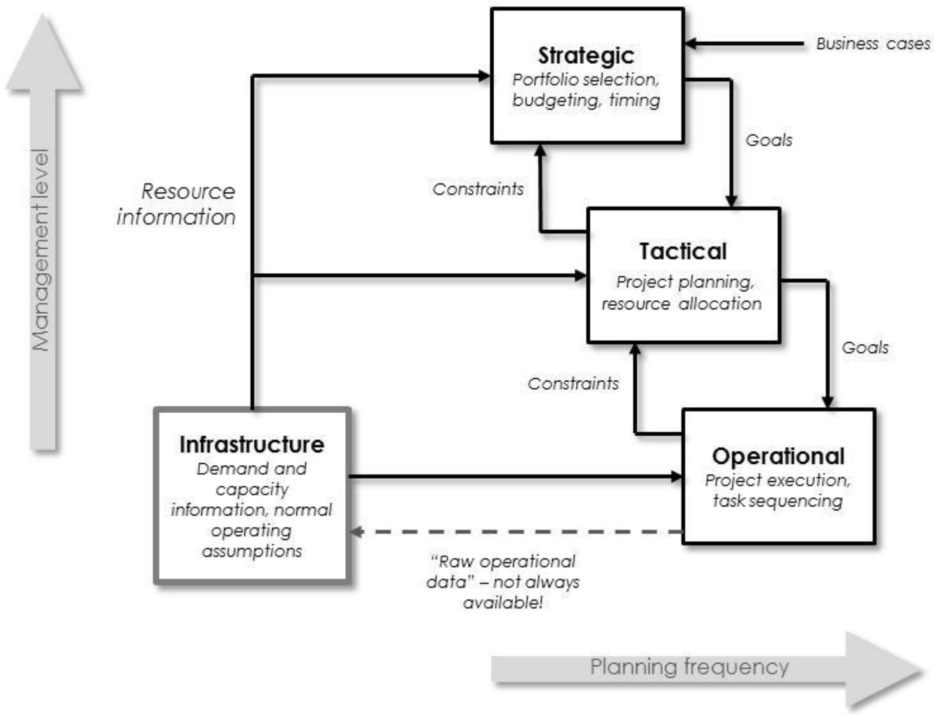


Figure 6 - Adaptation of Anderson and Joglekar's (2005) Hierarchical planning framework

Anderson and Joglekars' (2005) model serves a specific purpose in their paper: to link stochastic decision models and allow the potential for corrective action at all levels of planning. Their developed model is conceptual rather than an observation of practice: it provides an abstracted, simplified version of reality. The details of and interactions between the three well established planning levels (Strategic, Tactical and Operational) are well described in both the paper and other existing literature for example: Military - (Millett and Murray 1988); Logistics-(Schmidt and Wilhelm 2000); (Gustavsson 1984), whereas the description of the 4th infrastructure planning level is questionable: planning horizons and frequency of planning are described as "*not applicable*" (p.346).

In terms of resource planning, the literature reports a wide range of issues and approaches from a variety of perspectives; from physical tools and techniques that can be applied to organise data and generate estimates, to social issues such as organisational politics and personal agendas and biases through to personal issues, for example the cognitive process of making estimates and perceiving the complexities of the situation. Interviews conducted in the case study organisation reflected the same diversity of perspectives. This initial review of resource planning as a system has shown that resource information is fundamental to all levels of planning, it is poorly understood and improvements at this level (rather than at a local level) would have impact and benefits system wide. We have begun to address RQ 1: Can we provide an improved resource planning solution for NPD through the application of a Systems Approach and Systems Engineering tools and techniques? The next question to emerge is: Can this approach be achieved through improving the resource information system and if so, how?

In order that the diverse range of resource planning perspectives and issues can be appreciated; both within DePuy and in literature, three distinct perspectives have been adopted: Material, Social and Personal. As the aim of the research is to develop an objective, reliable understanding of resource information, and one as close to reality as possible, emphasis has been placed upon the quantifiable, Material view. The other views (social and personal), although no less "real" are important to how resource information works in practice but are not likely to reflect the essence of quantifiable data or information free from bias. Practically, it is useful to have an understanding of social and personal views so their influence on the quality of resource information can be managed and minimised rather than to accommodate personal or social preferences. For this reason the majority of this chapter focuses upon description of a material view. Personal and Social views are not the focus and receive less in-depth discussions.

This chapter documents findings from literature and compares the theory with evidence and examples of practical experiences within DePuy. To conclude we state the research questions that are generated and built throughout and specify the requirements of a new approach to resource planning in NPD.

3.1 MATERIAL VIEW OF RESOURCE INFORMATION IN NPD

Taking a material systems view provides us an opportunity to consider the physical circumstances or, in terms of a process - the 'physical' events or process stages that actually happen in order to make NPD resource planning work. The literature, and the current approach to planning (reflected in Anderson and Joglekar's model), can be categorised as Strategic, Tactical and Operational. At each level, the process differs as Design of Experiments the granularity of information required, the frequency of decisions, the horizons and the decision makers.

In this section, we present our experiences of the resource planning system in three flow charts; one for each level of the resource planning process.

3.2.1 STRATEGIC RESOURCE PLANNING

Strategic planning in NPD relates to optimising a portfolio of projects in-line with the goals of the organisation. This extends to understanding the ability of potential projects to contribute towards the achievement of organisational goals, ranking potential projects and selecting new projects and terminating projects that do not align with strategy. Anderson and Joglekar (2005) propose that strategic planning requires resource information and information from business cases. Essentially, the business case information is an outline of the project characteristics and it could also include resource information relating to the project. Observations and participation in resource planning activities within the case study company lead to the development of Figure 8 which expands on the simplistic view of strategic resource planning presented by Anderson and Joglekar (2005). The main focus of Figure 8 is the generation of the resource information as opposed to the mechanisms of portfolio optimisation.

The process of NPD planning is essentially about deciding which projects to assign resource to in order to stand the best chance of achieving the strategic goals i.e. making sure resources are being used effectively with respect to strategic goals (Cooper, Edgett and Kleinschmidt 1999; 2002). The decisions regarding where to assign resources is traditionally based almost exclusively on markets and product analysis (Wernerfelt 1984; Iansiti and Clark 1994). Understanding whether the business has the resources available to actually carry out the proposed projects is equally significant to setting the goals, and ought to begin with understanding the resource demand for planned projects and the resource demand across the portfolio (Cooper and Kleinschmidt 1993; Cooper 2003; Smith and Reinertsen 1998). Literature referring to the Resource Based View (RBV) extends this concept by suggesting that strategy should be built around an understanding of the unique qualities of the resources an organisation possesses if competitiveness is to be sustained (Peteraf

1993); (Lings, Wilden and Gudergan 2009). Whilst the resource based view of a firm is theoretically sound and has been successfully applied in practice (Barney 1991, Barney 2001), this paper specifically explores the practical issue of quantifying resource demand and capacity with a degree of confidence and in a manner that will support an overall pre-determined vision of the business. The availability of resources has an impact on the strategic goals that can be perused. This paper Design of Experiments not give attention to the formation of these goals.

(Van de Ven 1999) notes that plans developed in the front end stage often serve more as 'sales vehicles' than as realistic planning scenarios. Linear development frameworks (for example the Stage-Gate process – employed in DePuy and depicted in Figure 7) tend to produce incremental development. (Cooper *et al.* 1999) recommend the use of Strategic buckets to encourage a mixed selection of radically innovative and incremental projects in-line with organisational goals.

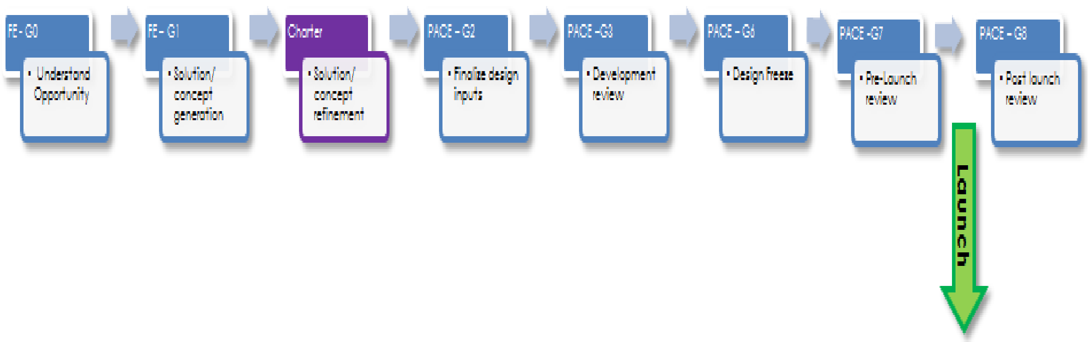


Figure 7 – The Stage-Gate process employed to manage New Product Development projects in DePuy

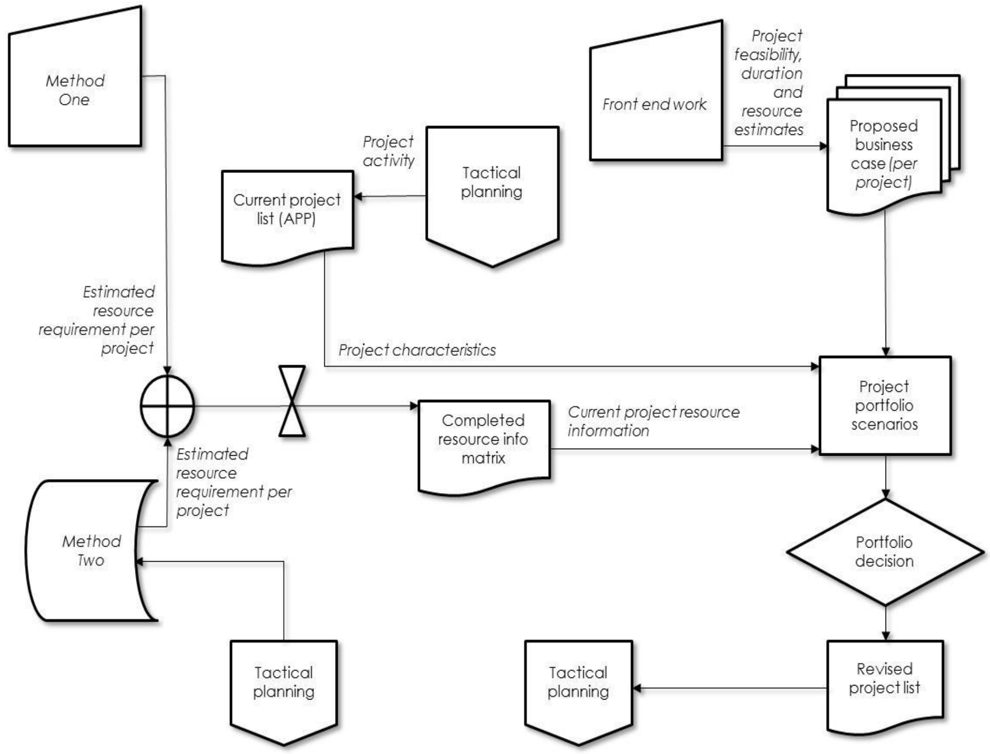


Figure 8: The observed planning process at a strategic level. Resource information merged with project information in order to make decisions about portfolio optimization. Resource information is either generated through estimates (method 1), rolled up from tactical project estimates (method 2) or, a combination of both is used – method 1 for potential projects and method 2 for projects already resourced. (Standard flow chart symbols used).

Resource information generating Methods One and Two shown in Figure 8 are quite different. UML sequence diagrams have been used to show in more detail how the information is generated. Figure 9 demonstrates Scenario One and how resource demand per project is estimated by functional leaders. Figure 10 demonstrates how estimations can be made by rolling up tactical project data. Comparing the two scenarios, it is clear why Scenario One takes longer – it involves more steps and includes the process of considering the nature of each project and generating estimations accordingly. This process can take weeks or, even months for a large portfolio of projects. Often by the time the estimations are collated, they are out of date as projects have been cancelled or the portfolio optimisation priorities have changed. Scenario Two takes less time. In-fact, for a project already underway (provided the data is organised in a suitable system), it can take seconds. However, the managers making the estimates in scenario two 'own' the projects and, as such may not be best placed to provide unbiased estimations. In the case study company efforts are underway to move from Scenario One to Scenario Two. This will not be a complete shift, as for new projects or potential projects scenario one estimates will still be required.

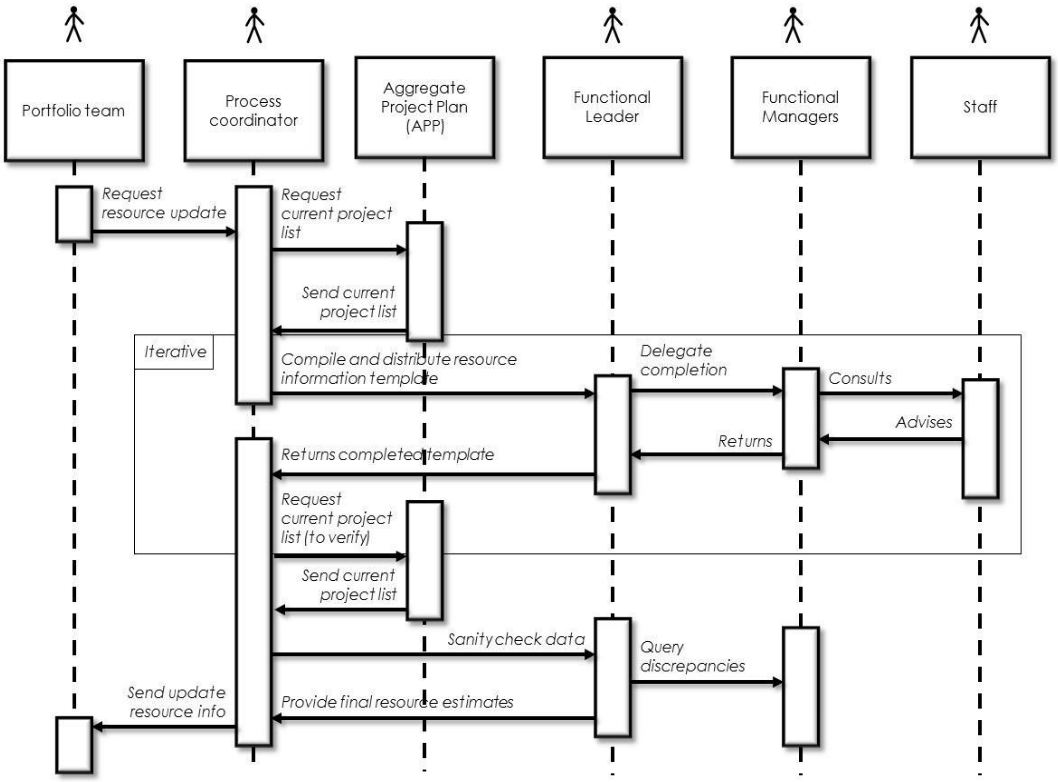


Figure 9 - UML sequence diagram. Observed Resource estimation generation Method One - Requesting estimates of resources required per function from managers using a template and updated project list.

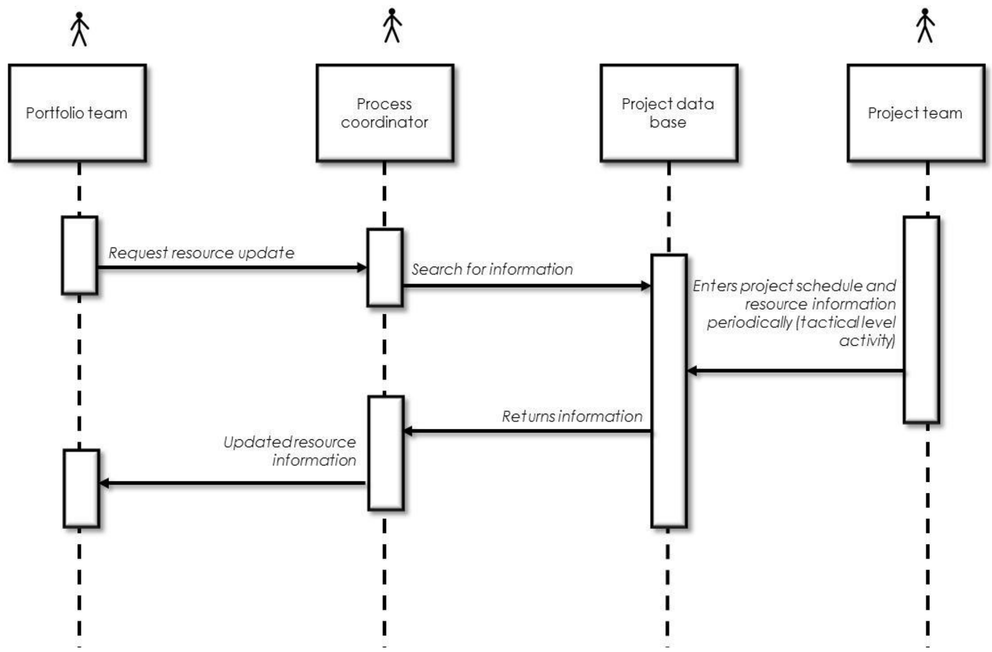


Figure 10 - UML sequence diagram. Observed Resource estimation generation Method Two – Estimates periodically updated by project teams ready to be retrieved as required.

Method One (depicted in Figure 9) aligns with a traditional body of work which examines the allocation problem *a priori* (De Maio, Verganti and Corso 1994); (Hendriks, Voeten and Kroep 1999); (Payne 1995) (Wheelwright and Clark 1992); (Repenning 2001). The researcher participated in the collection and analysis of data using method one to gain experience of current resource planning methods and the related issues. Several issues were identified namely, different managers have different perspectives of resource requirements, collecting estimates from management takes a lot of time (3 months) and during this period the project list has often changed. Method Two (depicted in Figure 10) moves on from this approach, pulling strategic resource information up from a tactical level of planning. This information includes consideration of the dynamics of multiple project environments in terms of activities being revealed and the fluctuating forecast patterns of resource availability as is typical in NPD (Engwall and Jerbrant 2003); (Cooper and Kleinschmidt 1993); (Joglekar and Ford 2005). In practice, each project schedules its activities independently with its own resources (Kim and Leachman 1993); (Speranza and Vercellis 1993); (Yang and Sum 1997). Although Method Two provides information which is generated in shorter time frames, with up to date project information available, it is still estimated on a project-by-project basis by managers who have invested in the projects.

In addition to the timeliness of estimates and the changing Aggregate Project Plan (APP), the accuracy of the actual estimates is also an issue at the strategic planning level. Detailed and theoretically rigorous approaches to portfolio optimisation are widespread – extensive examples are provided by (Kavadias and Loch 2004). However, without confidence in the information going into the optimisation process, rigour and effort invested in processing is largely wasted. Without 'actual' data (i.e. post-event recording of time spent on projects) to compare with predictions accuracy remains unknown. Despite the importance of accuracy, the literature advices against such data gathering measures in NPD. Timesheets are "*unpopular, misleading and open to interpretation*" (Pawar and Driva 1999). A contradiction can be perceived to exist between what are perceived as '*instruments of control*' or a means of measuring performance and organic management efforts to promote creative thinking and innovation (Webb 1992). Additionally, once exposed to time recording, the value of time becomes more explicit, consequently the effects on volunteered time could be detrimental (Pfeffer and DeVoe 2009). In order to be confident in the decisions made at a portfolio level, the organisation must have confidence in the accuracy of the estimates. Strategic level managers and portfolio planners have no means of assessing whether estimations are accurate or otherwise. A danger remains that poor information used blindly could potentially result in unjustified confidence being placed in decisions that are critical to the success of the business. Unless resource information is evidence based managers cannot be sure the best decisions are being made for the business.

At the strategic planning level the key resource planning issues are the timeliness of information and the low levels of confidence that can be placed in resource information due to unconfirmed accuracy. Without this, even the most rigorous portfolio optimisation approaches are rendered ineffective.

3.2.2 TACTICAL RESOURCE PLANNING

Tactical project planning proceeds once the portfolio has been decided upon. Planning at a tactical level involves setting out the means by which the project will be achieved. This involves forming a project team, deriving a starting plan then monitoring activities as they progress (where operational planning feeds in) and adapting the plan accordingly. In a multi-project environment, project managers often need to present a case to get more resource on their project. It is in the planner's interest to ensure that their project is resourced well enough to proceed efficiently and to plan otherwise the project may be perceived as less able (relative to potential or existing projects) to deliver in line with strategy and resources may be reallocated. Figure 11 demonstrates how resource estimates are central to tactical planning. Without an evidence based approach, personal agendas and biases will continue to exist.

In addition to understanding resource requirements, it is the responsibility of managers at a tactical level to ensure the correct resources from various functions are available for projects at the time they are required, and that they are configured in a manner that will allow the project (and portfolio of projects) to meet the organisational goals effectively and efficiently (Belhe and Kusiak 1997).

Resource planning in a NPD environment differs from other planning environments in that it is inherently characterized by uncertainty (Anderson Jr and Joglekar 2005); (Atkinson *et al.* 2006); (Pich *et al.* 2002); (Hastings and McManus 2004). Traditional planning environments tend to 'freeze' requirements early thus giving clear guidelines as to what must be achieved (De Weck and Eckert 2007); (Earl *et al.* 2005). Complexity is often cited as being the source of process improvement failure regardless of the type of process: from products (Repenning and Sterman 2002), to organisations (Park and Ungson 2001), to chemical plants (Venkatasubramanian *et al.* 2003) (Ford and Sterman 2003b, Ford and Sterman 1998, Ford and Sterman 2003a)Ford (2003) describes the "*hallmark*" of such failures as being disjointedness between the various elements of complexity and the mental models of the managers responsible. Managers can find it difficult to include interactions and feedback in such mental models. Consequently they often act in a manner which is seemingly sensible from a local, short term perspective but in the long run leads to failure due to the inevitably flawed sense of complexity (Diehl and Sterman 1995, Sterman 1994).

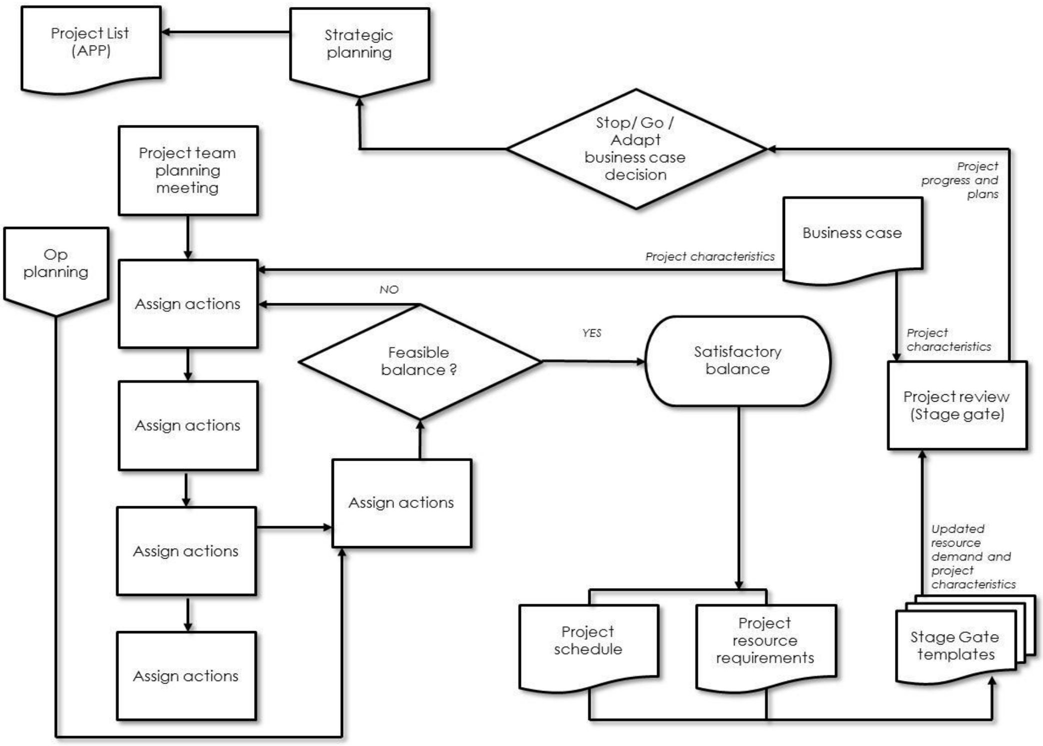


Figure 11 - Observed Tactical planning in NPD highlighting the source of resource information as estimations. Resource demand estimation is based upon estimations of the events and activities required to complete the project/ each project phase. (Standard flow chart symbols used.)

Most planning seeks to minimize uncertainty regarding the events and activities that may occur as a process becomes operational. Traditional approaches to planning are event and activity based (for example Work Breakdown Structures, Program Evaluation and Review Technique and Gantt charts (Özdamar and Ulusoy 1995) (Van Oorschot, Bertrand and Rutte 2005); (Kerzner 2006)). NPD differs from most planning environments in that it is an exploratory process where uncertainty must exist as an integral component of innovation (Tatikonda and Rosenthal 2000) (Sim and Duffy 2003) and each project is unique (Lévárdy and Browning 2009). If planners were fully aware of all the outcomes at the outset of a project there would be no purpose in carrying out and investing in the NPD process (Atkinson *et al.* 2006). Despite this difference and with no workable alternative to be found in the literature, planner's force-fit the same traditional tools to NPD, compensating for uncertainties by using estimates rather than actual data to make decisions (Chapman 2000; Gino and Pisano 2006). At a tactical planning level the key resource information issue relates to the accuracy or unknown accuracy of the estimations driven by the uncertainty and complexities inherent in the development process.

3.2.3 OPERATIONAL RESOURCE PLANNING

Operational planning is the action part of the process where progress is made. In this sense operational planning differs from the first two levels. The effects of the decisions made and processes employed for decision making play out here, impacting the capacity of each team member. At strategic and tactical levels the business has influence over the process steps whereas at an operational level they are very much up to the team member. At this level, the importance of the capacity of the individual becomes much more explicit as Design of Experiments the effects of workload upon productivity. A material view of the operational planning process is shown in Figure 12.

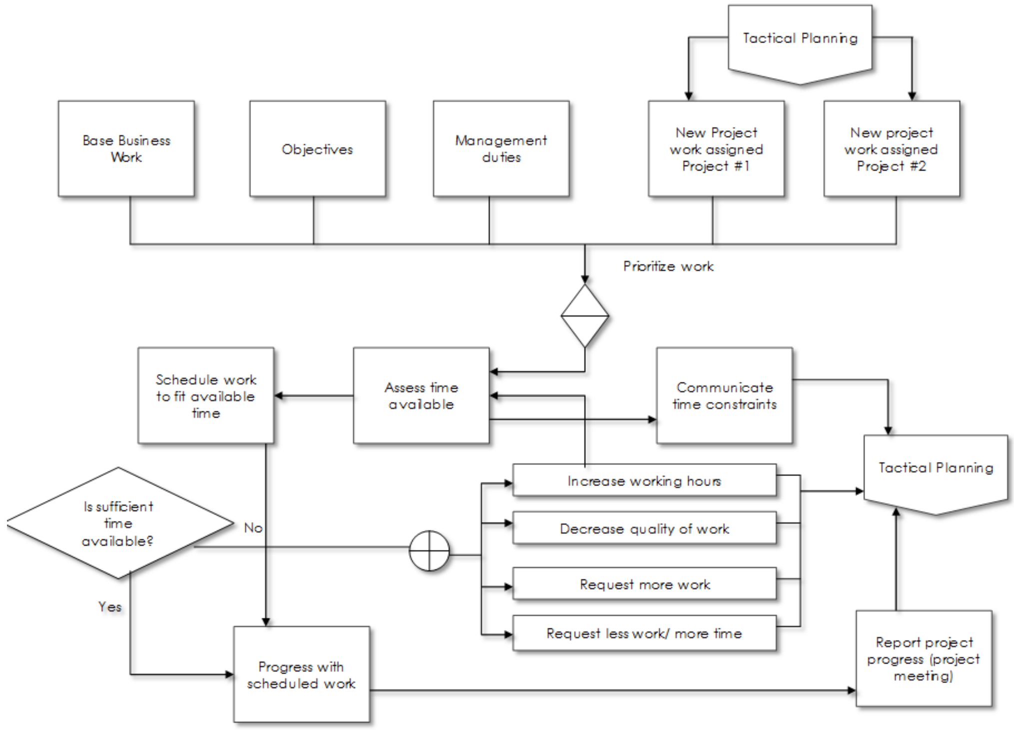


Figure 12 – Observed Resource planning at an operational level. Decisions made here are not often based on data or logic or, the "best" solution for the business but are heavily affected by political and personal agendas influenced by the effects of planning decisions further up the hierarchy. Standard flow chart symbols used.

It is clear from this view of the system that it is not only the number of people available to do work that is important but also the capacity of each member of staff to complete work. Wheelwright and Clark (1992) refer to the concept as 'the canary-cage approach', i.e. the number of projects assigned to each engineer has an effect on their capacity to make progress due to set up time and increased planning required. (Wheelwright and Clark 1992) suggest that two to three projects is an ideal amount for an engineer as this provides a balance between waiting for work to be completed by others and the amount of time required to plan and cognitively adjust to new tasks. Other factors are likely to influence this model, for example the organisational culture, the type and size of projects and, the attributes of the individual (Haque *et al.* 2000); (Schmidt, Montoya Weiss and Massey 2001).

(Anderson Jr and Joglekar 2005) model suggests that the resource demand and capacity information is generated at an operational level. This implies that time spent on projects is recorded post-event via a web-based logging system or timesheet document. In practice, no evidence could be found in the literature to suggest this is the case. Such activities are closely linked to performance management and business process re-engineering. In a time when redundancies are frequent, and in organisations where development staff are committed to providing quality work, close monitoring of such efforts could be detrimental. Also, before introducing a further bureaucratic measure it is important that purpose, value and effects of the measure across the systems are understood and communicated.

At an operational level, if we wish to have more confidence in resource information and resource planning decisions, there is a requirement for more formalised methods of assessing time available and ideal loading levels for project team resource. In other words a more accurate expansion of (Wheelwright and Clark 1992) "canary cage" theory inclusive of the characteristics of individual projects and possibly the skills, experience and character traits of the resources. Too much work acts as a stressor. As well as the short term drop in productivity, there may be longer term consequences of poor planning and resource information – not just immediately for the business in the short term, but also in the longer term as employees become de-motivated (Kim and Leachman 1993).

Many of the issues at this level are better reflected through personal and social systems views. It reflects the effects of planning. Planning at this level is a personal responsibility; although it affects other team members or other projects it is controlled by the person carrying it out. The effects of overloading staff can be detrimental to the business impacting stress, motivation and productivity (Mohr and Puck, 2007; Zika-Viktorsson *et al.,* 2006; Goldratt,1997). They are affected by agendas, perceptions and biases as well as organisational politics and perceptions of power and control.

3.2 SOCIAL VIEW OF RESOURCE PLANNING IN NPD

This section addresses resource planning from a social perspective. We review the effects of the resource information estimation process upon social practices, power relationships and the organisation as a whole. Adopting this view allows us to examine the effects of making estimations on the people at different levels as well as the interactions between levels.

3.2.1 POWER RELATIONSHIPS

Each level of planning exerts a different sort of influence over the planning system (See Table 6). Strategic management, at the top of the hierarchy determines the content of work and makes decisions regarding which project will run/ not run. At a tactical level, project managers and functional leaders control and manage the resource information – it is at this level that personal agendas, biases and the effect of political influence impact resource information. Operational resource (the project team members who carry out project work), influence productivity and the achievement of goals set at the strategic level. Although strategic managers are at the top of the hierarchy, they have little direct influence over the quality of resource information or the productivity of project teams. Conversely, despite the influence over the resource information used to make decisions, strategic managers make the decisions that have the most impact upon business success. Project management has little direct control of productivity although the information they provide will have an influence; by exerting their influence, each level of planning manipulates the success of other levels. Depending on the situation, this may or may not be in favour of the organization. For example, project principles are often shaped in positive ways to meet scoring criteria better; people can play games to establish criteria that support personal agendas (Englund and Graham 1999).

Table 6 - Spheres of influence and control

Planning level	Roles responsible	Influence
Strategic	Portfolio managers, directors	Resource Decisions
Tactical	Project management, functional leaders	Resource Information
Operational	Project team members	Resource Productivity

Perception of complexity impacts a managers partiality (Bendoly, Perry-Smith and Bachrach 2010). Whilst sharing resources may be of benefit to the organization as a whole, the direct benefits to a project manager may be less clear. In fact sharing resources may negatively impact the performance of the resource manager depending on how their performance is measured. It could be argued that, in the case of NPD, when the decision to continue or terminate a project is effectively taken out of the project managers' hands at each review, the logical option to promote project survival is to compensate by inflating resource demand predictions early on. Alternatively, the opposing behavior may be displayed. One functional manager in the case study company was highly reluctant to submit resource demand estimates for non-project work when the total demand for project work balanced with resource available. This manager perceived that not having enough resource to complete all assigned tasks reflected on their ability to manage. They were biased towards underestimating resource requirements. Clearly, neither form of bias (over or under-estimating) works in the favor of the organization.

3.2.2 SOCIAL PRACTICES

Everyone sees things differently based upon experiences and individual characteristics. When it comes to making resource estimations each person is likely to have a different view and as experience, skills, position, role, personality or any other characteristic of the individual changes the perspective of that individual is likely to change as well. Although it is highly complex to fully understand each individual's perspective, the literature reports certain patterns of behaviours that are played out as agendas and biases.

Some organisations exhibit culture based activities, incompatible with open and honest communication and control mechanisms. Such activities serve to protect managers who feel the complexity and uncertainty stems from their inability to cope (Ford and Sterman 2003b). Skewed, false and biased data transferring between levels is fundamentally unhealthy to the organisation as a whole. Such behaviours are described by (Sterman 2004) as '*conspiracies of optimism*', '*macho management*', '*blame culture*', and '*management misdirection*'. In any ostensibly cooperative situation, different individuals will have different priorities and perceptions of objectives, resulting in diversified approaches to issues, communication, and management of uncertainty and planning. The situation will be exaggerated if the knowledge and perceptions of uncertainty are inconsistently spread across the team (Chapman and Ward 2000); hence the need for open communication. (Atkinson *et al.* 2006) report that such behaviours reflect an inability or unwillingness to recognise the difference between bad management and poor performance due to factors out with management control, and good managers who apply proactive uncertainty management to reduce problems, and managers who are just 'lucky'. In organisations experiencing such issues there is likely to be a lack of trust and feelings of vulnerability in terms of opening up about competencies and issues. Lack of trust is exemplified in political behaviours "*when people choose their words and actions based on how they want others to react rather than what they really think*" (Lencioni 2002). Managers may ignore, hide or delay communications (Yassine *et al.* 2003); fail to recognise certain information in front of them due to organisational routines and filter (Henderson and Clark 1990) or distort data – often referred to as gaming (Ford and Sterman 2003a).

Terminating projects is likely to demoralize project managers and team members and could increase concerns about job security (Balachandra, Brockhoff and Pearson 1996). This is an effect of removing the decision making control from the otherwise autonomous team who on the whole coordinate their own activities. Gerwin and Moffat (1997) suggest that this has serious repercussions. Wheelwright and Clark (1992) point out the importance of shared understanding in decision making. Where the mechanisms for generating the decision-making information (resource information) is not explicit, the effects of withdrawing autonomy are likely to result in increased frustration and de-motivation, whereas if the decision logic can be clearly communicated, dissatisfaction with the outcome is more likely to be short lived. (Cooper 2006, Cordery *et al.* 2009) support this argument by demonstrating performance improvement increases with team empowerment.

Socially, actors in the planning system will wish to protect their own interest or the interests of their team. This may or may not be congruent with the interests of the wider organisation. An estimation-based resource information system allows biases, and agendas and misunderstandings to exist tacitly and unchallenged.

3.3 PERSONAL VIEW OF RESOURCE PLANNING

The personal view of resource planning examines the process unique to the estimator and the qualitative tools and techniques that can be used to manage complexities. We also explore the impact of the estimation process upon the individual beliefs, meanings and emotions of the other people in the organisation. Each will be discussed separately.

The process of generating estimates is applied to each of the estimations described in the material view. With numerous occurrences of estimations being made at each of the NPD planning phases, it is easy to see how things can become confusing; confidence in decisions can be lost, poor decisions can be made and political behaviours can emerge. The components of the estimation process are documented in Figure 13.

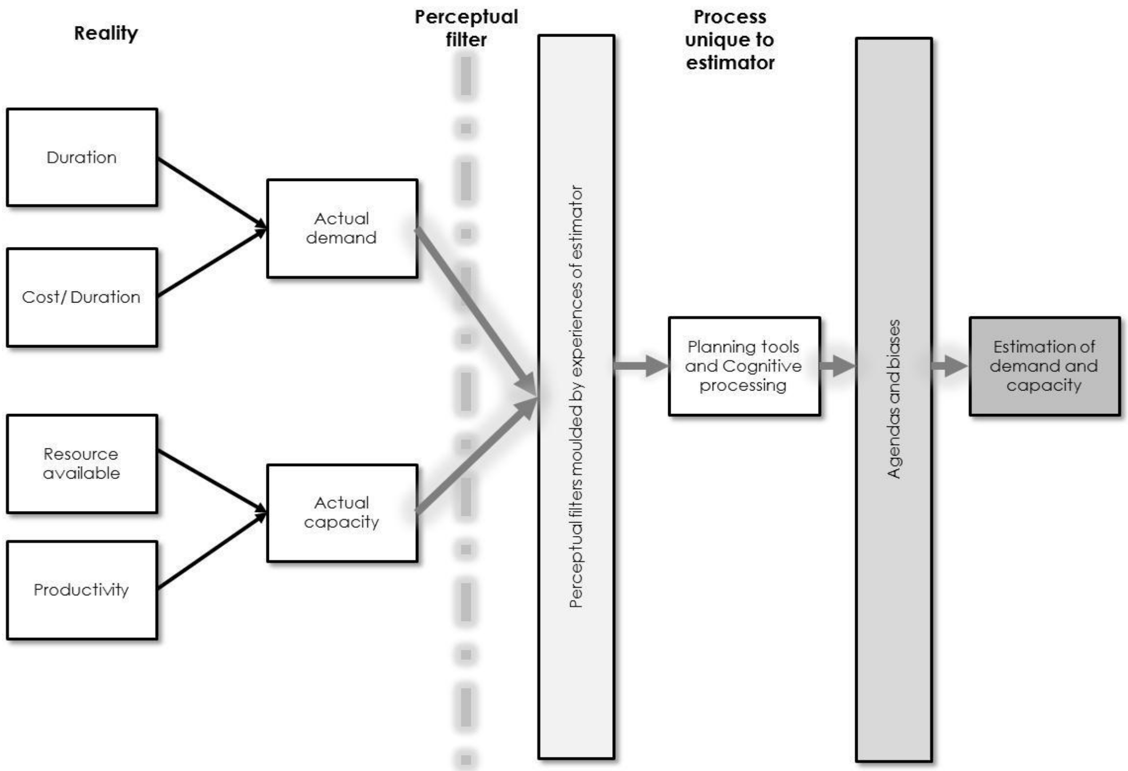


Figure 13 – Conceptualisation of the components of the estimation process: from literature and observation

Generating resource estimations is clearly complex even with experience. Usually the various decision components are not considered explicitly, a high level 'guess' is made based upon experience and tacit knowledge or analogies with previous projects. The dilemma of the manager is emphasised when the dynamic nature of a multi-project environment is considered (Lee and Miller 2004); (Zika-Viktorsson *et al.* 2006). The perception of the factors and their relationship to the estimate (independent of biases and agendas) is likely to vary from individual to individual. It is conceivable that the perception of each individual will be shaped by a number of dynamic factors including experience, personality, role, attitude to risk etc. The perception of each planner is likely to change with time and furthermore, perception is likely to change planner to planner. Differences in perception can lead to misunderstandings. The lack of transparency and inconsistency between approaches can provide context for the growth of the political behaviours described in the previous section. Tools used to formalise the process of capturing estimates could serve to compound the illusion of accuracy resulting in confidence being placed in inaccurate estimates that are superficially rigorous and effort-consuming to generate.

3. 5 THE FORMALISED PROBLEM

Appreciation of the resource planning systems has led us to the conclusions that an improved approach to developing resource information holds potential for system wide benefits. Key requirements of resource information are: ***Timeliness*** of resource demand and capacity information generation, ***Accuracy*** of resource demand and information, ***Consistency*** of resource demand and capacity information and, the ***Transparency*** of resource demand and capacity information. A summary of the key issues at each level is included in Table 7.

Table 7- Appreciation summary: Resource information needs to be timely, consistent, transparent and accurate

Systems view	Appreciation (Investigation outputs)
Material	Resource information used in NPD is based on estimation. This makes the whole NPD planning system much more complex, bureaucratic and **time consuming** than the one proposed by Anderson and Joglekar (2005). Additionally, the **accuracy** of the end result is un-established resulting in low decision confidence.
Social	If a new approach is to be implemented, it is critical that it is **transparent** and **consistent** in order that personal agendas and biases are minimised and the goals of the organisation become the focus.
Personal	The complexities and uncertainties of NPD make resource planning difficult. Decisions made (as well as the process of making decisions) can affect motivation, productivity, effectiveness and, ultimately business success. Transparent resource information will improve confidence, trust and consequently and motivation for Project Core Team members as well as having an impact upon their job demand levels.

It is clear from the discussions generated by each view, that there are several shortcomings with the current planning system. Material, social and personal views of planning are connected. In order to develop a practical solution we must consider each aspect. The key concern, fundamental to all levels of planning is:

RQ2: HOW CAN NPD ORGANISATIONS BETTER UNDERSTAND RESOURCE DEMAND PER PROJECT?

Our understanding of the current methods used suggests that a transparent, timely, consistent and accurate method is required. One means of doing this could be to develop a predictive model. This leads to RQ3 which serves to specifically address RQ2.

RQ3: CAN WE GENERATE A PREDICTIVE RESOURCE DEMAND ALGORITHM?

4.0 ASSESSMENT OF PREDICTIVE MODELLING POSSIBILITIES

The preceding chapter set out the fundamental issues associated with the resource estimation process in NPD. Timeliness and accuracy of resource information are the main concerns, closely followed by consistency and transparency. Both timeliness and consistency could be guaranteed by a predictive model. Through formulaic, statistical processing of inputs a model will theoretically generate resource information quickly without the need for any specialist knowledge required to make resource estimations. Using the tool an experienced manager and a complete novice would generate the same response for any given set of inputs.

The degree of transparency is dependent upon the method procedure applied and accuracy will remain unknown until the model has been developed and its outputs verified against actual project data.

Creating a predictive model is the most obvious avenue to explore.

This chapter explores the first series of considerations that were made when considering the possibility of applying predictive modelling to address DePuy's resource information challenges. The main considerations are the modelling method (section 4.1) and the considerations of the modelling mechanics. For example: which inputs to use and how to quantify the output i.e. resource (section 4.2).

4.1 PREDICTIVE MODELLING METHODS

A variety of forecasting methods are presented by Armstrong (1985). Current resource forecasting methods (with the exception of COCOMO) tend towards the left hand side of Figure 14.

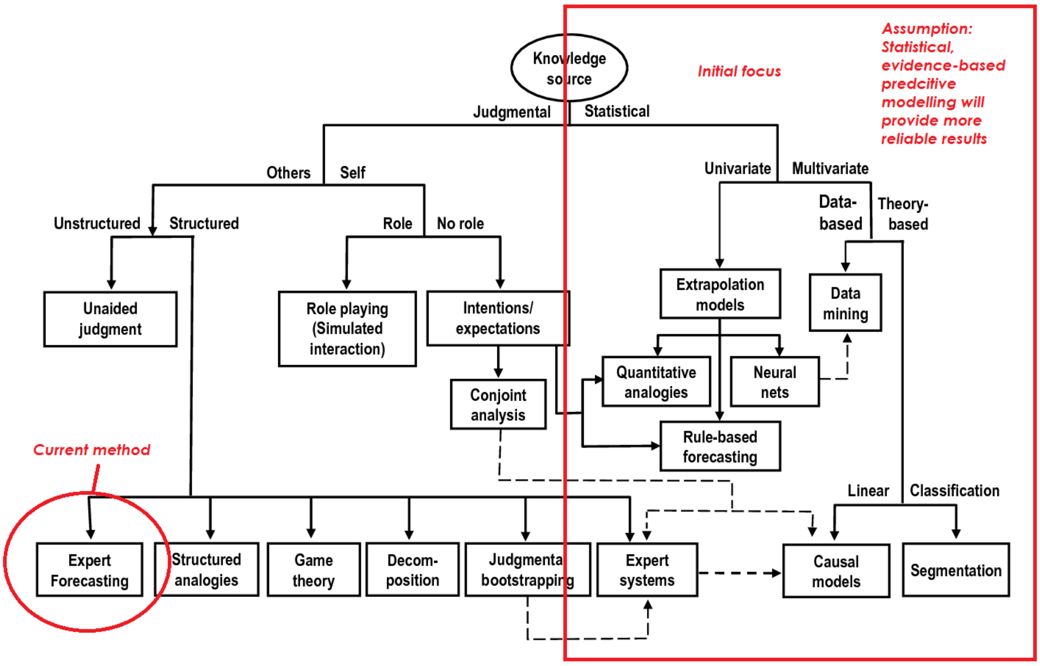


Figure 14 – Forecasting methodology tree. Adapted from Armstrong (1985) to show current method in DePuy. Initial research focus on statistical methods as evidence (past project data) based approach should instil more confidence in model accuracy.

In practice, methods such as structured analogies are applied at a tacit level. The issue with such judgemental methods is the scope for agendas and bias. Section 4.1.1 examines the judgemental methods presented by Armstrong (1985) and assesses their potential to be applied.

Statistical predictive modelling would mitigate the need for estimations and would allow project managers to gain control of resource information, thus enabling them to make transparent decisions free from agendas and bias with the interest of the business at heart. In Section 4.1.2 Statistical modelling methods are considered against the resource information requirements generated through the assessment of current practice and theory: accuracy, timeliness, consistency and transparency.

4.1.1 JUDGEMENTAL MODELLING APPROACHES

(Armstrong, Green and Statistics 2005) report a comprehensive range of judgement or estimation-based demand forecasting methods (non-specific to NPD). Table 8 summarises each method and provides examples of where it has been observed to have been applied in practice or how it could be used in an industrial, practical context as a planning tool, or in an academic context with a view to providing more insight to the estimation process.

Table 8: - Methods for developing judgemental demand predictions (i.e. estimates) derived from (Graefe and Armstrong 2011, Armstrong *et al.* 2005)

Method	References	Description	Observed to be used in NPD planning in practice.	Potential to be applied
Unaided Judgement		Estimates that do not use evidence based procedures. Valid when expert is unbiased, receive timely, accurate and well summarised forecast feedback.	Yes, commonly used method of deriving resource estimations.	Actual demand data required for comparison; Simple relationships and a stable well understood environment are also required. Therefore, Low potential.
Delphi	(Linstone and Turoff 1976)	Forecasts are gathered from 5-10 experts and gradually refined.	No – too time consuming for standard NPD practice.	Potential to provide insight into knowledge and reasoning of resource planners.
Structured analogies	(Green and Armstrong 2007)	Search for a scenario similar to situation for which prediction is required. (Range of experts providing one opinion each).	Yes, although in an ad-hoc rather than structured manner.	
Game theory	(Shubik 2006)	Identifies incentives that motivate parties and deducing decisions that they will make. Low accuracy reported in literature.		Potential to provide further insight into agendas and biases.
Judgemental decomposition	(MacGregor 2001) (Webby, O'Connor and Edmundson 2005)	Divides the forecasting problem into parts. Different methods may be used for each part. Useful for high uncertainty situations.	Partially – estimations are commonly divided by project/ function/ time.	
Judgemental bootstrapping	(Goodwin 2002)	Used to create a formal model from experts subjective judgements. Regression equation. Less likely to improve accuracy when there are many variables or, correlations between variables.	No – too many confounding variables to use regression models.	Could be used to create a predictive model where no data is available.
Expert systems	(Jackson 1990)	Structured rules used by experts. More accurate than unaided judgement. Requires a combination of methods to develop system.	No	

Despite such extensive methods being available, none of the above with the exception of unaided judgement and the tacit, non-explicit use of analogies has been observed in practice or found in the literature. The NPD resource planning literature is more likely to refer planners to highly generalised heuristics. For example: "*a wise planner consumes no more than about 50 % of one person's time*" (Englund and Graham 1999) or, "*fewer projects means more actual work gets done*" (Wheelwright and Clark 1992).

Estimation affects individual productivity in the sense that overloading induces stress and divides the attention of staff whilst potentially increasing the overall time required for re-familiarising with frequently shifting packets of project work. Additionally, quality of work may be affected (a key motivator for many development engineers). The negative consequences of overloading experienced by the people carrying out project work can affect trust in decisions made at higher levels: an understandable resentment for planning processes, bureaucracy and management can build which in turn leads to further reductions in productivity and a lack of willingness to embrace new improvement initiatives.

Fundamentally, an estimation-based system is open to the risk of reduced productivity and decisions being made at all levels that do not align with the interests of the organisation.

4.1.2 STATISTICAL FORECASTING METHODS

Various modelling methods exist but some are more suitable than others. As per the criteria originally laid out in Chapter 3, the method must be accurate, timely, consistent and transparent. Armstrong, (1985) describes a wide range of methods for modelling knowledge. Initially, we favour a statistical approach over a judgemental approach. The judgemental approach was instinctively dismissed as judgements can be closely associated with agendas and bias. An evidence-based approach utilising past project data offered a preferred route from a business point of view. It is critical that there is confidence in the information decisions are based on, and if it is evidence based this infers confidence.

To establish a starting point, the some of the statistical methods presented in **Error! eference source not found.** were compared against the requirements of a new approach to resource planning information. A matrix describing the comparison is presented in Table 9.

Table 9 – Modelling method comparison matrix

Modelling method	Description	Accuracy	Timeliness	Consistency	Transparency
Neural Networks	Models data via hidden layers. Can learn and adapt as system inputs and relationships to outputs change over time.	Unknown	Good	Good *	Poor
Rule/ case based forecasting/ categorisation	Data sets organised according to rules or past cases or data.	Unknown	Good	Good	Fair
Regression analysis	Statistical relationships between inputs and outputs quantified.	Unknown	Good	Good	Fair

Some discussion of the matrix scoring is included below.

Accuracy As the concept of relating resource requirements to project characteristics is a novel approach to resource planning in NPD, no evidence of the application of these methods in this context could be found, therefore accuracy is largely unknown. Only through future actions can this be determined.

Timeliness In the form of a predictive model, each of the methods would be expected to be timely. Case or rule based models would depend upon the data base used and the mechanism of responding to queries.

Consistency As all methods involve the formalisation and storage of knowledge, the response generated each time for exactly the same scenario could be assumed to be consistent. The exception to this rule is the neural networks which would be expected to develop as the business changed. This would offer agility over consistency.

Transparency The traceability, simplicity and clarity of data driving the predictions would vary depending upon the method used. Neural networking hides all the logic between input and output; no knowledge could be derived regarding the mechanisms of each prediction. Regression analysis and categorisation could provide some traceability, although in the case of regression the simplicity and clarity may be an issue.

Based on the matrix in Table 9, the most logical routes forward are regression analysis and categorisation. This is the route the researcher took: attempting regression analysis (the tried and tested method) first before moving onto categorisation. Development of a suitable modelling process is discussed in-depth in the following chapter.

4.2 CONSIDERATIONS FOR PREDICTIVE MODELLING

In addition to selecting a modelling method, there are several different aspects of the mechanics and form of the predictive modelling that need to be considered before we move forward. These are:

- How to quantify resource.

- How to mirror resource demand changes over time – Resource requirements are not uniform throughout a project.
- What can we use to predict resource demand? What inputs have an effect upon the output?

Each one of these points will be considered separately.

4.2.1 QUANTIFYING RESOURCE

Resource must be considered in conjunction with time; whether we consider resource and time together (man hours) or as separate but related entities (Full Time Equivalent (FTE) and hours), time must be reflected in predictions.

Using man-hours isolates the resource predictions from any real sense of time. Without a real-time component there will be no clarity about which period the man hours are required over and as such totalling resource required within a functional group or across a portfolio of projects will not be possible. Predicting FTE's and duration would require two distinct but related models.

4.2.2 MODELLING VARIATIONS IN RESOURCE OVER TIME

Resource requirements for most functions vary depending upon the project phase.

One possibility would be to model the resource requirements month-by-month or by quarter. Another approach would be to model the resource requirements by Stage-Gate phase: the duration of Stage-Gate phase could be modelled AND the resource per Stage-Gate phase could be modelled.

The Stage-Gate process employed in DePuy is called PACE (Project Actualisation and Commercialisation Excellence). The purpose of a Stage-Gate process is to ensure that the projects are making good business sense as they progress. Each "gate" is essentially a review meeting in which project progress, plans and the business case are systemically reviewed. Projects can pass, pass conditionally or fail each Stage-Gate. Failed projects are terminated. Over the period of time the researcher has been in DePuy, the Stage-Gate process has expanded. Originally, the Stage-Gate process addressed projects from Charter through to launch but more recently; the process has been extended to included "front-end design" phases.

Consultation with portfolio managers suggested that the high level resource-per Stage-Gate-phase approach would be preferable even though project managers and functional leaders preferred the resource-by-quarter approach as this aligns with how they currently plan.

As the model will primarily be used for portfolio planning, the resource will be modelled using the Stage-Gate phase approach in the first instance. Because this will include both resource and duration information, it will be easily convertible (via macros or similar) to resource required per quarter or even per month. This will allow the Stage-Gate phase dates to be overlaid onto the project calendar – something highlighted as being "very useful" by portfolio managers. Using the alternative approach; predicting resource by quarter or by month would neglect any Stage-Gate phase duration information and as such, would not be quite as effective for portfolio planning.

Additionally, past project resource information within the case-study company is stored in a resource per Stage-Gate format.

To allow resource to be modelled over time, one set of models will describe resource (FTE) per stage gate phase and another set of models will describe the duration of each Stage-Gate phase.

4.2.3 SELECTING APPROPRIATE INPUTS

Two key approaches are documented in existing planning methods.

- Traditional planning models look to events and activities and utilise heuristics to derive resource estimations (judgemental approaches).
- Predictive cost models use physical characteristics of a product to feed resource estimations (sometimes in combination with events and activities) (statistical approach).

Each approach will be discussed further. A third option is also proposed in section 4.2.3.3.

4.2.3.1 RESOURCE MODELLING WITH EVENTS AND ACTIVITIES AS INPUTS

Although events and activities are widely used in resource planning through Programme Evaluation and Review Technique (PERT) modelling, Gantt charts and Work Breakdown Structures (WBS), there are two fundamental issues with using events and activities as inputs to a predictive resource model.

1. There is a large amount of uncertainty associated with the events and activities required for NPD. The events and activities required are the very source of uncertainty in NPD. The occurrence of particular events or activities and the variation of them are too uncertain for this to be used as an input.
2. Estimations about the events and activities are not considered until the project is underway, and the estimations require a significant resource investment in the form of project planning. To be useful, the models must be able to function well before this level of information is considered. The models must work when the projects are just beginning to be scoped, when their feasibility as a concept is being established.

4.1.3.2 RESOURCE MODELLING WITH PRODUCT CHARACTERISTICS AS AN INPUT

Cost modelling software for the defence industry utilises data from thousands of past projects to develop cost and resource models (Madachy and Brown 2008, Boehm *et al.* 2000, Boehm and Valerdi 2008). Product characteristics relating to physical variables such as dimensions, weight or characteristics relating to function such as weapons payload, drive train, engine type and communications systems are used to derive resource and cost estimations. Another example comes from software development where product features such as lines of code or application are used to predict cost and resource requirements (Boehm, 2000).

In most instances, cost or investment required takes primary concern over the number of people required. Although for DePuy, cost is of minimal concern and human resource is critical, we can learn from cost modelling examples which in many cases include a human resource required component. One such example is parametric cost modelling software usually based upon a variation of the Constructive Cost Model (COCOMO). Fundamentally, COCOMO for software development has a very simple structure.

Equation 1

$$\text{Man months} = \text{F1 (Thousands of delivered source instructions)} * \text{F2}$$

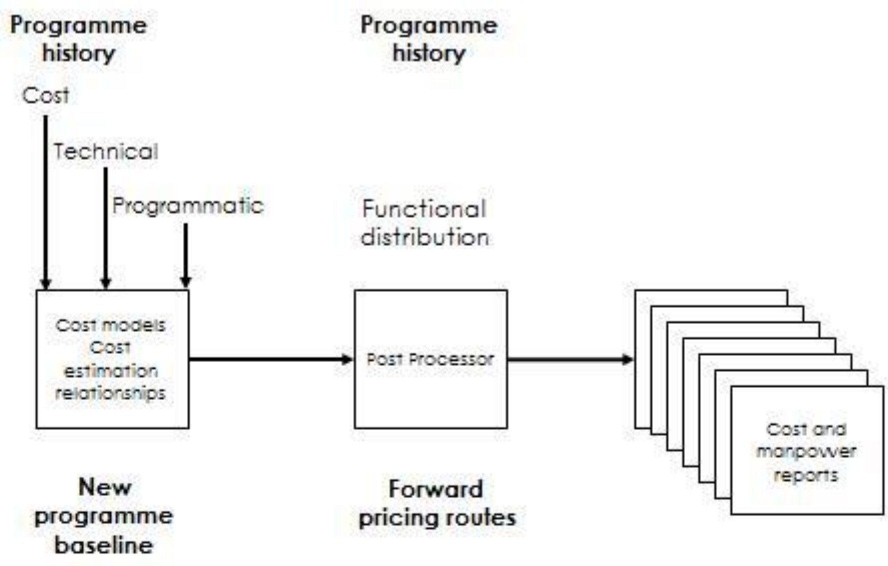


Figure 14- Parametric cost estimation concept (from NASA cost estimation handbook)

demonstrates the fundamental concept. As the top half of the figure suggests, COCOMO models are created using historical project data. Through completion of the data and statistical testing and analysis, regression curves are fitted to describe the relationships between the parameters of past projects and the cost/ manpower required. In order to create accurate models, data from thousands of past projects are required. Due to the large volume of data required it can be difficult for one company to create an accurate model. Data can be gathered from numerous similar companies within one industry and sold back in the form of a predictive model. True planning (**http://www.pricesystems.com/company/about_price.asp**) utilises over 11,000 past projects describing over 30 years of industry. SEER estimations suites by SEER Galorath **(http://www.galorath.com/)** provide a model based upon 8,000 plus past projects. Customers for these model developers tend to be government agencies or defence and aerospace contractors and manufacturers.

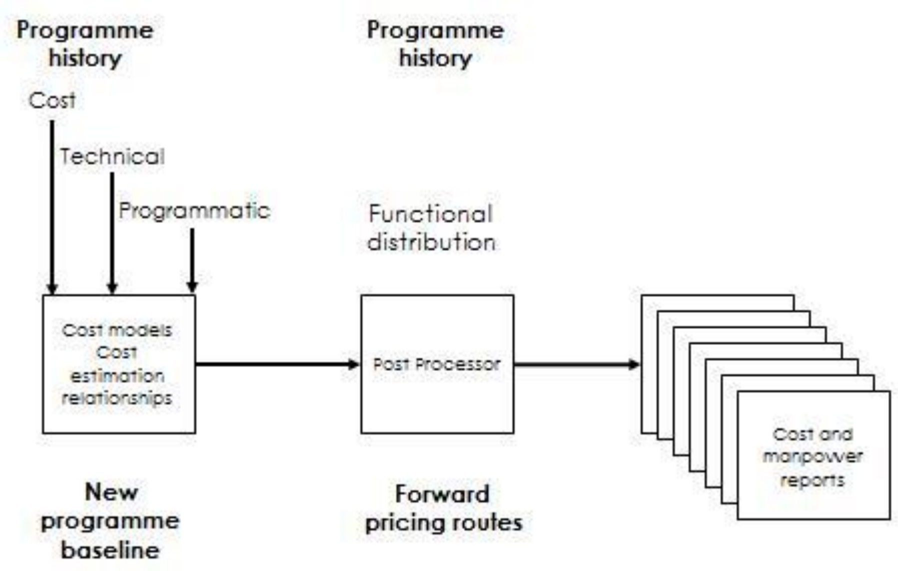


Figure 14- Parametric cost estimation concept (from NASA cost estimation handbook)

For a medical device development company, relating such parameters to resource is less reasonable for three main reasons.

1. Firstly, there is no obvious link between physical or functional factors and the resource requirements. A larger implant for example, will not necessarily take any longer to design, develop or manufacture than a small implant.
2. Secondly, the dimensions or functionality of an orthopaedic implant is unlikely to be established at the outset of project. Although in some cases, it may be. For example, if the project is to develop an additional size of an existing implant. Usually, these features emerge through design work and discussions with surgeons as the project progresses.
3. Finally, the physical or functional subtleties between one hip or knee implant and another are most likely not pronounced enough to reflect the variation in resource. There are small physical differences between products yet large differences in resource. Any model capable of reflecting this would have to be very accurate and sophisticated.

4.1.3.3 PROJECT CHARACTERISTICS AS A PREDICTIVE MODEL INPUT

Neither events and activities nor product characteristics provide suitable inputs for a predictive resource model for NPD. Anderson and Joglekar (2005) recommend using "Type of project" to form estimations of resource demand. No evidence of this being applied in practice or the mechanisms required in doing so has been found. The use of "Project Type" labels is documented widely in strategic and portfolio planning literature under various guises: strategic buckets (Cooper 2006, 2003; Chao and Kavandias 2008) or the BCG Share/ growth matrix (Morrison and Wensley 1991). Type of project can be defined by different labels. In DePuy, various labels have been used through time but the most recent terminologies are: transformational, substantial, incremental and maintenance. Delving deeper, definitions of the "Type of project" starts to reveal specific project characteristics and the Project type itself is no longer a characteristic but a means of grouping characteristics. Different types of projects may share similar characteristics: the characteristics are not exclusive to the project type.

- Project characteristics could be vague or specific. It is likely that even very early on, in the very first stage of describing a project or even a market gap, some estimates could be made about the form a project might take (as opposed to the form the product might take). We know that the product developed will be launched in certain countries or that it will be relatively novel but we are unlikely to know dimensions or surface finishes.
- The characteristics of one project and another are likely to be quite different. A "substantial" project could be a large simple project or a medium sized complex project. It could be novel or completely standard. Resource requirements within "substantial" could vary significantly depending upon these things.

- Projects with one set of characteristics are likely to require a different set of resource from projects with another set of characteristics: there is a logical link.

Exploring the link between project characteristics and resource demand is a novel approach to the problem of predicting resource demand (existing methods do not consider project characteristics) yet project characteristics seem to be the most suitable option for resource modelling in this context.

4.2 APPLYING MODELLING METHODS

Section 3.5 discussed potential modelling methods. A statistical approach was favoured over a judgemental model. Regression analysis and categorisation were the methods with most potential to meet the requirements. The application of each is discussed in section 4.2.1 and 4.2.3 respectively.

4.2.1 REGRESSION ANALYSIS

Regression analysis is the only method documented to have been applied to developing predictive cost and resource models. Data from thousands of past projects is tested and analysed generating models that can predict project cost and resource requirements with astonishing claims of consistent accuracy (between 2 % and 5 %).

The suitability of regression analysis depends upon the quality and quantity of past project data available. This section discusses the data required and the suitability of the data for regression analysis.

4.2.1.1 DATA REQUIRED

Data is required describing both the inputs (project characteristics – see section 4.1.3.3) and the outputs (resource per function in FTE's and project phase duration –

see section 4.1.1). Establishing which project characteristics and a source of past project data will be discussed separately.

4.2.1.1.1 PROJECT CHARACTERISTICS

In order to establish which project characteristics may have an impact upon resource demand in each functional group, a series of activities took place. A brainstorm, a survey and a survey feedback/verification exercise.

Firstly, a ½ day brainstorming session was held with three business leaders (The Director of Development Services, the Innovation Process Leader and the Innovation Process Manager). Each of the business leaders selected was in a role that allowed them an overview of the development process as a whole and some knowledge of each of the functional groups involved. The subject of the brainstorm was "which project characteristics impact NPD resource demand". The business leaders were asked to focus on characteristics that would be known in the earlier stages of a project and consider factors that influenced each of the functions. Some of the characteristics were thought to influence most functions whilst others were thought to be functioning specific. The session was mediated by the researcher. A list of 30 project characteristics resulted from the session.

As the project characteristics impacting each individual function can be quite different (and it is expected that the relationships between characteristics and resource required will be very different for each function), a separate model will be required for each functional group.

The number of factors included in a regression model has an impact upon the number of past projects required (See Figure 15Figure 15). To reduce the list a survey was developed to establish which factors were perceived to be most influential to each function. Managers were asked to select "high" "medium" or "low" to describe how they felt each factor impacted upon resource required in their group. The results for each function are detailed in Appendix 1.

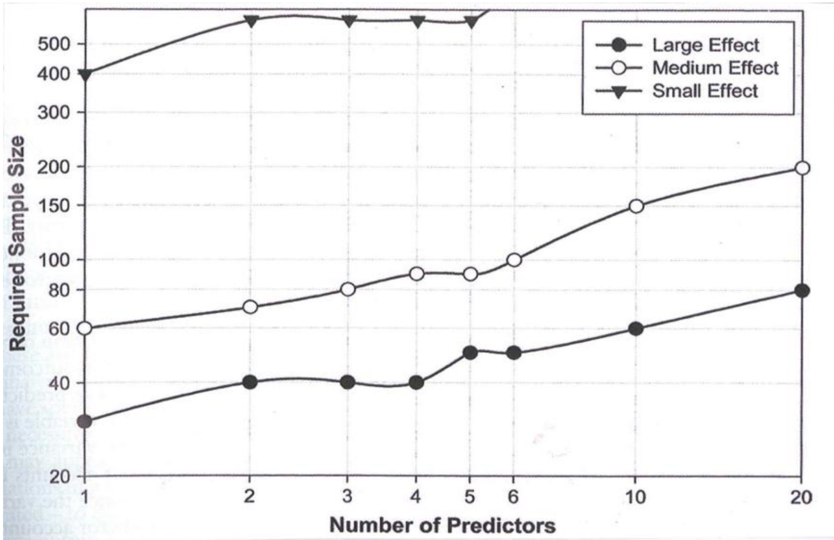


Figure 15 - Required sample size vs. number of predictors from Field (2009)

Results were fed back to managers and functional leaders via email. A discussion was held either through a face-to-face interview or over the telephone to verify the results with at least one person from each group. One of the key issues raised was

"*It depends*"

– For example:

"*Sometimes the number of instruments can have a massive impact upon our resource, especially if they are all novel and even more so if they are novel and complex instruments. However, if the instruments are simple and familiar then we will hardly require any resource no matter how many*".

This suggests that there are interactions between project characteristics. Discussions suggest that the interactions are likely to be numerous and difficult to identify/ quantify. Regression analysis Design of Experiments not identify interactions although it will test interactions that are queried. Each interaction queried would be considered equivocal to another factor in the model. From Figure 15 it is clear that with a small sample size we are restricted in terms of the number of factors that can be modelled. Considering all possible interactions (or even a sub-set of interactions) would greatly reduce modelling efficiency.

4.2.1.1.1 DATA SOURCES

We require information about project characteristics and about the resource used on past projects (FTE's and project phase duration).

Within DePuy, the most comprehensive source of such data is the Stage-Gate process templates. The Stage-Gate templates for each project contain:

- Project characteristics (input)
- Estimated Stage-Gate phase duration
- Actual Stage-Gate phase duration
- Estimated resource requirements per function per Stage-Gate phase.

In terms of duration data, both actual and estimations exist. A model could be developed using actual data and the results could be compared with the estimated predictions.

In terms of resource data only estimates exist. DePuy do not use timesheets. This means that any predictive model for resource would have to be based upon estimations rather than actuals. At best, the resource aspect of the model would only be as accurate as the predictions currently made. Without actual data, there is no means of conclusively establishing accuracy.

Completed Stage-Gate templates are stored in an online repository. Files were listed for 400 projects. Although based on Figure 15 this Design of Experiments not seem ideal, it was thought that with 400 projects some information about the main relationships could potentially be derived. Each Stage-Gate template was stored in a separate excel file, for each complete project 8 excel files should exist: one for each Stage-Gate review. Different data components are described in each worksheet of each excel file. Several different versions of the Stage-Gate templates exist, with each version storing slightly different information. The Stage-Gate templates were designed to manage the innovation process, not to store data for post-event analysis. Much of the data was incomplete: in many instances the resource information or large parts of project characteristic data were missing. Where most of the information was available but not all, interviews were conducted with members of project core teams and project plans were reviewed to establish data missing retrospectively.

From the 400 projects, useful data was found for just 27. This was not enough to meet the assumptions required for regression analysis.

4.2.1.2 ASSUMPTIONS FOR REGRESSION ANALYSIS

Four assumptions must be met for regression analysis (Field, 2009). These assumptions are:

1. The sample is representative of the population (normally distributed)
2. The error is a random variable and the variance of error is constant over observations (homoscedasticity).
3. There is no multicollinearlity: the inputs are independent, it is not possible to predict one input using one or more of the others.
4. There is no error in the independent variables.

It is rare that all these conditions are ever met in practice. Often useful models are developed without the conditions being met. However, the further the model deviates from the assumptions, and the less likely it is to be useful.

4.2.2 REGRESSION ANALYSIS RESULTS AND SUMMARY

As we have some control over which independent variables (project characteristics) to use, this assumption can be met in theory. Data from the 26 projects was analysed using SPSS. In most instances models could not be generated at all because the data were so far from meeting the assumptions. Attempts were made to transform the data (i.e. convert the data to a normal destruction by applying a log and square root transformations (Field, 2009, page 155). However, these all attempts were unsuccessful – there was not enough data to convert to a normal distribution.

Regression analysis as a predictive modelling method was not suitable in this context for two main reasons:

1. There were not enough past-project data available and
2. Interactions could not be tested.

It is possible that the assumptions could have been met if more data had been available. COCOMO models suggest that with enough data such models can indeed be useful.

4.2.3 CATEGORISATION

Had regression analysis proved successful, it is unlikely that other methods would have been investigated. However, given that extensive efforts had been invested in collecting past project data, it was decided that it ought to be used to develop even a very rough, approximate model. The data for which projects were available was divided by "project type" and into several other groups defined by project characteristics using an unstructured, exploratory approach.

A prediction was made based upon an average for each category (See Figure 16). When compared with the original predictions made by managers it appears that in many cases using an average of past projects would approximately be as accurate.

(Ideally, data would have been removed from the sample set and tested against each model, however as the sample set was so small and variations in accuracy so large, testing in this manner would have been inconclusive). At this stage, the approach was conceptual, to explore possibilities for developing a model without regression: - reserving data for verification was not important until the feasibility of the method was tested.

	Duration 1-2	Duration 2-3	Duration 3-6	Duration 6-7	Duration 7-8	
Maintenance average	**9.6**	**21.4**	**23.8**	**16.25**	**-**	The minimum values are low because sometime gates were not carried out or carried out together.
Max value	22	52	43	35	-	
Min value	0	0	2	2	-	
Line ext average	**18.2**	**59.7**	**41.4**	**13.1**	**74.7**	The minimum values are sometimes low because gates were not carried out or carried out were together.
Max value	52.0	140.0	149.0	35.0	119.0	
Min value	0.0	10.0	3.0	2.0	40.0	
New system average	**54.86**	**111.57**	**49.00**	**34.00**	**-**	Min values are higher. More gates are carried out for more complex projects.
Max value	83.00	234.00	80.00	34.00	-	
Min value	13.00	30.00	18.00	34.00	-	

Figure 16 - Categorising project phase duration based on actual values for 26 past projects for three types of project.

The concept of experimenting with different levels was also explored. Different combinations of categories could be presented in a large number of different orders. Creating and testing each model using Excel™ would take an unfeasible amount of time and it would be difficult to discern whether the best possible model structure had indeed been reached. Background research into other predictive techniques revealed an approach called Categorisation and Regression Trees (CART) in which various algorithms could be used to find the best arrangement of levels for the data available. This method allows identification of confounding variables. Where logistic regression can only represent simple distributions with data conforming to assumptions, trees can represent or at least approximate arbitrary distributions (Witten *et al.* 2011). One of the most widely used and well established algorithms is the C4.5: an update of the ID3 algorithm. This was readily available through a tool developed by another researcher at Strathclyde University (**http://www.viktordorfler.com/doctus/**). Through collaboration and discussions, the tool was employed to categorise the data available using case-based reasoning. One of the models developed using *Doctus* is presented in Figure 17. The C4.5 algorithm (and similar algorithms) is based on the principle of Information Entropy. Each possible tree combination is associated with a specific entropy value (information gain). The C4.5 algorithm quickly assessed the various ways in which the tree can be split at each node and chooses the format with this highest information gain. For each specific model we wish to build, there will be different ways to order the factors. For example, it may be most informative to establish duration gate 3-6 by dividing the projects into two categories: high number of instruments and small number of instruments. Alternatively, it may be more informative to divide the projects by clinical trial requirements then divide the projects that do need a clinical trial by the number of implants. There are literally thousands of combinations. The C4.5 algorithm finds the best combination with minimal effort.

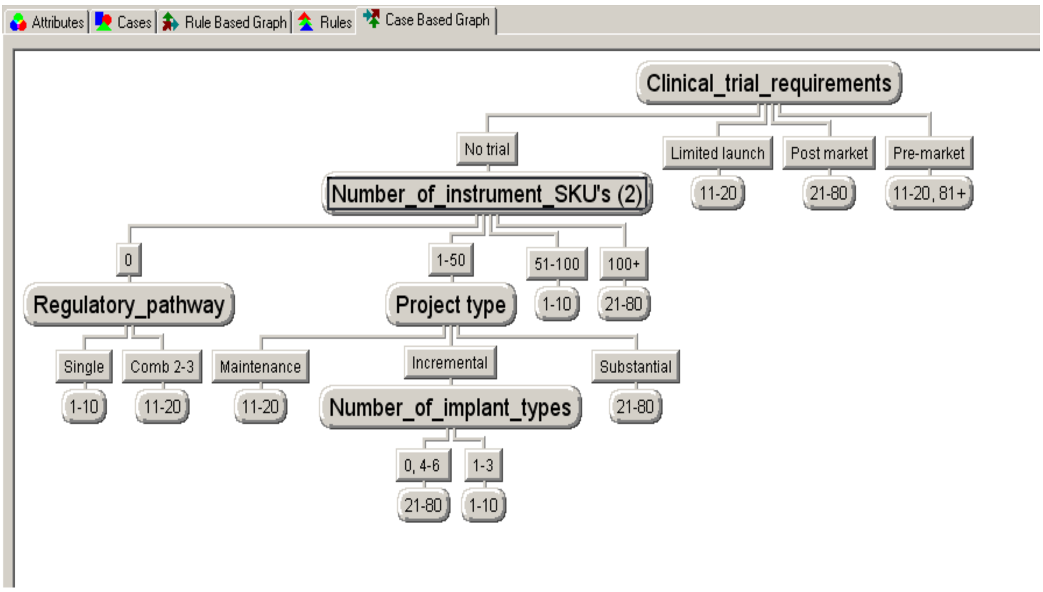


Figure 17 - Case based predictive model - Duration Gate 1 -Gate 2

One notable feature of Doctus is that the outputs are not in integers but in ranges.

From Figure 17 "clinical trial requirements" alone provides the best indicator of Duration Gate 1 – Gate 2. If no trial is required duration predictions are slightly more complex. "Number of instruments" is the next most important factor, providing the most information gain. If the "number of instrument types" is less than 50 "Project type" must be considered, and if there are no instruments at all "regulatory pathway" must be considered. In instances where "project type" is incremental, "number of implant types" is the most important factor. The durations are shown in months at the foot of the tree. A series of models were developed: one for each Stage-Gate phase.

The models provide a completely accurate representation of past project data. However, they are less useful for prediction unless the project to be predicted can be described using identical parameters at identical levels to those described by the past projects featured in the tree. With just 10 different categories, each set at three different levels, there are potentially 5040 different project scenarios that might occur. A useful predictive model must be capable of making estimations for every one of the scenarios not represented by the data.

One of the key benefits of using categorisation algorithms was the ability to identify confounding variables – a shortcoming of regression analysis. The key benefit of regression analysis is the ability to predict for scenarios for which we don't have data. The methods could compensate for each other. If confounding variables were identified using categorisation before moving on to regression, the most significant relationships and interactions could be included in the regression model with minimal testing. However, this is not useful in this context as we do not have enough past project data.

4.3 SUMMARY OF EXISTING PREDICTIVE MODELLING APPROACHES

Two different modelling methods have been applied. Fundamental reasons exist making each method unsuitable for application in this research context. Regression analysis requires a larger body of past project data to create an accurate model and Design of Experiments not account for confounding variables but Design of Experiments predict scenarios outwith available data. Categorisation accounts for confounding variables and Design of Experiments not require a large body of data but Design of Experiments not predict for scenarios outwith available data.

A modelling method is required that will make predictions for combinations of projects for which we do not have past project data. With no past project data, estimations or a judgemental method will be required.

4.4. REQUIREMENTS OF A MODELLING APPROACH

Fundamentally, existing methods do not meet the requirements presented in this context. In addition to timeliness, accuracy, consistency and transparency a further two requirements for modelling have been uncovered. These are:

1. If the modelling process is to be practical rather than just theoretical, the method used should not rely upon past project data as it is not widely available. ***If a predictive model is to be developed it will require the use of estimations in addition to or in place of actual data.***
2. For the model to be useful it must be capable of predicting a wide range of scenarios and not just organise existing project data.

It is unfeasible to gather estimations for every possible project scenario. What we require is a means of selecting specific project scenarios in order to extrapolate approximate results.

Design of Experiments is a potentially promising method. It allows a wide number of scenarios to be predicted and understood with a very small number of experimental runs. The method involves gathering data for very specific experimental scenarios. Consequently, the method is not usually applied to retrospective data as is unlikely that the specific pre-design scenarios (often extremes) will exist. Given that the options for utilising retrospective data have reached an unfruitful conclusion, there may be scope to apply Design of Experiments in an alternative and novel way. If estimations rather than actual data are collected and hypothetical project scenarios are used rather than actual experiments a model could potentially be created.

Originally, statistical rather than judgemental modelling methods were preferred as the agendas and biases associated with the existing judgemental estimation process compromised accuracy and confidence in results. However, using an approach such as Design of Experiments to harness judgemental data and to create a predictive model would not necessarily evoke all the issues associated with traditional, unstructured estimations. The three main issues with judgemental estimations are addressed below:

1. **Agendas and biases associated with project ownership**

   If we can ***design hypothetical project scenarios*** *they would not be associated with actual or owned projects. It is reasonable to assume that the agendas and biases associated with ownership would no longer exist.*

2. **Perceptual biases based upon experience limitations**

   There is potential to minimise perceptual bias and bias based upon experience by examining the opinions of several experts in combination. The issues associated with the time taken to collect data could be accepted.

3. **The lengthy time taken to produce and gather estimations: by the time they are collated they are often out of date.**

   If the tacit considerations were modelled the results could potentially be generated instantly rather than over the course of months.

Applying an approach based upon designed experiments to modelling expert opinion is novel and as such, there is no precedent of how it ought to or could be carried out in practice. In the following chapter, we provide an overview of how the process could be applied and explore the details and options available at each step.

4.6 APPLICATION OF DESIGN OF EXPERIMENTS TO CREATING A PREDICTIVE RESOURCE MODEL

In order to create a model capable of predicting resource demand and project phase duration without relying upon past project data, we explore the options and procedure required to apply Design of Experiments to modelling expert estimations using hypothetical project scenarios in place of physical designed experiments and measure responses.

This chapter introduces Design of Experiments as it is traditionally applied before detailing at a very high level the conceptual idea of how it has been applied in this research context. The application of Design of Experiments in this context comprises the novel contribution of the research made by this thesis. The specific contributions are highlighted and a focused, systematic literature review is presented to provide evidence to support the novelty of the contribution.

4.6.1 INTRODUCTION TO DESIGN OF EXPERIMENTS

Originally applied to Agriculture research, Design of Experiments stems from practical rather than theoretical roots (Fisher 1971). The powerful nature of the results and the depth of insights that can be generated suggest that a labour intensive, complicated statistical process must be required. In fact, the opposite is true: the processes and assumptions fundamental to Design of Experiments are really remarkably simple (Rao *et al.* 2008, Hockman and Berengut 1995). Ronald A. Fisher is credited with developing Design of Experiments. Fisher was interested in studying the effects of different soil treatments upon the yield of wheat. Reviewing past experiments, he realised that agronomists were aware of the sources of variation but unable to manage them whilst experimenting. The results of the experiments were inconclusive. One could have suggested that the results showed one variety of wheat to be superior to another whilst one could also argue that the variation in yield could be attributed to soil conditions, rainfall or variations in measurement. Fisher developed a collection of techniques for settling such issues: techniques for designing experiments and techniques for analysing and interpreting the results of experiments (Fisher 1925, Fisher 1926, Fisher 1935).

Figure 18 provides an overview of the Design of Experiments process. Firstly, the independent factors must be **described**: what is likely to have an impact upon the response? This information could come from existing research, observations or experience. The factors (project characteristics) impacting the response (resource required) in this specific research context has already been detailed prior to regression analysis in section 4.1.2.2.

In the next stage, the **Design of Experiments** is selected. Rather than actually design each individual experiment from scratch, a design of a specific type is selected from a finite set (catalogue). The designed experiment details a series of experimental runs and the combinations and levels of factors to be tested in each run. The appropriateness and limitations of each design must be understood by the researcher, as different designs are appropriate in different contexts.

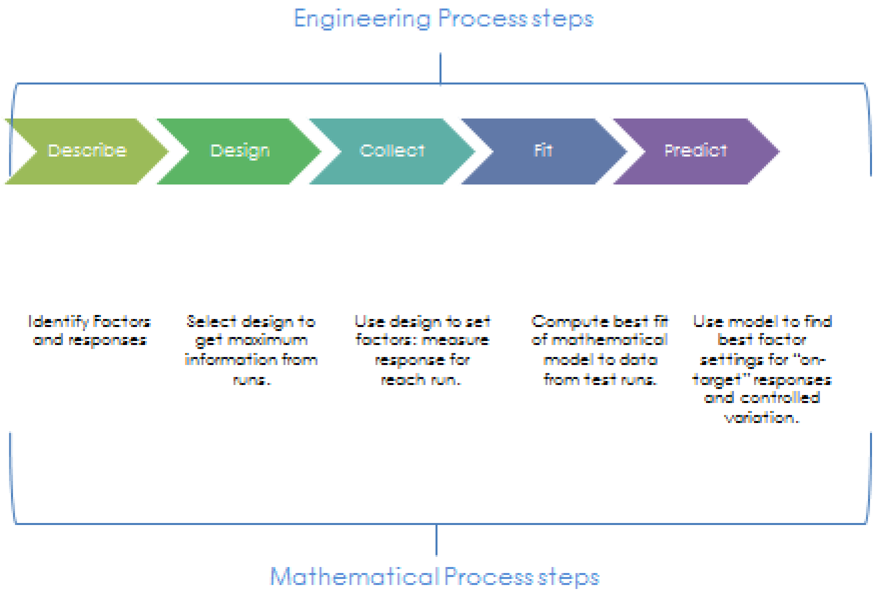


Figure 18 – Key process steps used to apply Design of Experiments.

The next step involves conducting the experiments or **collecting** the response data. This process is largely prescribed by the Design of Experiments selected.

The final two stages relate to analysis of the experimental results. Simple statistics are used to assess how well the response data echoes the variation in the designed experiment. The effect of each factor and confounding effects can be assessed and if desired a regression model can be **fitted**. The goodness-of-fit of the model is assessed using further statistics and the model is "tuned" by adding and removing factors to produce the best fit or predictability. Finally, the model (results of analysis/ regression equation) will be used to make some form of **prediction** (usually about best settings of input parameters).

Design of Experiments can be described as a methodology for systematically applying statistics to experiments. Experiments can be thought of as exploration and analysis of the effects of changing independent variables upon dependant variables or the effects of varying inputs upon output. This concept is demonstrated in Figure 19. Rather than varying and testing inputs randomly or using the traditional vary-each-factor-one-at-a-time approach, Design of Experiments prescribes the most efficient and effective means of deriving maximum knowledge about the general system-wide effects of inputs upon outputs with minimal experimental cost.

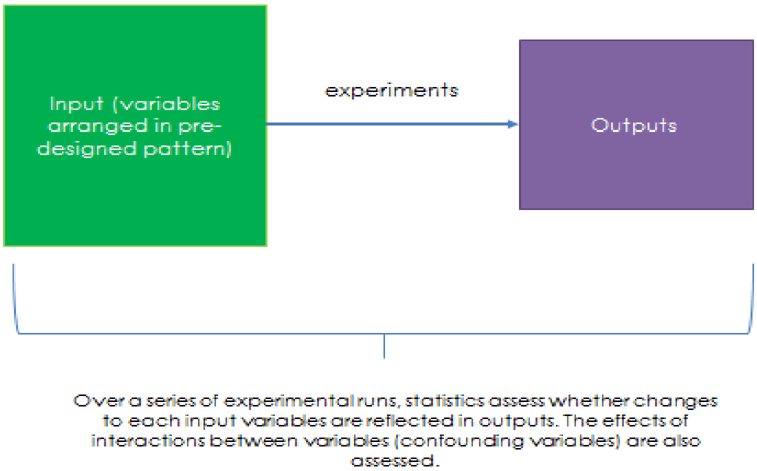


Figure 19 – Concept of Design of Experiments. Inputs are varied per experimental run in a pre-defined pattern. Statistics are used to measure the effect of varying each factor over a series of experiments.

The statistical process behind Design of Experiments is frequently explained and visualised using a cube plot (Hockman, 1995). When there are three factors, it is possible to visualise each possible input as a coordinate within a cube as is shown in Figure 20. Each coordinate can be defined by the three factors or a point on each of the three axes. For more than three factors a *"hyper-cube"* is *required.* Although a hypercube is difficult to visualise the same statistical principles can be applied.

The example in Figure 20 examines an experiment on cake baking in which cooking time (X1), Oven Temperature (X2) and volume of filling (X3) can be altered between minimal and maximum values.

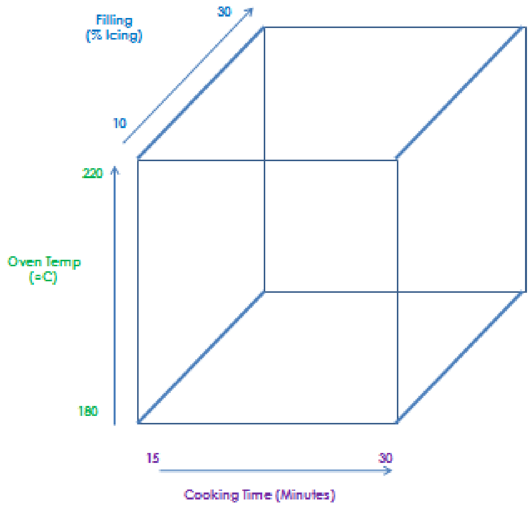


Figure 20 - A cube plot representing the design space for baking a cake

Within the cake design space there are almost infinite variations of cake. To determine which cake design favours best in taste tests, thousands of cakes could be made without a satisfactory conclusion reached. There would be no means of establishing whether most of the variation had been accounted for (perhaps the variation in cake mix ingredients or the cooling time (for example) has more impact than any of the three factors shown on the cube plot). There would be no means of establishing when we had baked enough cakes or whether baking one more cake might lead us to the ultimate combination of variables.

Depending upon the objectives of the experiment and the environment in which the experiments were being conducted, different types of design may be suitable. Design can be broadly divided into two categories: two level designs and multi-level designs. The experimental design and analysis for each will be discussed separately.

4.6.1.1 TWO-LEVEL FACTORIAL DESIGNS: THE EXPERIMENTAL DESIGN

Using a Design of Experiments approach, we can quickly get an overall impression of the effects of each factor and the interactions between factors upon cake taste. Selecting a factorial experimental design will allow us to get a broad, high level view of the significance of each factor and the significance of interactions with as few as 8 test cakes. The knowledge about the influence of each factor could then be used to bake a cake that was likely to receive a high taste test score.

Two-level designs can be either full factorial (all possible high/ low combinations of factors) or fractional factorial (a fraction of all the possible high/low combinations).

Full factorial designs include experiments for all combinations of variables at both high and low settings. For the three factors in the cake baking example, each of the runs is represented by a blue circle as is shown in Figure 21.

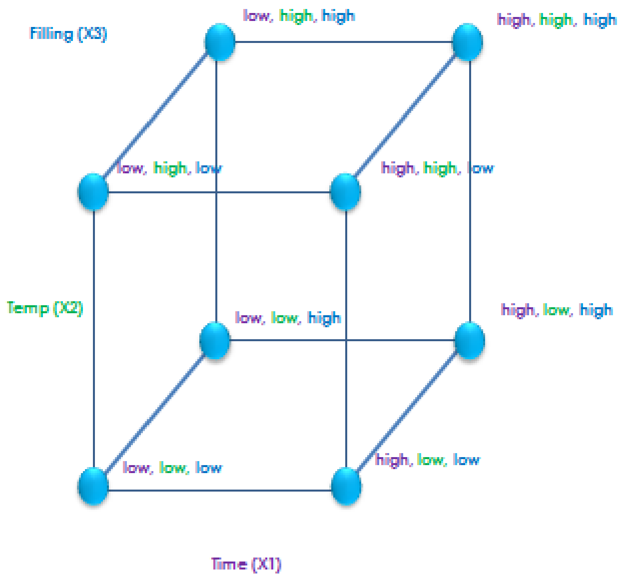


Figure 21 – Eight experimental runs required for a full factorial design with three factors

Table 10 also shows the responses(Y) collected: the taste test score per run.

Table 10 – Full factorial design for cake bake taste test

Run	Cooking time (minutes) X2	Oven Temp (○C) X1	Filling (%) X3	Taste test score (response) Y
1	15 (low)	180 (low)	10 (low)	3
2	15 (low)	220 (high)	10 (low)	2
3	30 (high)	180 (low)	10 (low)	7
4	15 (low)	180 (low)	30 (high)	5
5	30 (high)	220 (high)	10 (low)	3
6	30 (high)	180 (low)	30 (high)	9
7	15 (low)	220 (high)	30 (high)	3
8	30 (high)	220 (high)	30 (high)	1

The response scores (Y) translating to specific experiments can also be visualised on a cube. This is shown in Figure 22 below.

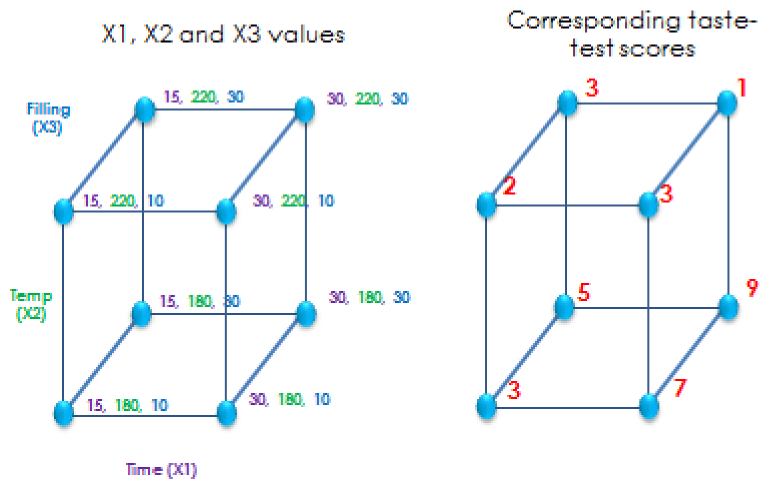


Figure 22 – Taste test score corresponding to experimental runs.

The left hand plane of the cube includes all the factors for Time (X1) at its lowest setting. The right hand plane of the cube includes all the factors for Time (X1) at its highest setting. Moving left to right along the bottom front edge, the top front edge and the edges parallel to these at the back is representative of the effect changing cooking time (X1) has upon Y (response) whilst over temp (X2) and filling (X3) remain constant.

4.6.1.1.2 FACTORIAL DESIGNS: FITTING AND PREDICTING

To calculate the effect that X1 has upon Y, the behaviour of Y on the right hand plane is compared to the behaviour of Y on the left by subtracting the average response on the left from that on the right. In this case, the effect of X1 upon Y is calculated as:

Equation 2

$$((7+3+1+9)/4) - ((3 + 2 + 3 + 5))/4) = 5 - 3.25 = 1.75$$

The effects of X2 and X3 are determined in an identical way: the effect of X2 is calculated by comparing the top and bottom planes and the effects of X3 are calculated by comparing front and back planes. The effects of X2 (average top – average bottom) and X3 (average back – average front) respectively are -3.75 and 0.5. We can deduce that X2 has a more significant effect than X1 or X3, X2 is negatively correlated with taste test score whilst the other two factors are positively correlated.

Through 8 experiments, we have been able to compare three pairs of planes. Interaction effects are the effects that combined sets of variables have upon a response. Interactions are calculated by comparing diagonal planes.

For example, the effect of X1 at high vs. low X2 can be calculated as:

Equation 3

$$((3+2+7+9)/4)\ -\ ((2+3+7+9)/4)\ =\ 5.25-3\ =\ 2.25$$

The interaction between X1 and X2 is more significant than the effects of X1 alone.

Software such as can be used to calculate the effects of all factors and sets of interactions. Once all the effects and interactions have been calculated coefficients for each term can be combined to form a regression model. Coefficients are always half of the effects and follow the same sign.

A regression equation can be generated to describe the relationship between inputs and outputs. In addition to the effects of each factor or interaction included in the model, the regression equation will also include a constant term. The regression equation for the cake taste test could follow the format shown below:

Equation 4

$$Y = constant\ + (X1 * 0.875) + (X2 *\ -1.875) + (X3 *\ 0.25) + (X1 * X2 * 1.125)$$

Where X1, X2 and X3 are either 1 or -1 depending upon the high or low value selected. Assuming linear relationships, X1, X2 and X3 could also be values between 1 and -1 to reflect corresponding variations between high (+1) and low (-1) values considered in the experimental runs.

The goodness of fit of the model can be measured by R-squared. R squared is the proportion of variability in the data that is accounted for in the regression model and can be calculated by

Equation 5

$$R^2 \equiv 1 - \frac{SS_{\rm err}}{SS_{\rm tot}}.$$

Where SS err is the Sum of the squares of the residuals. (The square between the data points and line of best fit).

Equation 6

$$SS_{\rm err} = \sum_i (y_i - f_i)^2$$

And SS tot is the total sum of the total squares. (The squares between the data points and the average).

Equation 7

$$SS_{\rm tot} = \sum_i (y_i - \bar{y})^2,$$

A graphical representation of the sum of the residuals and the sum of the squares is presented in Figure 23

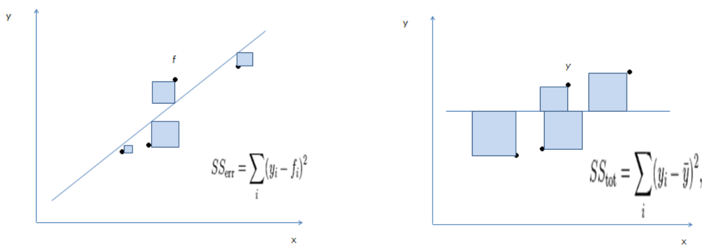


Figure 23 - The difference between the square of the residuals (left) and the total sum of the squares (right)

Too many factors will result in a model that describes the data in the experimental runs well but Design of Experiments not fit other scenarios. A model with fewer factors will be less specific, more general and is likely to describe a wider range of scenarios although there is a danger it may be too general. Tuning the model involved finding a balance between number of factors and the ability of the model to reflect the variations in data. This is reflected in the R-squared (adjusted) value. R-squared (adjusted) is calculated as:

Equation 8

$$\bar{R}^2 = 1 - (1 - R^2)\frac{n-1}{n-p-1} = 1 - \frac{SS_{\text{err}}}{SS_{\text{tot}}}\frac{df_t}{df_e}$$

Where *p* accounts for the number of factors in the model (excluding the constant term), df_t is the degrees of freedom (*n*– 1 of the estimate of the population variance of the dependent variable), and df_e is the degrees of freedom (*n* – *p* – 1 of the estimate of the underlying population error variance).

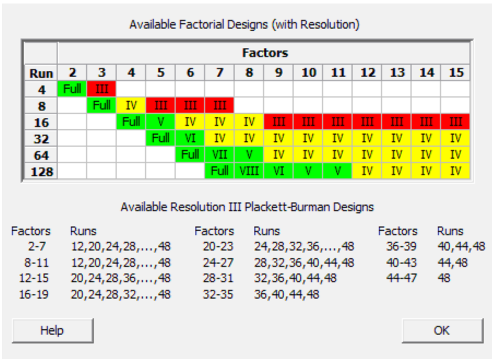
Predictions will be made with a tuned model: the model that offers the best predictability i.e. the highest possible R-squared (adjusted) value.

In addition to calculating the effects and generating regression equations, software such as Minitab™ is often used to calculate all the effects, coefficients and interactions simultaneously as well as the R-squared and adjusted r –squared values. Graphical outputs such as cube plots and Pareto charts aid the process of tuning.

4.6.1.2 FRACTIONAL FACTORIAL DESIGNS

Fractional factorial designs work on the same principles as full factorial design but are often used to reduce the number of runs to manageable and cost effective levels. In instances where a degree of granularity is acceptable, this can be an effective alternative to more in-depth full factorial experimentation. Fractional factorial designs include a fraction of the full designs experiments. Not all interactions will be evident: the resolution of results will be reduced. This is the cost of reducing the number of experimental runs.

Figure 24 shows the effects of reducing the number of runs upon the resolution of the design.



Available Factorial Designs (with Resolution)

	Factors													
Run	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Full	III												
8		Full	IV	III	III	III								
16			Full	V	IV	IV	IV	III	III	III	III	III	III	III
32				Full	VI	IV	IV	IV	IV	IV	IV	IV	IV	IV
64					Full	VII	V	IV	IV	IV	IV	IV	IV	IV
128						Full	VIII	VI	V	V	IV	IV	IV	IV

Available Resolution III Plackett-Burman Designs

Factors	Runs	Factors	Runs	Factors	Runs
2-7	12,20,24,28,...,48	20-23	24,28,32,36,...,48	36-39	40,44,48
8-11	12,20,24,28,...,48	24-27	28,32,36,40,44,48	40-43	44,48
12-15	20,24,28,36,...,48	28-31	32,36,40,44,48	44-47	48
16-19	20,24,28,32,...,48	32-35	36,40,44,48		

Help OK

Figure 24 - Minitab screenshot. Designs available: number of runs, number of factors and resulting resolution

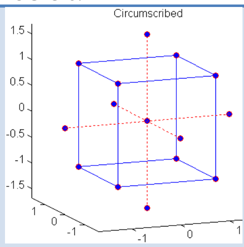
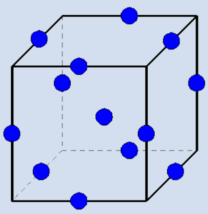
Level III resolution designs indicate designs with 3 elements in a chain. An experimenter would not be able to separate their confounding effects. If the effect of factor A or BD is significant it would be unclear whether this was due to A or due to the BD interaction. These designs are associated with a level of risk. Care must be exercised when tuning the model to fit the data.

Level IV resolution designs indicate that two factor interactions confound with other two factor interactions. For example, in a 16-run, six-factor two-level design, the AB interaction is confounded with the CE interaction. This a resolution IV design, since we have four elements in the alias chain AB=CE. Again, the effects of AB and CE cannot be separated. In a resolution IV design, two-factor interactions are not confounded with any main effect, so this design is a lot safer than a resolution III design, it allows study of up to 8 factors with only 16 runs, quite a cost-effective solution.

4.6.1.3 DESIGNS WITH MORE THAN TWO LEVELS

Factorial designs assume a linear relationship between input and output variables whereas response surface or multi-level designs allow curvature of the effects to be measured. To measure curvature, we require at least three levels and therefore more experimental runs. Usually, when more runs are available, a sequential approach to Design of Experiments is recommended. A factorial or fractional factorial design would be employed to "screen" insignificant factors. Following "screening", a more in-depth view of the whole design space or a proportion of the design space could be gained through a secondary series of more detailed experiments. The second design could again be factorial (with insignificant factors removed) or could feature more levels to test the linearity or curvature of the response curve. Various multi-level designs exist. Some of the most commonly used design include Central composite designs), Taguchi designs, (Taguchi, 1986) and Box-Behnken designs (Box and Behnken, 1960). Each design type is summarised briefly in Table 11 below.

Table 11 – Commonly used designs featuring three or more levels.

Type of design	Description	Cube plot for 3 factors.	Advantages	Limitations	References
Central composite design	Builds upon factorial design. Includes a centre point and axial points (points in the centre of each cube face).		Relatively simple. Fractional versions available.	Extreme values required.	Myers, (1971). "Response Surface Methodology" Boston: Allyn and Bacon
Taguchi Design	Essentially fractional factorials Designs featuring very few experimental runs. Often used to assess which factors impact process variation.	18 designs classified into 3 groups: 2 level (essentially Placket –Burman type designs). P- level Mixed level Type 1 and 2 are "saturated". 5/ 6 arrays in group 3 are "unsaturated" – not all columns are used. This can create errors.	Very few experimental runs required. Don't have to test all combinations. As few as four runs are required.	Only suitable when there are no/ minimal interactions and only a few factors contribute significantly. Not recommended in isolation (without factorial/ screening design first). Understanding the effect of unsaturated columns can be difficult and can lead to faulty results.	Taguchi (1986) "Introduction to quality engineering" Designing quality into products and processes" Lin(1994 (Lin 2007)) "Making full use of Taguchi's orthogonal arrays" Quality and reliability international. Vol.10.
Box – Behnken design	Design of Experiments not contain an in-bedded factorial design. The geometry of the design is sphere like rather than cube like.		Avoids combinations that are extreme, Less centre points needed as edge points are closer to the centre. Useful ifyou are interested in the centre region. Less runs needed than for full factorial central composite. Designs.	Less useful if you wish to understand extremes. Design of Experiments not include fractional versions of the designs.	Box and Behnken (1960) "Some new three-level designs for the study of quantitative variables" Technometrics Vol 2, no.4

If it was desirable to know more about the influence of each factor and build the optimal cake, 3-level experiments could be conducted using Response Surface

Method (Box and Wilson 1951). The response surface method essentially involves generating information about the variations in factors across the design space. When thinking of this as a cube-plot a surface mesh can be visualised. Each node on the mesh represents an experiment. Response surface analysis can be performed using multi-level experimental designs. The mesh view allows the investigator to identify local optimums and stable areas within the design space. Such information can prove useful for decision making: in some instances it may be beneficial to replicate factor levels that will result in an optimal solution with tight tolerances, for example when manufacturing high-end, bespoke items whilst in other instances for example mass manufacture of safety critical devices, it may be more beneficial to select a design that Design of Experiments not offer optimal performance but instead offers adequate performance without requiring tight tolerances. This concept is demonstrated in Figure 25.

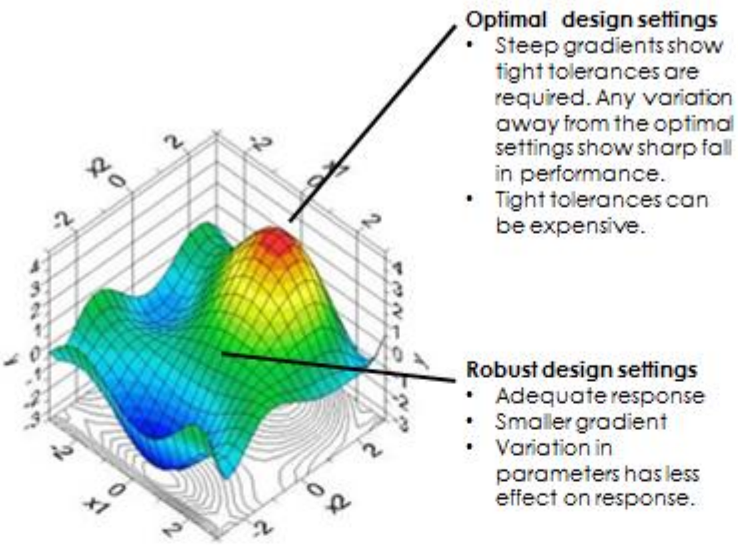


Figure 25 - response surface method can be used to find optimal or robust design variable settings.

The optimal cake may depend on very exact levels of each parameter which may be difficult or expensive to control to within tight tolerances. If we wished to create a consistently good cake a design could be selected that would lend itself to identification of a robust combination of input factors that generate high scoring taste test responses without relying upon tight tolerances.

4.6.2 THE APPLICATION OF DESIGN OF EXPERIMENTS IN THE CONTEXT OF THIS RESEARCH

Generally, Design of Experiments is applied in a the traditional format: to provide an understanding of the effects of inputs upon outputs with a view to allowing inputs to be optimised or selected for robust design.

Conversely, this research looks to apply Design of Experiments for the sole purpose of predicting the outcome with no attempt to control input variables. The traditional approach and the conceptual essence of the approach proposed by this research are compared side-by-side in Figure 26.

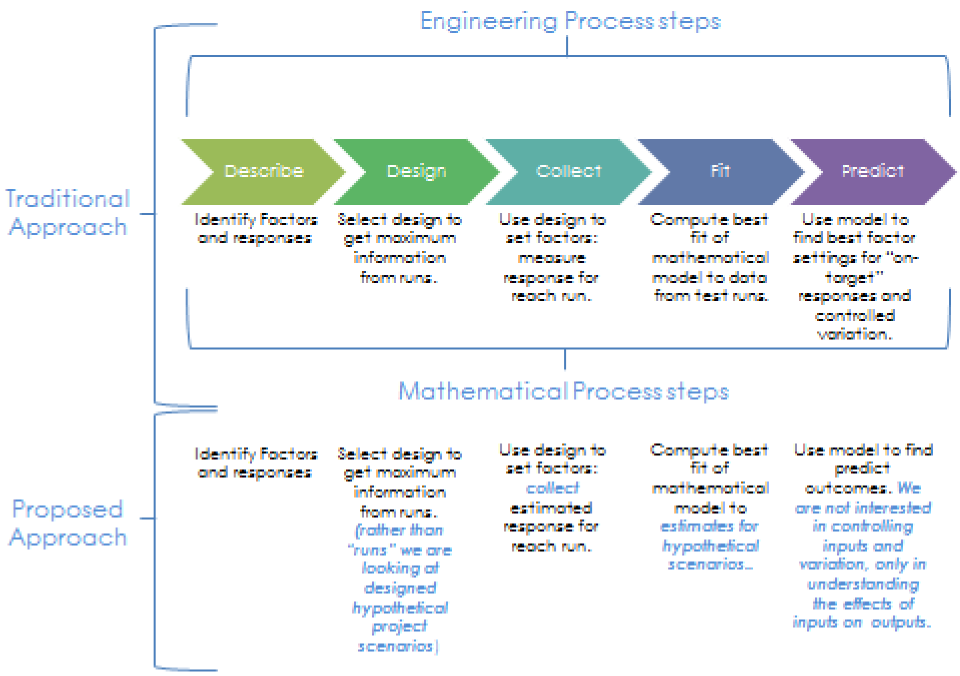


Figure 26 - The traditional approach to Design of Experiments and the approach to Design of Experiments proposed in the context of this research

Key differences between the traditional approach and the approach applied:

1. **Estimations about hypothetical scenarios will be used in the place of physical or simulated experiments.**
2. **Tacit, subjective expert knowledge is being modelled as opposed to objective, measureable information.**
3. The results will be used to make a prediction about outputs rather than to select or maximise inputs.

The first two of these key differences form the contribution to knowledge offered through this thesis.

4.6.3 EXISTING APPLICATIONS OF DESIGN OF EXPERIMENTS

Section 4.6.2 demonstrates in theory, how Design of Experiments could be adapted and used to develop a predictive model for resource demand in NPD. Through a literature review, we explore how Design of Experiments is currently used to predict and enquire whether any similar research has been conducted previously with a view to informing the approach taken in this context and in order to delineate a gap in knowledge.

4.6.3.1 LITERATURE REVIEW METHODOLOGY

Tranfield, Denyer and Smart (2003) establishes some criteria for developing a systematic literature review. Communicating and formalising the decisions made and logic behind decisions helps to ensure that the review is robust, logical, and repeatable and thus the result can be defended as good quality evidence. The review has been conducted by the doctorate researcher however; the search terms were discussed and agreed with other academic staff.

It is critical that each stage, the number of papers found and the decisions made are clearly documented in addition to the findings and outcomes.

4.6.3.1.1 SOURCES

A wider background narrative on the workings and applications of Design of Experiments has been conducted as part of the research process however, in order to provide a manageable level of evidence; this review focuses specifically upon academic journal papers.

Design of Experiments has been applied in a wide range of disciplines. ProQuest, a database search tool was used to search 22 journal databases.

To narrow the search, to ensure only good quality results and to maximise the chance of the results being relevant to an application of Design of Experiments (as opposed to generally about Design of Experiments as might be featured in a book) the search was narrowed to peer reviewed journal articles.

4.6.3.1.2 TERMS

As this research is specifically interested in the predictive capabilities of Design of Experiments, the search terms used were: "Design of Experiments" AND "Predict". The search was conducted to the level of article abstract as we were looking for example where the use of Design of Experiments for predictive purposes was one of, or was supporting one of the key contributions of the paper.

4.6.3.1.3 SEARCH RESULTS

107 results were returned, of these 17 did not document the actual application of Design of Experiments. 15 of the 17 referred to Design of Experiments in the context of potential future work and have been disregarded. The other two papers discussed Design of Experiments generally specifically providing background and examining why it has not been more widely applied (Sreenivas 1998; Hockman 1995). No reasons were arrived at other than a general lack of awareness and the false perception that complex statistics must be driving something so powerful.

4.6.3.1.4 ANALYSIS PROCESS

In order to establish the novelty of the research contribution, each of the 90 papers were read by the researcher with a view to providing an answer to the following five questions:

1. What was the source of data used to provide responses to designed experiments?
2. What was the nature of the scenarios considered?
3. What field has the Design of Experiments been applied to?
4. Why has Design of Experiments been applied?
5. Where did the response data come from?

Using Nvivo, a qualitative data analysis tool each of the 90 papers was coded according to responses to the above questions.

A summary of the responses to each question is summarised in the followings section.

4.6.3.2 RESULTS

The purpose of the literature review was not to explore the subtleties of each application of Design of Experiments in great detail, only to document the extent to which Design of Experiments is or isn't used in various fields and, to support evidence that this thesis provides a novel contribution. A high level summary of the break-down of coded items in response to each question is included under each heading.

4.6.3.2.1 WHAT WAS THE SOURCE OF DATA USED TO PROVIDE RESPONSES TO DESIGNED EXPERIMENTS?

- 78 % of papers (70/90) sourced data from physical experiments
- 26 % of papers (24/90) sourced data from virtual experiments (FEA, CAD, CFD etc.).
- 9% of papers (8/90) sourced data from both physical and virtual experiments
- For 4/90 papers it was unclear whether the data was derived from an experiment or a simulation- Design of Experiments was not a main feature of the paper and was not reported in sufficient detail to answer this question. The source was either physical or a model/ simulation of reality.
- 0 % of papers (0) sourced data from expert opinion, estimates or any other source.

4.6.3.2.2 WHAT WAS THE NATURE OF THE SCENARIOS CONSIDERED?

The factors are the things that define the subject of the experiment. They may describe a product or process or the effect a product or process has upon another subject. Usually they are physical (size, weight, chemical composition, pressure applied) or a function of time (no. of cycles, drying time).

- This research was interested in whether or not any non-physical factors have been considered and specifically whether or not project characteristics have been considered.
- 97.8% of papers (88/90) physical characteristics
- 2.2 % of papers (2/90) considered other types of factors

Some examples of the physical characteristics from a range of fields are included in Table 12 below.

Table 12 – Characteristics considered examples from different fields

Reference	Example of factors used	Comments
Ilgin and Gupta (2010)"**Comparison of economic benefits of sensor embedded products and conventional products in a multi-product disassembly line**", Computers and Industrial Engineering, 59. pp. 748-763.	**Inputs:** • precedence relationships among the components • The routing of different appliance types through the disassembly line. **Outputs** • Costs – disassembly, disposal, testing, backorder, transportation, holding. • Revenue • Profit	Two separates types of device have been compared using two orthogonal designs. ***Non-physical example*** ***Qualitative factors*** ***Physical experiments***
Salem, Rekab and Whittaker (2004) "**Prediction of software failures through logistic regression modelling**", Information and Software Technology, 46, pp. 781-789.	• Modem type: Generic or Hayes • New connection : 1 or 0 • TCPIP see: Assigned or Specific • Dialling option: pulse or tone	***Non-physical example*** ***Qualitative factors*** ***Simulation used rather than physical experiments.***
Munoz-Escalona, Diaz and Cassier (2012) "**Prediction of tool wear mechanisms in milling AISI 045 Steel**" Journal of Materials Engineering and Performance, Volume 21(6)	• Cutting speed (12 levels) • Feed per tooth (3 levels) • Depth of cut (3 levels)	***Physical experiments*** ***Quantitative factors*** ***Typical Design of Experiments application*** Trails were spilt into two groups. L18 (61932), design (Taguchi) used for each group. Total of 36 experimental runs.
Lee and Bang (2006) **"Robust design of an automobile front bumper using Design of Experiments"** Proc. IMechE Vol. 220 Part D: J. Automobile Engineering	The thicknesses of the inner beam, outer beam, and stay are treated as design variables. .	The robust design procedure for a bumper, considering the uncertain thicknesses, is presented ***Quantitative factors***

		FEA experiments
Sharma *et al.* (2008) **"The effect of pharmaceuticals on the nanoscale structure of PEO–PPO–PEO micelles" Colloids and Surfaces B: Biointerfaces 61**	Micelle core size (*R*1), micelle corona size (*R*2), intermicellar interaction distance (*R*int), polydispersity (σ), and aggregation number (*N*agg); critical micelle Concentration (CMC); drug solubility and apparent micelle–water partition coefficient (*K*mw).	***Quantitative factors*** Physical experiments

Other types of factors considered were:

1. The precedence of activities (removing components) and routing through a disassembly line (Ilgin and Gupta 2010) and
2. The characteristics of software (product characteristics) that impact failure – in this instance Design of Experiments was used to design the test/ validation cases for a logistic regression model (Salem *et al.* 2004).

Out-with the systematic review, background research uncovered evidence of Design of Experiments having being applied (at least anecdotally) in service and marketing industries, typically associated with qualitative rather than quantitative, physical methods. Several case studies are investigated in a book "*Testing 1-2-3*" (Ledolter and Swersey 2007). Examples of case studies within the book are documented in Table 13 below.

Table 13 – Factors included in case studies within Testing 1-2-3 (Ledolter and Swersey, 2007)

Case study description	Factors used	Comments
Example from manufacturing – "Cracked pots".	Peak temperature Cooling rate Clay composition	Manufacturing example in a marketing and service text book.
Direct mail credit card offer	Annual fee Account opening fee Initial interest rate Long-term interest rate	Factors set at "current practice" and "new idea" – a perceived incentive. The purpose of the study is to find which incentive works best.
Improved online learning	Textbook Readings Homework Software Sessions Review Lecture notes	Two levels for each factor. Rather than looking at just two experiments. We can look at all combinations of the two factors.

Direct mail credit card campaign	Envelope teaser Return address Official ink stamp Postage Graphics Sticker Signature Reply envelops Interest rate Free gift value… (19 factors in total).	Factors describe the product presented to the customer "the main campaign material". Two levels for each factor - 20 experiments can be conducted using a placket-burman design to show main effects and some interactions.
Baking a cake	Temperature Time	3 level design
Bottle filling operation	Pressure Speed Carbonation	3 level design
Eagle brands (in store promotion)	Packaging (regular or deluxe) In store samples (no/ yes) Coupons (no/yes) Fat percentage (current/ reduced) Gold sticker (no/ yes) Lettering (current/ new)	Which marketing incentives work best? Which combinations of marketing incentives work best?
Magazine price test	Cover price Subscription price Number of copies on news stand	3 level design Which combination maximises sales/ profit?
Magazine subscription mail promotion	Act now insert (not included/ include) Credit card (no/ yes) Offer Guarantee Testimonials Bumper sticker Style (gutsy/ballsy).	 Which combination maximises subscription uptake?
Peak electronics	Lamination roll thickness Lamination exit temperature Developer spray pressure Developer breakpoint Post lamination hold time	Manufacturing process problem.

The marketing and service operations case study example refer to a number of manufacturing problems. Marketing and service operations examples centre almost exclusively on sales incentives. Factors include physical product packaging characteristics, or characteristics of product placement that may impact sales or subscription uptake. Exceptions include alternative/ additional marketing strategies such as in store samples and free gifts.

Within the systematic review, no evidence was found of project characteristics being used to create a Design of Experiments based predictive model.

Taguchi is synonymous with DoE and quality engineering. His work closely relates to manufacturing and production. Although the Taguchi designs are not any more powerful than other methods (in fact it could be argued that in cases where they are truly original, they are less powerful and more complicated than other designs), Taguchi is perhaps more synonymous with DoE than anybody else, even the founding father Fisher. One reason for this could be that the context in which Taguchi developed the DoE arrays. The surrounding "principles of quality engineering" are easier to engage with than just a statistical process. Perhaps this is why this field to which Taguchi belongs has adopted DoE more readily than others.

4.6.3.2.3 WHAT FIELDS HAS THE DESIGN OF EXPERIMENTS BEEN APPLIED IN?

In order to establish whether or not Design of Experiments has previously been in a resource planning context, we noted the field of application for each of the 90 papers. A summary of the subject area or focus of the 90 papers is documented in Table 15. The most common application is manufacturing engineering, closely followed by Material Science. Often, the subjects are combined when tool wear or material properties are examined under varying parameters. This type of study typically provides insights (often counter-intuitive) into which parameters need to be controlled. When creating exact tolerances and consistent processes is costly, this sort of insight can help inform process investment decisions.

Table 14 – Example studies from a range of fields

Field	Reference example	Study description/ comments
Automotive	Neugebauer *et al.* (2011) Predicting dimensional accuracy of Mechanically joined car body assemblies" Key Engineering materials Vol. 473	Also coded as manufacturing. Different methods of joining car body components are examined. Simulated as well as real experiments are conducted.
Bio-fuels	Berrios *et al.* (2009) "Application of the factorial Design of Experiments to biodiesel production from lard" Fuel Processing Technology, Vol.90, no. 12.	Factorial experiment used to predict optimal process parameters.
Biology	Levin (2010)"Nasty Viruses, Costly Plasmids, Population Dynamics, and the Conditions for Establishing and Maintaining CRISPR-Mediated Adaptive Immunity in Bacteria"	Experimental populations of bacteria used to test the response to different conditions/ combinations of conditions.
Chemical Engineering	Bautista *et al.* (2009)"Optimisation of FAME production from waste cooking oil for biodiesel use"	Also coded as bio-fuels Factorial design and central composite design used. Factors: fatty acid concentration, temperature and catalyst concentration.
Manufacturing	Munoz-Escalona *et al.* (2012), "Prediction of tool wear mechanisms in face-milling"	Taguchi Experiments
Material Science	Mahmoud, El-Kady and Al-Shihri (2012) "Mechanical and corrosion behaviours ofAl/SiC and Al/Al2O3 metal matrix nanocomposites fabricated using powder metallurgy route"	Taguchi experiments
Orthopaedics	Isaksson *et al.* (2008) "Determining the most important cellular characteristics for fracture healing using Design of Experiments methods" Journal of theoretical biology	Also coded as biology Level IV resolution design to screen factors followed by a three level Taguchi design which was used to study the non-linearity of the ten most important factors.
Pharmaceuticals	Kenakin (2008)Receptor theory." Current protocols in pharmacology	Predicting drug effects under a variety of circumstances
Physics	Mohamed Sheriff *et al.* (2008) Optimization of thin conical frusta for impact energy absorption	Also coded as material science. Factors = geometrical parameters. Box – Behnken design used. Mathematical model created using response surface methodology.

Table 15 – Applications of Design of Experiments in various fields

	Automotive	Bio fuels	Biology	Chemical Eng	Electronics	Manufacturing	Material Science	Orthopaedics	Other	Pharmaceutical	Physics
Automotive	8	1									
Bio fuels	1	5		1							
Biology			11					1			
Chemical Eng		1		15		2				1	
Electronics					2						
Manufacturing	2			2		46	20				
Material Science				1		20	27				
Orthopaedics			1					3			
Other									2		
Pharmaceutical				1						2	
Physics						1					3

4.6.3.2.4 WHY HAS DESIGN OF EXPERIMENTS BEEN APPLIED?

Design of Experiments is usually applied for a combination of reasons. The 90 papers were reviewed and explicit reasons were noted. Reasons explicitly stated have been coded and summarised in Table 16.

The main reasons why Design of Experiments would be applied is that provides a granular overview of how a system is behaving without having to conduct a high number of experiments. The effects of factors and interactions between factors can be established with confidence with relatively simple analysis. Conducting a reduced number of experiments can be especially useful when they are expensive or impractical to conduct.

Design of Experiments has only been used to make a prediction about an occurrence or event in one other instance (Salem, 2004). This was specific to predicting software failures. Even in this specific instance, the underlying study motivation was to develop the most test procedure to identify software failures. The factors beings studies were the parameters of possible test designs. In every other instance, Design of Experiments has unambiguously been applied with a view to finding optimal settings for process parameters.

No evidence of Design of Experiments being applied to predicting project duration or resource required per project has been found.

4.6.3.2.5. DATA SOURCE FOR DESIGN OF EXPERIMENTS RESPONSES

All of the 90 papers sourced response data for Design of Experiments runs from either physical experiments, simulations or a combination of both. No papers were found where expert judgement or estimations were used.

Table 16 – Key reasons for applying Design of Experiments

	To understand significance of factors and interactions	To generate a regression model	To minimise the no. of exp required	To provide data for a simulation	To reduce computational expense	To reduce the no. factors considered in a simulation	To train ANN	To validate a simulation	To forecast/ predict software failure
To understand significance of factors and interactions	57	7	4			1			
To generate a regression model	7	22	2	1					1
To minimise the no. of exp required	4	2	12				1		
To provide data for a simulation		1		5		1			
To reduce computational expense					3				
To reduce the no. factors considered in a simulation	1			1		5			
To train ANN			1				11		
To validate a simulation								4	
To forecast/ predict software failure		1							1

4.6.3.6 SUMMARY OF DESIGN OF EXPERIMENTS APPLICATIONS

Design of Experiments is used in a wide variety of fields. Most papers reviewed are concerned with Manufacturing and/or Material Science although subjects range from the lifespan of low-earth orbit batteries (Reid *et al.* 2007) to the effects of pharmaceuticals (Sharma *et al.* 2008).

Although Design of Experiments has been applied in a variety of fields, it is often applied prescriptively. (Which makes sense because this way we can see it is applied in a robust and repeatable way). In this research, necessity (a shortage of past project data) has forced us to consider Design of Experiments in a novel way: to predict project duration and resource requirements using estimates about hypothetical project scenarios.

Although Design of Experiments has been applied in a variety of contexts before, this thesis claims that this application in this context has novel aspects.

The novel aspects claimed are:

1. **Design of Experiments has not be used to develop a predictive resource planning model.**
2. **Design of Experiments has not been used to capture and model expert tacit knowledge.**

In the following Chapter we look at how Design of Experiments can be adapted and applied in the context of this research.

CHAPTER 5 APPLICATION OF DESIGN OF EXPERIMENTS TO PREDICTIVE RESOURCE MODELLING

In previous chapters, the requirements of a novel process for developing a predictive resource model in an NPD environment, with the absence of an abundance of past project data have been set out. Design of Experiments has been identified as potential means to satisfy the requirements.

This chapter explores the development and application of a modelling process in the context of DePuy Orthopaedics, the sponsoring company as well as in Scottish Water an external company from a completely different industry. The conceptual idea is revisited: each step is explicitly laid out and the key questions relating to modelling process design are reviewed before a more detailed process is developed and rolled out. The modelling process is applied to six different functional groups within DePuy in the form case studies. Four of the six case studies follow a 8 run fractional factorial design, one of the case studies (Test Group) features two sub-models: one for instrument testing and one for implant testing using fractional factorial design and the final case study (Design Engineering) features a 8 run Taguchi design with two sub-models: one for instrument design and one for implant design. The four fractional factorial designs follow the designed process and are reported together in detail. The case studies for Test Group and Design Engineering did not work as well, reasons for deviation from the designed modelling process are documented, the process applied is laid out and the limitations of the application Design of Experiments in this context are discussed.

5.1 THE PROCESS FOR DESIGN OF EXPERIMENTS MODELLING

The first stage (**describe**) has already been completed (please see section 4.2.1.1.) To begin we review the conceptual process and identify the key questions to be addressed through a pilot study. Some of the modelling steps have already been completed when attempting other modelling methods. Completed steps are featured in the top half of Figure 27. Steps still to be completed are featured in the lower half of Figure 27. Questions relating to the design of the study had to be addressed before business leaders across DePuy were engaged. Questions relating to study design are discussed in section 7.2.

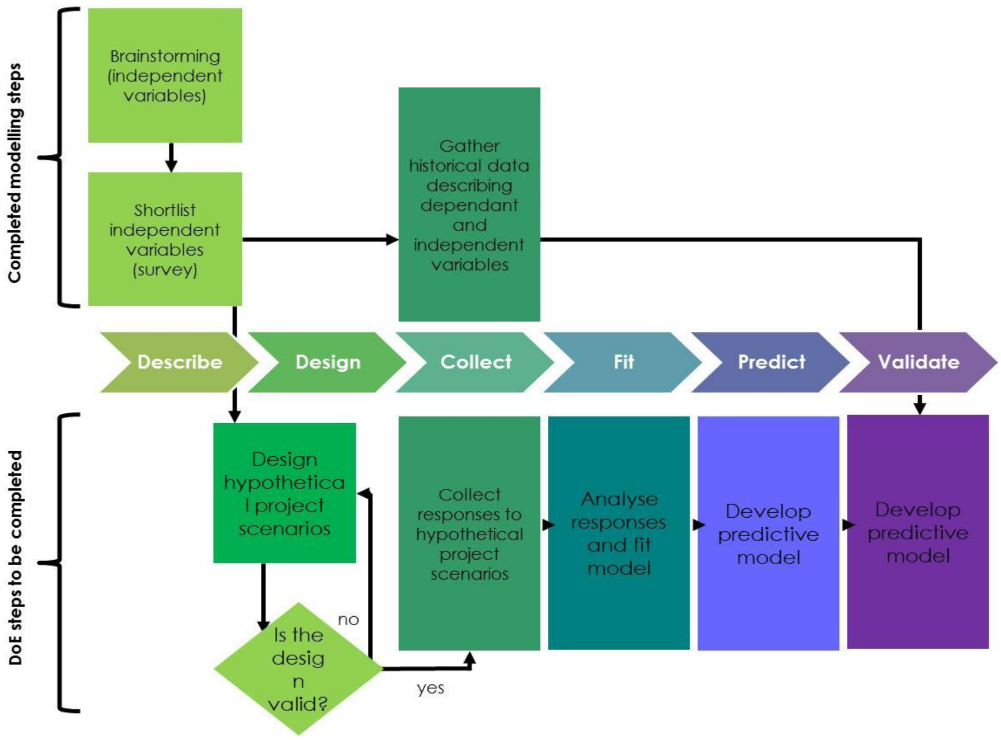


Figure 27 - Conceptual Design of Experiments predictive modelling approach

Table 17 below discusses each stage in model detail.

Table 17 – Detail of the Design of Experiments predictive modelling approach

Phase	Activities	Purpose	People required	Outcomes
Describe	Brainstorming	Exhaustive list of factors/ project characteristics perceived to have an impact resource demand.	Business leaders or people with a cross functional view of NPD projects, researcher.	A list of 20 – 40 factors. Some factors specific to one function and some factors generally applicable across multiple functions.
	Survey – factors	Shortlisting the factors. Finding factors specific to each functional group. Present the full list of factors, ask functional leaders to determine the perceived impact upon their group "high", "medium" or "low".	Functional leaders and managers. People with experience of what drives resource demand in each group, researcher.	A shortlist of project characteristics perceived to have most impact upon each function. (approximately 3-6).
Design	Pilot	To establish the feasibility of a study and the practical experimental design restrictions.	Business leaders. People who support the modelling project with a reasonable idea of the resource requirements in a specific function.	The practical specifications of experimental design – Maximum number of runs and number of levels required
	Select Design	Select a pre-determined design array for each functional group based upon the number of factors, the number of runs and the number of levels required.	The researcher/ model developer.	A design template.
	Create experimental survey	Populate the pre-determined, general experimental design with hypothetical project scenarios, factors specific to the function and fields for responses required.	The researcher/ model developer.	An experimental survey unique for each functional group.
	Verify survey design	Check that the experimental design makes sense, that the factors managers will be asked to consider do indeed reflect the considerations they make when developing resource estimations.	Functional managers, researcher.	A survey ready to distribute.
Collect	Distribute survey	Send the survey to relevant people so they can populate. Make sure the process is clear and that people are on-board with the concept. Select people who have experience making resource estimates.	Researcher, Functional leader and business leaders (advice on who to ask). Gain leadership support to gain buy-in for modelling concept across business.	
	Gather survey responses	Collect completed templates.	Survey respondents, researcher. Business leaders,	Completed survey templates.

			functional leader support to chase-up non-respondents.	
Fit	Analyse variation in responses and derive regression model	Assess how well the responses reflect the variation in the project scenarios.	Researcher	A basic regression model. Understanding of which factors are most significant.
	Assess goodness of fit and tune regression model	Remove and re-add factors to/ from the regression model to inflate the R-squared value.	Researcher.	A model that reflects the variation in data.
Predict	Transfer the regression model to excel.	Use excel (or similar) to enable quick and easy predictions.		A predictive model for resource required per project phase. One model for each functional group.
Validate	Gather past project data – qualitative data describing projects and quantitate resource and duration data where available.	Asses how well the modelling process has worked. Design of Experiments the model represent a view of reality?	Researcher.	Information about model accuracy.
	Select model with best predictability	Where multiple versions of models have been developed, asses which model predicts most accurately.	Researcher.	The best possible (given the available data). A model with known accuracy.
	Verify with managers that the predictability is reasonable.	This is especially critical when past-project data is in short supply. Would the estimates they generate for actual projects be very different from the predictions made by the model?	Functional leaders, business leaders, researcher.	Knowledge regarding whether or not managers would be happy to accept the model predictions.
	Repeat the process in an external company.	Test the repeatability and generalizability of the modelling process.	External company – (Scottish Water) Business leaders, functional leaders. Researcher.	Knowledge about the generalizability and repeatability of the modelling approach.

5.2 PILOT STUDY

A pilot study was designed and conducted in order to establish the best experimental approach to take. Different Design of Experiments designs exist. We require a design that will ensure reasonable responses. The aims of the pilot study were:

1. To establish the ideal number of runs/ experiment resolution.
2. To identify whether simple two level models were adequate or if more complex three levels models would be required.
3. To identify the best survey format.

Three business leaders on-board with the predictive modelling research project were recruited to take part in the pilot process. They were the Director of Development Services, the Innovation Process Leader and the Innovation Process Manager. The recruits were in a unique position in that they had an understanding of the NPD process as a whole as well as being familiar with the aims and objectives of the research project.

Operations were chosen arbitrarily as a function for the case-study. From the "Factors impacting resource demand" study, the factors perceived to be most significant were selected and an experiment was designed using Minitab as a guide.

The results of the pilot study in relation to the aims are documented in following sections. Section 5.2.1 documents an exploration of the survey format, 5.2.2 – the ideal number of runs and sections 5.2.3 and 5.2.4 document the results derived from two and three level pilot models respectively. General observations of unanticipated issues are documented throughout and the key pilot study findings are documented in section 7.2.5.

5.2.1 FORMAT OF EXPERIMENTAL DESIGN SURVEY

Several different options could be used to present the hypothetical project scenarios. Three different formats were tested through discussion with the pilot group.

1. Textual description of each scenario with a table to complete in which respondents could enter project phase duration and resource required per project phase duration.
2. A list of project characteristics with a description of the level per scenario with a table to complete in which respondents could enter project phase duration and resource required per project phase duration.
3. A table combining project characteristics, level setting and boxes for responses for each scenario.

Option 3 (a combination of inputs and outputs combined) was unanimously preferred over the first two formats as it allowed easy comparison between scenarios.

5.2.2 NUMBER OF RUNS

Designs are only available with fixed number of runs. The number of runs depends upon the number of factors, the number of levels each factor is considered at and the level of detail required in the predictive model. Experiments with fewer runs are less expensive whilst experiments with a greater number of runs will provide a more detailed view of the system, possibly with more information about interactions and curvature (nonlinearity) of responses.

At first a 32 run fractional factorial experiment was designed and the three managers were asked to complete resource and duration estimates for each scenario. Managers were unable to complete this study. Two main reasons were given:

- Firstly, there were too many scenarios. Each scenario required a significant amount of consideration and the sustained concentrations over 32 scenarios was not feasible.
- Secondly, the differences between the 32 scenarios were very subtle. The business leaders found it difficult to really make a distinction between the resources requirements of some.

The number of runs was reduced from 32 to 16 and then from 16 to 8. An experimental design with 8 runs took two of the business leaders just over an hour to complete and one of the business leaders around ten minutes. Completion time of anything over an hour was deemed unreasonable especially when high levels of concentration would be required to distinguish between scenarios. It was anticipated that designing a full study experiment with any more than 8 runs would result in a very low response rate.

5.2.2 TWO LEVEL STUDY.

A model was developed based upon the pilot study responses; a separate model was developed for each business leader's response. The models from respondent one and two had high r-sq. and r-sq. adjusted values whereas the responses from respondent 3 had much lower r-sq. and r-sq. adjusted values. The correlation shows in Figure 28 between response time (consideration given) and the accuracy of the models suggests that the more consideration given to the responses, the more accurate the models. Neither respondent completed the scenarios in order, each started with the scenario they felt more familiar with and adapted estimations for other scenarios from this point. This suggests that randomising runs in this instance will not have any effect upon minimising noise.

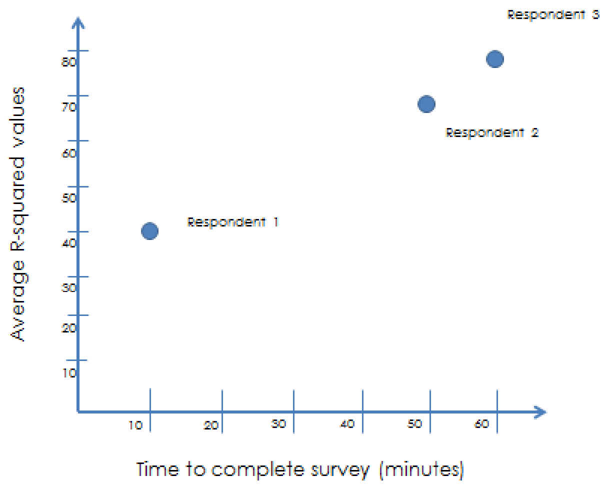


Figure 28 – Time to complete survey vs. R-squared (reflection of scenario variation in responses given)

5.2.3 THREE LEVEL STUDY

The two level fractional factorial designs assume an approximately linear relationship between resource demand/ project duration and the independent variables. To check that this is a reasonable assumption to make, a 3 level pilot study was developed using an L9 (3^{4-2}) Fractional Factorial Design 4 Factors at Three Levels (9 runs). Figure 29 provides an example of approximate linearity in the responses. In all instances the responses were approximately linear. As the purpose of the model is to establish approximate relationships this was deemed sufficiently adequate. In the actual study, the success of the model will be determined by how well the model predictions compare with past-project data.

Respondent 1 and Respondent 3 participated in this study. Respondent 1 completed the survey in 15 minutes; Respondent 3 completed the survey in around 55 minutes. This time, respondent three noted that the subtleties between each scenario were harder to distinguish between.

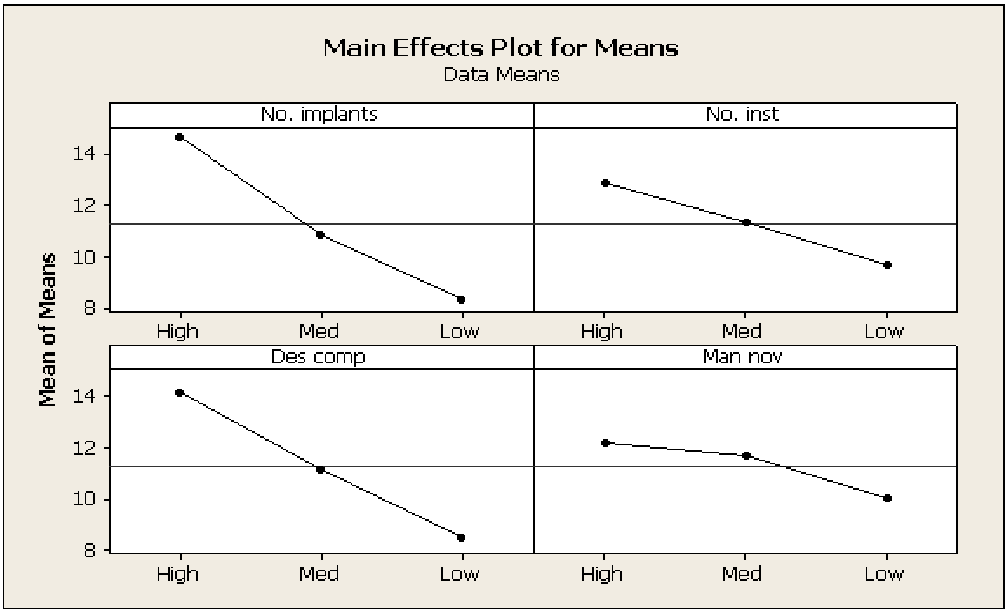


Figure 29 - example of a main effects plot showing approximate linearity.

5.2.4 LEARNING FROM THE PILOT STUDY

Lessons from the pilot study are applicable to the main study.

Three key lessons are:

1. The experimental survey should ideally be kept to 8 runs.
2. Two level fractional factorial designs should be sufficient.
3. The care and attention of respondents plays a part in the accuracy of the model. It is advisable not to pressure respondents to participate if they are reluctant to devote time to considering responses or are uncooperative with the study motives.

5.3 FIVE FRACTIONAL FACTORIAL CASE STUDIES

Five of the seven functional groups studied were satisfied with a fractional factorial design. The method used to develop a predictive model for the five functions is reported in this section. Each step of the process, from design through to validation is discussed.

5.3.1 DEFINE

Models for five functions: Project Management, Bio-Engineering, Regulatory, Marketing and Quality were developed using a fractional factorial design. The designs for Project Management and Bio-Engineering were identical whereas the designs for the other three functions were slightly different in that they involved different factors: different factors were perceived to impact resource demand.

Starting with the results of the "factors impacting resource demand" survey results a set of factors to be included in the model was defined. Factors included in each model must meet certain specifications which were not necessarily considered in any great depth during the initial survey process.

- Factors must not be decomposable. Each factor should not be described by other factors. (This is why "project type" has not been included). In addition to using up "factor space" (the number of factors is limited), this could create confusion. If a factor can be decomposed it would be impossible to determine which aspect drove the response.
- Factors must be such that they could be determined with reasonable accuracy at the outset of a project i.e. they should be a component of the

conceptual project proposal rather than project information that becomes apparent only when the project is underway.

The factors for each function from survey to those used in each design are considered in Table 18 below.

Table 18 – Process of defining factors for each function

Function	Factors from survey	Key discussion on: **1.** Is each factor decomposable? **2.** Is each factor determinable at the outset of a project?	Factors used in design.
Project management and Bio-Engineering	No. of Instruments New or existing technology Core competency/ capability Project type Launch time pressure Regulatory pathway	Number of implants was also perceived to be of some significance. New of existing technology, regulatory pathway, core competency can all be summed up with "design complexity, design novelty and material technology novelty". "Project type" and launch time pressure are not really project characteristics. Project type is a combination of different factors and launch time pressure is independent of the nature of the project.	No. implants No. instruments Design complexity Design Novelty Material technology
Regulatory	New or existing technology New or existing market Clinical evidence required Technology acceptance Regulatory pathway Testing/ validation required	Number of implants is important. What type of new technology? – Better replaced by "Material technology novelty, design novelty and man pro novelty". This will also cover regulatory pathway and clinical evidence requirements. Testing validation required related to novelty factors plus design complexity.	Number of implants Manufacturing process novelty Design complexity Design novelty Material technology novelty.
Marketing	New or existing technology New or existing market Project type Launch time pressure Budget restriction Surgeon team size Strategic value	Strategic value is important. New technology / market can be replaced by design novelty. Budget restriction shouldn't impact the requirements, only the capacity. Launch time pressure needs to be adjusted for post-model. Project type is not a real factor.	Strategic value Design complexity Design Novelty Surgeon Team Size

Quality	Not included in original survey. Factors decided though later discussions.	Number of implants Number of instruments Design complexity Manufacturing process novelty Production volume

5.3.2 DESIGN

Fractional factorial designs have been selected based upon the following:

- A maximum of eight runs is permitable
- Due to the assumption of linearity, a two level design will suffice.

Four of the five functions feature five factors. With eight runs at two levels we are limited to a quarter factorial design. Marketing is the only functional group with just four factors; this permits a half factorial design.

With both half and quarter factorial designs, care must be taken when removing factors as confounding effects are not always accounted for. It may be unclear whether an effect is attributed to a factor or to the interactions between factors depending upon the aliases. In such cases it is best to err on the side of caution and keep both factors in the model.

Survey designs for each of the four functions are included in Appendix 2a.

5.3.3 COLLECT

Designs were sent to functional leaders by email. Functional leaders were asked to nominate several functional managers to complete the survey. The number of responses received and the format of the responses varied. For some functions, managers replied individually, in other instances a combined response from a number of managers was received and in other instances only one response was received. Table 19 shows the number of responses received for each function, the number of models developed.

Table 19 – Number of responses and models per function

Function	Responses	No. of models developed
Project management	2 (separate)	3 sets of models: 2 individual models, 1 combined model. Each set contains 14 models: 7 models for duration per Stage-Gate phase and 7 models for corresponding resource per Stage-Gate phase. Total = 42
Bio-Engineering	1 response.	One model set containing 14 models: 7 for duration per stage gate phase and 7 for corresponding resource. Total = 14
Regulatory	1 response for resource, 4 responses for duration.	One model for duration: Gate 6-7 is the only phase that regulatory have an impact upon). This was developed by combining 4 responses. 2 models for resource: Gate 6-7 and Gate 7-8. Regulatory resource required for all other project phases is consistent no matter what type of project. Total = 3
Marketing	1 response (combined view of 2 leaders).	7 resource models, No duration models. Marketing do not have an impact upon project duration. Total = 7 models
Quality	1 response (combined view of 4 managers).	7 duration models and 7 corresponding resource models. Total = 14 models

Initially, the motivation for collecting several responses was to include multiple corner points with a view to reducing noise (biases due to different experiences and perceptions). Not all functions were modelled simultaneously, thus it was possible to learn lessons from one function and apply these to another. The first model to be developed was for Project Management. Two responses were received for project management and several approaches were taken to modelling (as is discussed in the following section "Fit"). Each set of responses was modelled individually and, the responses were combined, with each corner point replicated. When compared with past project data, it transpired that two (or more) responses are not necessarily better than one: For project management the model based on the response of respondent 1 was far superior to the model based upon the response of respondent 2. Respondent 2's response compromised the combined model.

It should be noted that designs were developed for other functional groups including Operations and Clinical however, despite several meetings, emails and telephone calls no responses were received. The reluctance to take part despite the long-term time savings was never explicitly apparent although the question was put forward on several occasions.

5.3.4 FIT

Minitab™ has been used to fit analyse the survey results. Results have been analysed one model at a time.

Full analysis for Project Management function is included in Appendix 4. Models for the other four functions have been developed in an identical fashion.

An example of the analysis process for one sub-model: Project Management Duration Gate 3 –Gate 6 is included below.

To begin we can examine the residual plots in order to assess how well the assumptions of regression analysis are met. From Figure 30 it is clear that the distribution of the residuals is not normal, the observation order appears random although the second set of observations (respondent #2) differs from residuals attributed to respondent #1: the first set mostly have a positive value, the second set are mainly negative. Essentially, the normal distribution in Figure 30 shows nothing of great concern and although the assumptions of regression are not absolutely met everything is as expected.

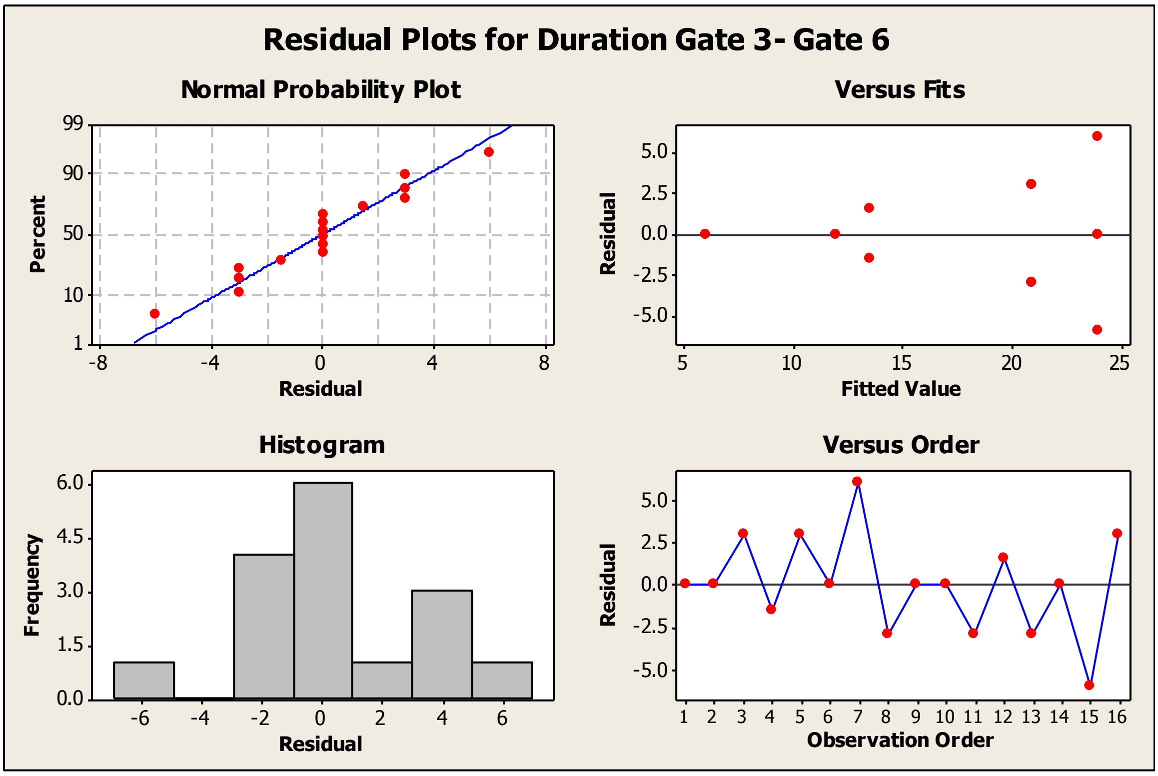


Figure 30- Residual Plots for Duration Gate 3- Gate 6

The next thing explored is the effects of the project characteristics upon duration Gate 3 - Gate 6. This was observed through the main effects plot (See Figure 31), the Pareto analysis (Figure 32) and the interaction plot (Figure 33).

From the Main Effects Plot in Figure 31 we can see that Number of implants and Material Technology novelty appear to have negligible impact upon the duration of this phase. The Pareto chart in Figure 34 suggests that Design Complexity and Design

Novelty have most impact upon duration between Gate 2 and Gate 3.Figure 32 also suggests that there are some interesting interactions. Interactions are explored further through Figure 33

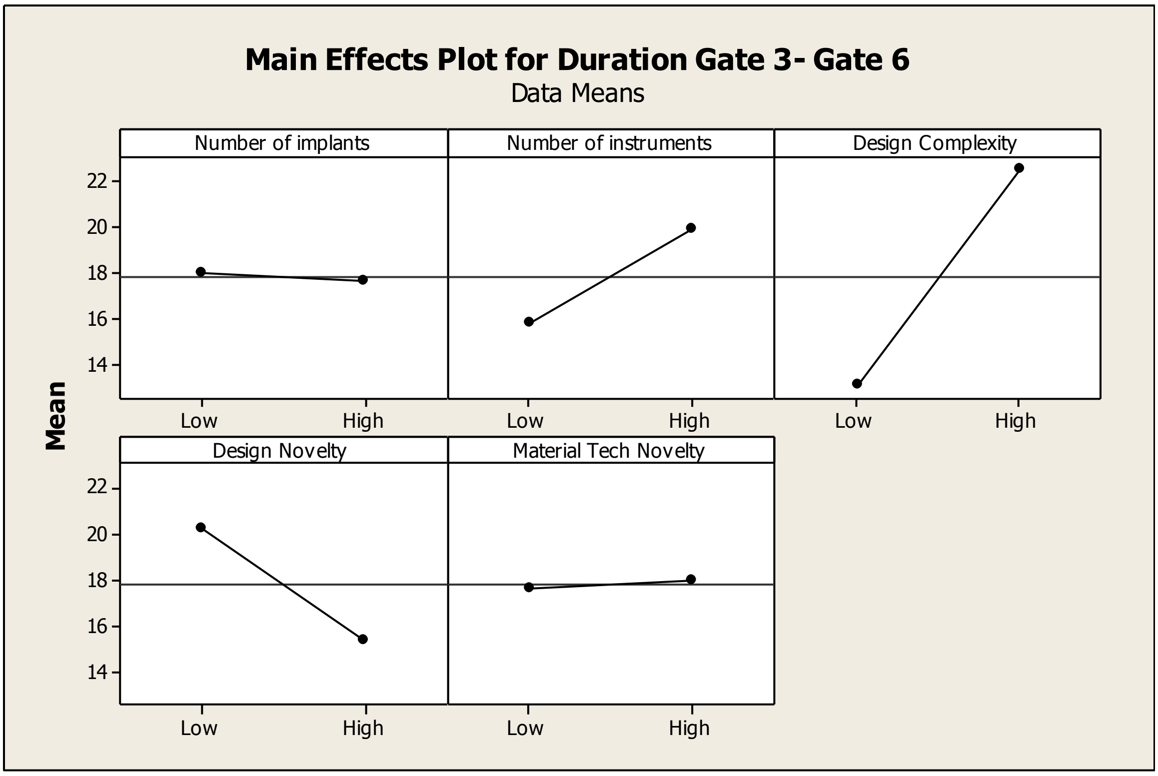


Figure 31 - Main Effects Plot for Duration Gate 3 - Gate 6

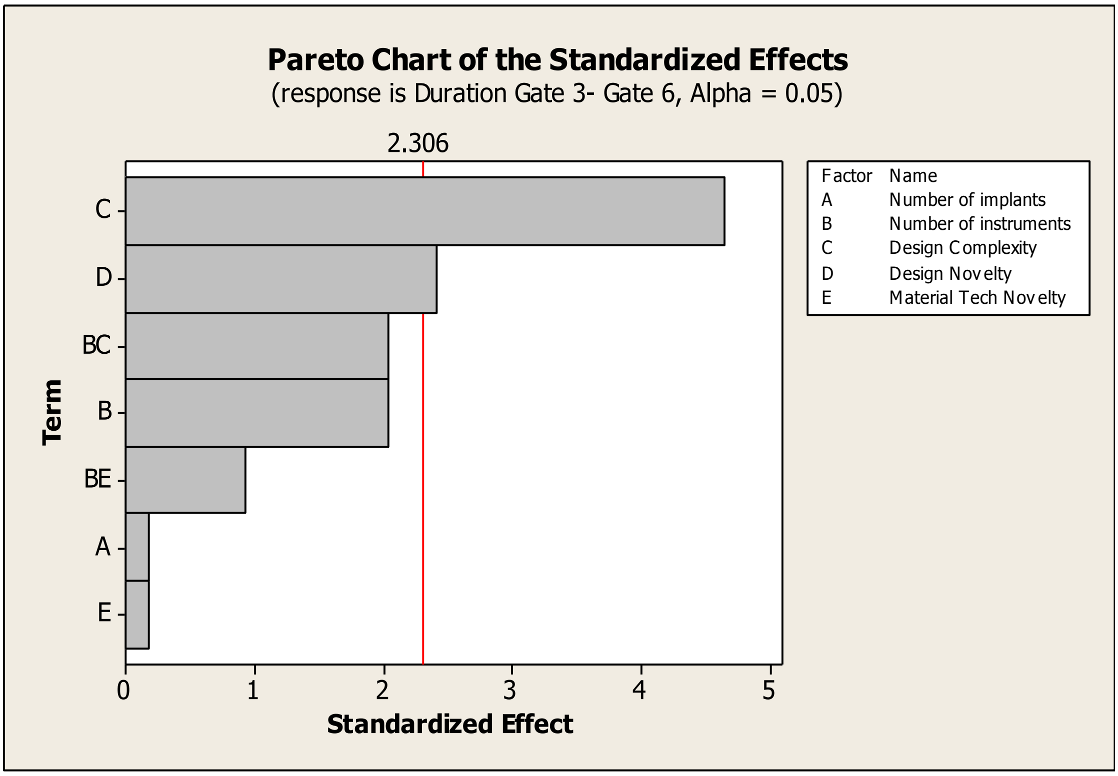


Figure 32 - Pareto Chart of the Standardized Effects (when confidence level is set to 95 %)

Figure 32 indicates that Design Complexity and Design Novelty are the only statistically significant factors (when the confidence level is set to 95 %). Interactions between Number of Instruments and Complexity and Number of Instruments and Material Technology are also indicated as impacting project duration however such interactions are not statistically significant.

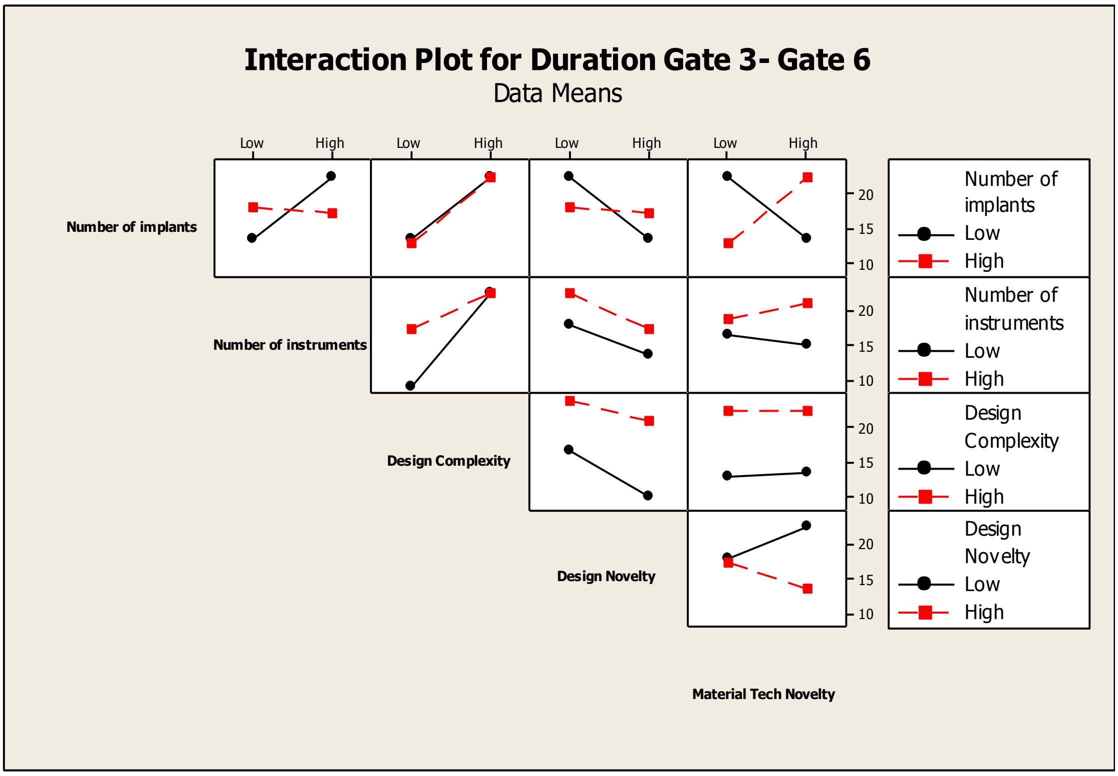


Figure 33 - Interaction Plot for duration Gate 3- Gate 6

Figure 33 suggests that as design complexity increases the effect on project duration when the number of instruments is low. The effect of a high design complexity is not affected by the number of instruments however; a low number of simple instruments appear to have less effect upon duration than a high number of simple instruments. This sort of effect is expected and logical but could not be detected through normal regression analysis, it would have to be specifically identified a priori then analysis conducted to assess the effect of the interaction rather than the interaction itself emerging from results.

To examine the model in more detail we can look at the constant, the coefficients and the p-values. These are displayed in Table 20

Table 20 - Constant, coefficients and p-value Duration Gate 3- Gate 6: all terms

	Coefficient	P-value
Constant	17.813	0.000
Number of implants	-0.187	0.857
Number of instruments	2.062	0.075
Design Complexity	4.687	0.002
Design Novelty	-2.438	0.042
Material technology Novelty	0.187	0.857
No. instruments * complexity	-2.063	0.075
No. instruments * Material Technology	0.938	0.380

For a factor to be considered significant we are looking for a p-value less than 0.05. From Table 20 it is clear that this only applies to Design Complexity and Design Novelty. The model has an associated R—Sq. adjusted value of 66.41 %. Removing the less significant terms form the model may improve predictability and simplicity.

The next step involved removing all the factors not shown to be statistically significant and reassessing the model. From Table 21 below we can observe the revised constant, coefficients and p-values.

Table 21 – Constant, coefficients and p-value duration Gate 3 – gate 6 revised model: only statistically significant terms

	Coefficient	P-value
Constant	17.813	0
Design complexity	4.689	0.001
Design novelty	-2.437	0.056

The R-sq. adjusted value for this model is only 55.36 %. Removing all the factors apart from design complexity and design novelty has had a detrimental effect upon predictability.

The next step involves reintroducing the next significant factors. Number of instruments and the interaction between instruments and design complexity are re-introduced. The revised model is shown in Table 22 below.

Table 22 – Constant, coefficients and p-value duration Gate 3 – gate 6 revised model version two: reintroducing terms

	Coefficient	p-value
Constant	17.813	0
Design Complexity	4.688	0.45
Design Novelty	-2.238	0
No. instruments	2.062	0.21
No. instruments * complexity	-2.063	0.045

The revised R-Sq. adjusted value is 72.73 %. Figure 34 shows that the only other remaining possibility of improving the predictability would be to attempt removing the interaction BC.

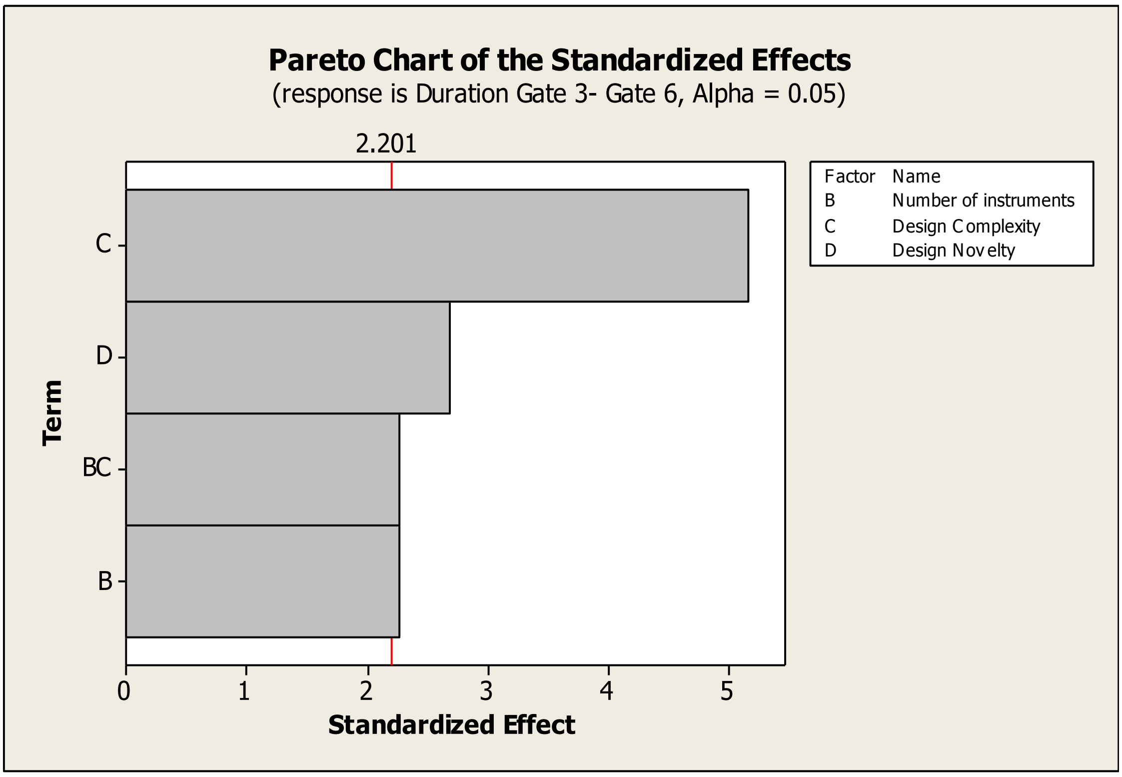


Figure 34 – Pareto Chart of the Standardized Effects (there would be no benefit in removing number of instruments as we would also need to remove the interaction).

The final step is to examine the effects of removing the interaction BC. This is demonstrated in Table 23.

Table 23 - Constant, coefficients and p-value duration Gate 3 – gate 6 revised model version three: removing interaction

	Coefficient	p-value
Constant	17.813	0
Design Complexity	4.688	0.001
Design Novelty	-2.438	0.039
No. instruments	2.062	0.74

The model shown in Table 23 has an R-Sq. adjusted value of 63.32 % - not as favourable as the previous model shown in Table 22. With the data set provided and using both responses combined as replicated corner points, the model displayed in Table 22 most accurately reflects the variations.

The mathematical model for Duration Gate 3 – Gate 6 (based upon the Project Management model responses) is:

Equation 9

$$Duration\ (3-6) = 17.813 + (4.688 * Design\ complexity) + (-2.438 * Design\ novelty) + (2.026 * no.of\ instruments)$$

Where, Design complexity, Design Novelty and No. of instruments can be either "High" (+1) or "low" (-1).

A summary of the coefficients of each of the models (duration and resource per Stage-Gate phase) for each function are included in Appendix 5.

Overall, the models fit the variation in data well. The R-squared and R-squared adjusted values for each model, for each function are included in Table 24.

For the benefit of DePuy, guidance on how to create the models is provided in Appendix 6a.

Table 24 – R-squared adjusted values for tuned models per function

Function	Duration Gate 0 - Gate1	Duration Gate 1- Charter	Duration Charter – Gate 2	Duration Gate 2 – Gate 3	Duration Gate 3- Gate 6	Duration Gate 6- Gate 7	Duration Gate 7- Gate 8
Project Management	100	82.05	87.61	53.33	71.75	Unknown	Consistently 12 months.
Bio-Engineering	97.43	91.95	69.57	92.22	98.63	100	
Regulatory	No models				61.41		
Quality	100	100	Unknown	Unknown	91.14	84.63	
	Resource Gate 0 - Gate1	**Resource Gate 1- Charter**	**Resource Charter – Gate 2**	**Resource Gate 2 – Gate 3**	**Resource Gate 3- Gate 6**	**Resource Gate 6- Gate 7**	**Resource Gate 7- Gate 8**
Project Management	Unknown	91.14 %	100 %	77.42%	91.86 %	100	Unknown
Bio-Engineering	100	100	100	100	80.38	91.86	100
Regulatory						unknown	unknown
Quality	100	100	100	87.5	95.71	100	91.14

R-squared (adjusted) values for the models range between 53 and 97 % (100 % when there is no variation in resource required between projects). On average not including 100% values, the R-squared (adjusted) value resulting from using this method is 81.35 %.

Defining a "reasonable" R-squared for any type of model is not necessarily straight forward, In most instances very low R-squared values would suggest that there the model is unable to reflect variations in the data and is therefore invalid. Conversely, very high R-squared values (across a large sample size) can indicate collinearly or multiple input parameters indicating the same thing. With a large sample size, variations in perceptions and the tacit process of estimation would be expected to impact upon the ability of the model to reflect the variations in data. In such cases, a lower R-squared value would be reasonable.

In this case all models are formed from just one opinion so a high R-squared adjusted value could be expected. The tuning process and approach used is evaluated further in section 5.6.2.

5.3.5 PREDICT

For each function, the collection of models (as featured in Appendix 5) have been converted into a useable tool using Microsoft Excel™.

For each characteristic the excel model features a drop down list containing three level label "high", "low" and "medium" corresponding to (-1), (1) and (0) respectively. Because a linear relationship has been assumed, 0 has been added so non-extreme project scenarios can also be estimated. As a level is selected, a formula translates the qualitative factor to the corresponding quantitative value (1, 0 or -1). Another formula then multiplies the corresponding coefficients by the quantitative value associated with the level, plus the constant in order to make a Figure 35 and Figure 36 explain the procedure.

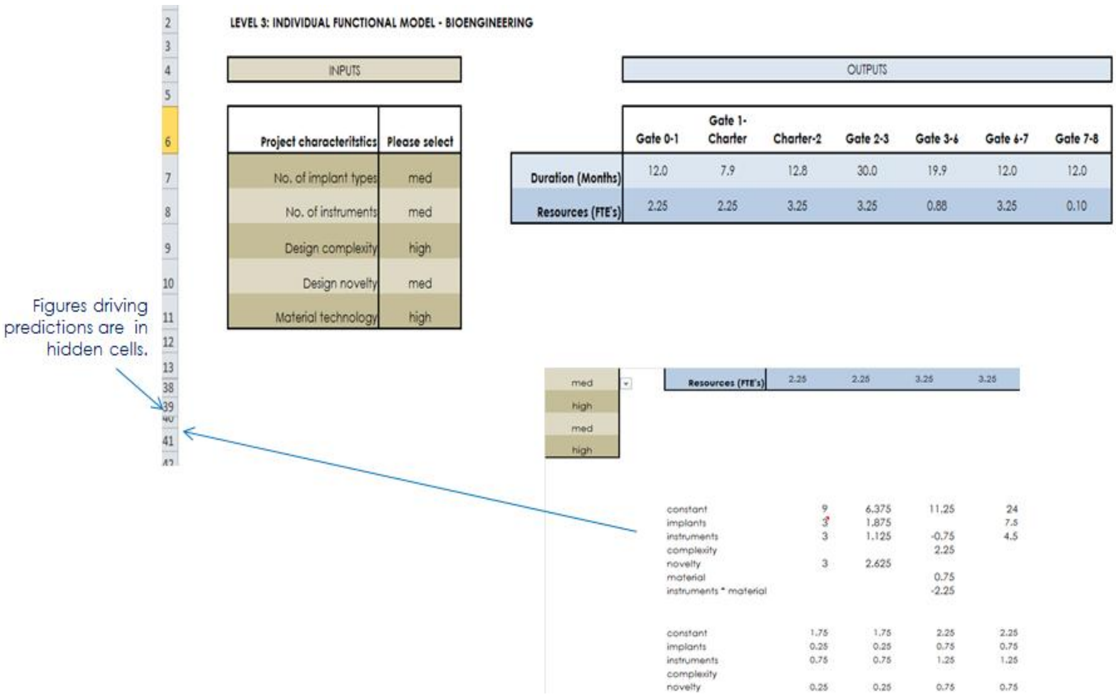


Figure 35 – The model coefficients are stored in hidden cells.

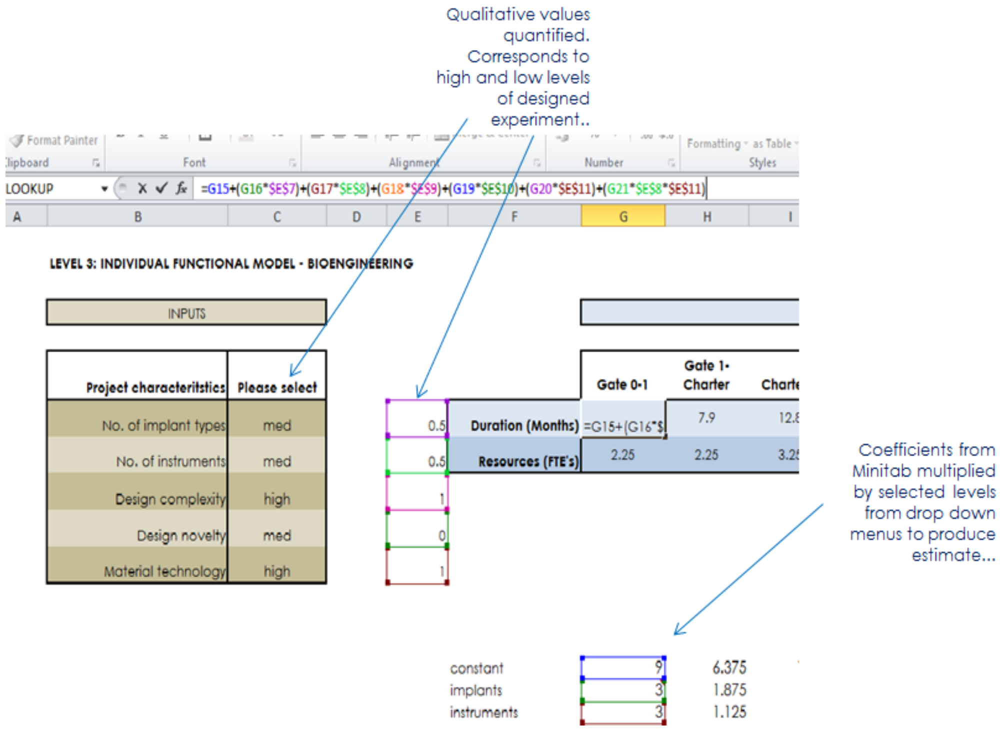


Figure 36 – High, med and low values correspond to quantitative values. Formula for prediction shown.

For each function, each set of models was transferred to an Excel™ predictive tool to make comparison with past project data easier. Once compared with past project data, the most accurate version of the model has been used as *the* predictive tool per function.

An example of the predictive model working, relating to the Tuning example presented in the previous section 5.3.4 is detailed below.

Step 1:

The factors considered to be significant were typed in. The levels associated with each factor were inserted in a drop-down menu. This is shown in Figure 37.

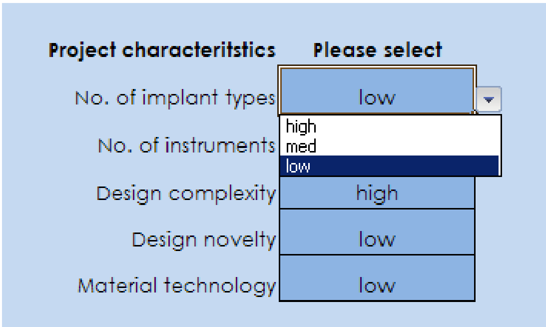


Figure 37 – A drop down menu created to describe the 'levels' of each factor.

It is worth noting that although the analysis only describes each factor at 2 levels, the predictive model describes each factor at 3 levels. A linear relationship has been assumed. Theoretically, as long as a corresponding scale is derived (see step 2) the number of levels in the predictive model could be increased.

Step 2:

For each factor, each level is associated with either High (+1), Medium (0) or Low (-1). The 'IF' was used to create a link between the selection of a factor in the drop-down menu and Figure 38

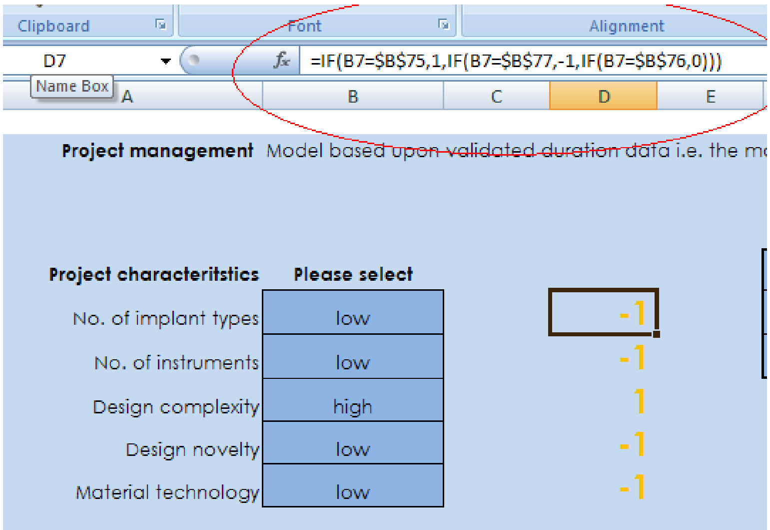


Figure 38 – Linking 'levels' with a numerical value

Step 3:

A matrix was created to display duration and resource demand for each phase required. This is illustrated in Figure 39.

	Gate 0-1	Gate 1- Charter	Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Gate 7-8
Duration (Months)							
Resources (FTE's)							

Figure 39 - An empty matrix

Step 4:

The constant and coefficients derived for each model were transferred. This is illustrated in Figure 40. The constant and coefficients relating to the example provided in section 5.3.4 are highlighted with a red circle.

Model based upon combined responses

Please select	
low	-1
low	-1
low	-1
low	-1
low	-1

	Gate 0-1	Gate 1- Charter	Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Ga
Duration (Months)	1.5	10	1	12	16	8	
Resources (FTE's)	0.7	0.3	0.4	0.4	0.4	1.10	

			co-efficents					
duration	Coefficients	Duration	Constant	1.75	11.8125	5.5625	17.25	17.8125	10.125
			Instruments	0.25	0.9375	1.8125			2.625
			Complexity	0.25	1.3125	2.6875	3	4.6875	1.875
			implants				1.5		
			novelty				1.125	-2.4375	-2.625
			material		1.3125				
			instruments * complexity	0.25	1.6875				
Resource		Resource	constant		0.4	0.43125	0.3875	0.56875	1.05
			Instruments		0.05		0.0125	0.10625	0.05
			Complexity		0.075	0.01875	0.0125	0.10625	0.0375
			implants				-0.0125		-0.05
			novelty				0.0125	-0.04375	-0.05
			material				0.0125		
			instruments * complexity					0.04375	

Figure 40 – Constant and coefficients from Minitab analysis

Step 5:

For each prediction required (for each predictive model generated), an equation was typed to link the constant, the coefficients and the various level selected for each factor. As the levels change, the coefficients are multiplied by a different value and the predicted phase durations and resource demand varies. The equation highlighted with a red circle in Figure 41 below demonstrates how the prediction is formed.

The duration for Gate 3- Gate six = 17. 813 + (complexity * 4.688) + (novelty * -2.4375)

Where complexity and novelty are either = high (+1), medium (0) or low (-1).

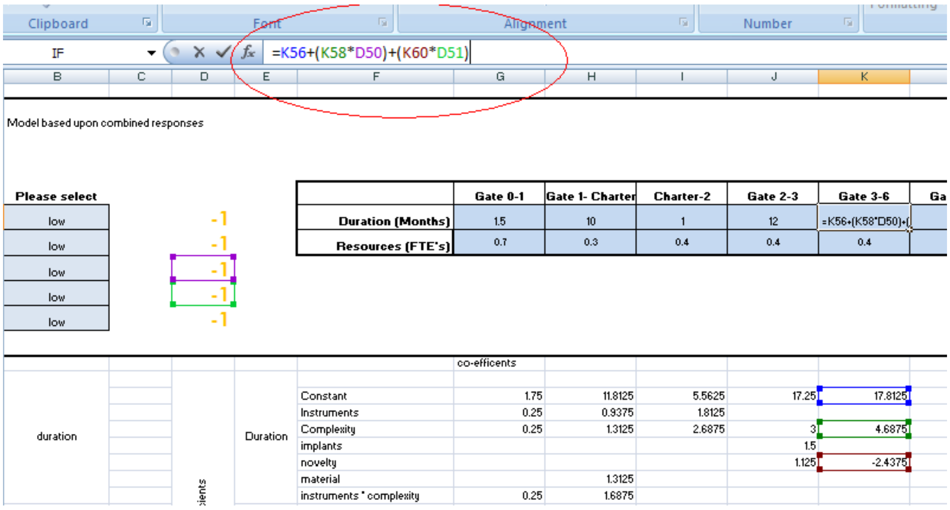


Figure 41 – creating a predictive model. Components for Gate 3- Gate 6 Duration.

5.3.6 VERIFY

The aim of this study is to examine the feasibility of Design of Experiments in terms of

1. Modelling the tacit process of managers and
2. Developing a predictive resource model that is accurate, timely, consistent and transparent.

In order to assess the ability of the model to echo tacit estimation processes, the model must be compared with estimates from past or on-going projects.

In order to assess the accuracy of the model, the model must be compared with actual project data.

Each of the models has been compared with past project data, Data was collected for 29 different past projects. Not all data was available for each project. For some stage gates data was available for as few as 9 projects.

For the duration aspects of the model spider diagrams have been used to summarise the differences in accuracy between models and managers estimations. The data is presented across projects rather than present data at an individual project level. The one drawback of presenting data in this way is that extreme predictions have been cancelled out. Vast over or under predictions are averaged and could potentially suggest an accurate model when in fact; this may not be the case. To supplement the spider diagrams the standard deviation of error per model is also noted. The standard deviation reflects the range of errors: a high standard deviation requires further investigation if the model appears to have a low average error. In some cases, a vast spread of errors may all be either over or under predicting in such cases it is unlikely that the model will be accurate. Duration models can be compared with the original estimates (where available and actual duration data are available).

As no actual resource data is available, the resource models can only be compared with the original resource estimations. These comparisons are also represented in spider diagrams. Although it is impossible to determine conclusively whether the model or the estimates are more accurate, discussion with managers about the nature of functional project activities has provided some insight.

Models for each of the four functions are addressed separately below. Duration and resource data exists for all functions except Quality. For Quality, no resource data has been captured and comparisons can only be made with duration data. In this instance, verification was based upon the impressions of the Quality leader and his assessment.

5.3.6.1 VERIFICATION PROJECT MANAGEMENT

Three models were developed for Project Management: one model combined the responses of Respondent 1 and Respondent 2 with a replicated corner point. First the duration aspects of the models are reviewed before the most accurate model (the model derived from data provided by Respondent 2) is compared with the original resource estimations.

5.3.6.1.1 VERIFYING PROJECT MANAGEMENT DURATION MODELS

Figure 42 presents a spider diagram which shows both under and over-predictions. The black series labelled "actual" represents zero error; it essentially marks the x axis. Series data falling within the black x-axis, towards the centre of the diagram represents under-predictions and data between the x-axis and the edge of the graph represents over predictions.

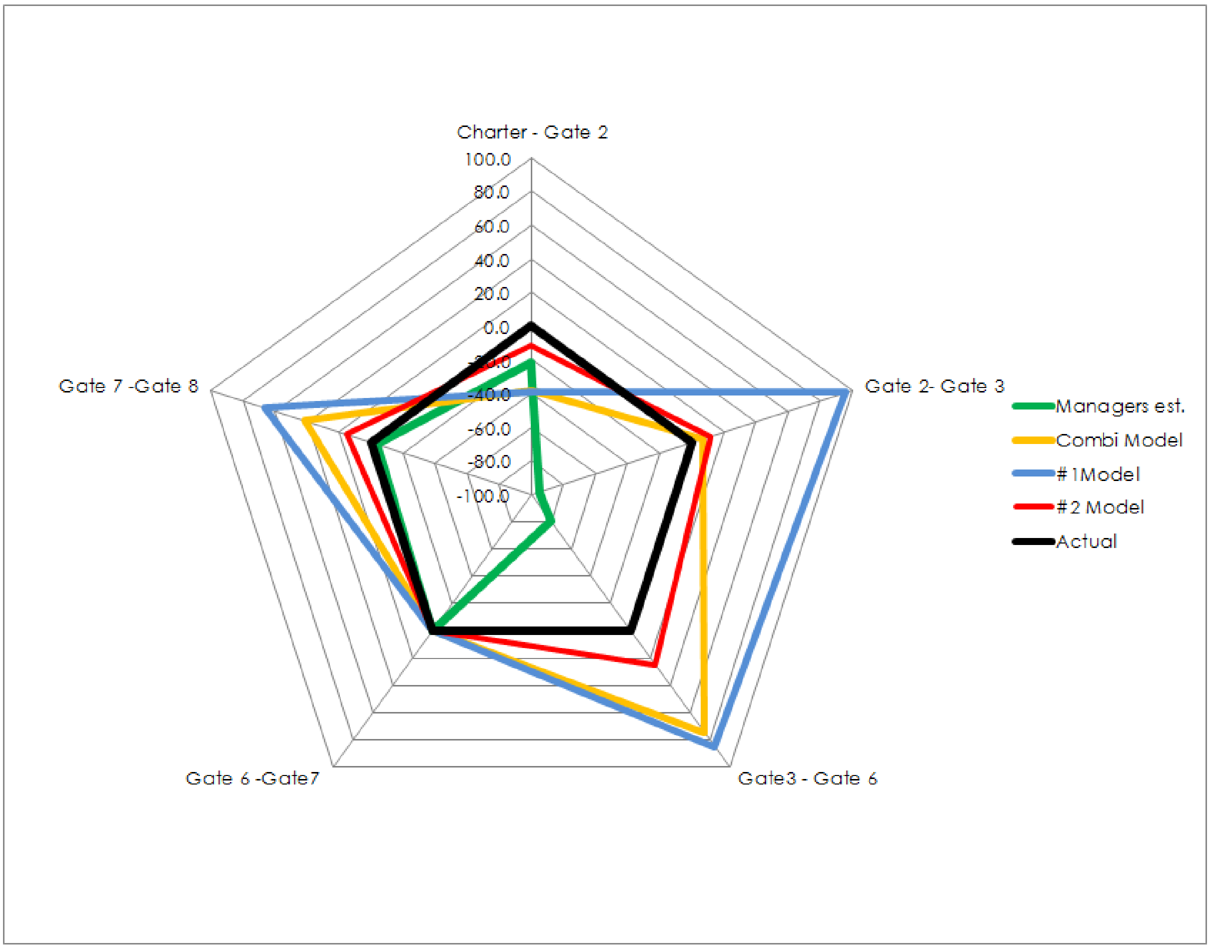


Figure 42 –Error (months) between Project Management predictive models and actual data.

Figure 42 illustrates the tendency of managers to under-estimate project phase duration. It is clear that the least accurate means of estimating is derived from Respondent 1's model and the most accurate means of estimating is derived from Respondent 2's model. The combined model has been compromised as respondent 1's data skews the overall prediction. This suggests that in this instance, for this specific application having multiple corner points is not necessarily the best approach to take.

Table 25 documents the standard deviations of each of the duration prediction approaches and notes the number of projects included in the analysis.

Table 25 – Standard deviations of various project management models and the number of project include in comparison.

	Estimations	Combined	R1	R2	Number of projects
Charter - Gate 2	3	6	6	6	12
Gate 2- Gate 3	15	16	17	17	12
Gate3 - Gate 6	9	10	10	10	12
Gate 6 -Gate7	2	4	6	3	9

From Table 25, it is clear that although Respondents 2's model is most accurate, the standard deviation is higher than that of manager's estimations in every instance. Between Gate 2 and Gate 3 and between Gates 3 and Gate 6 this is of little consequence as managers are consistently getting it wrong. Although the model and the estimates are approximately similar at Charter – Gate 2 and Gate 6 to Gate 7 and Gate 7 to Gate 8 the model is less consistent at getting it right. However, this is not as serious as one might first imagine as the standard deviations are comparable with the original estimates. As the model will primarily be used at a portfolio management level, the errors will be averaged over a portfolio of projects.

5.3.6.1.2 VERIFYING PROJECT MANAGEMENT RESOURCE MODELS

Project management resource model predictions have been compared with original resource requirement estimations made by managers where data could be found. Data was collected from Stage-Gate templates. There is one template per Stage-Gate. Not all of the templates contained comprehensive data so not all projects could be compared at every phase. The number of projects included in each comparison varies. Figure 43 to Figure 46 illustrate the comparison between model predictions and original estimations.

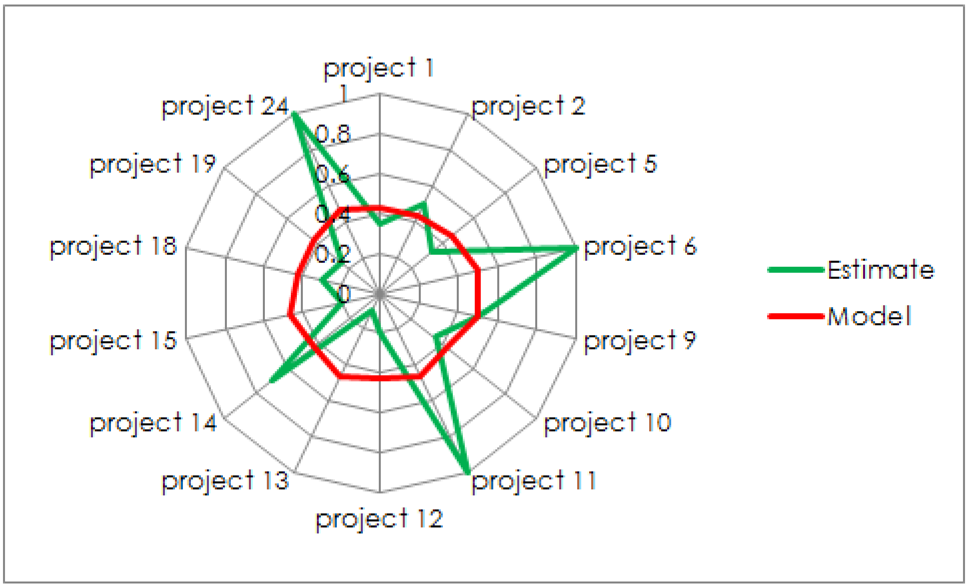


Figure 43 – Resource management predictions for Charter –Gate 2: oriental estimates vs. predictive model.

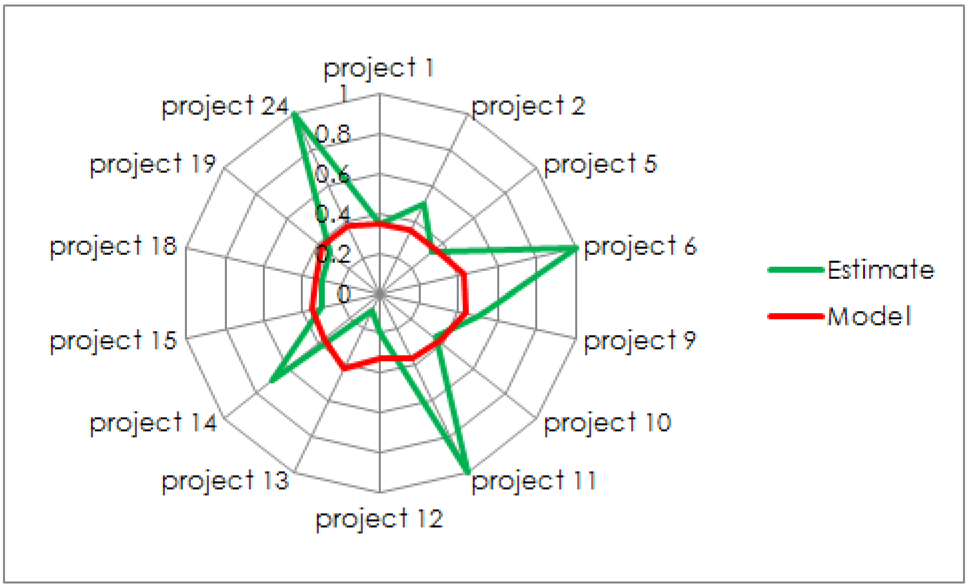


Figure 44 - Resource management predictions for Gate 2 – Gate 3: oriental estimates vs. predictive model.

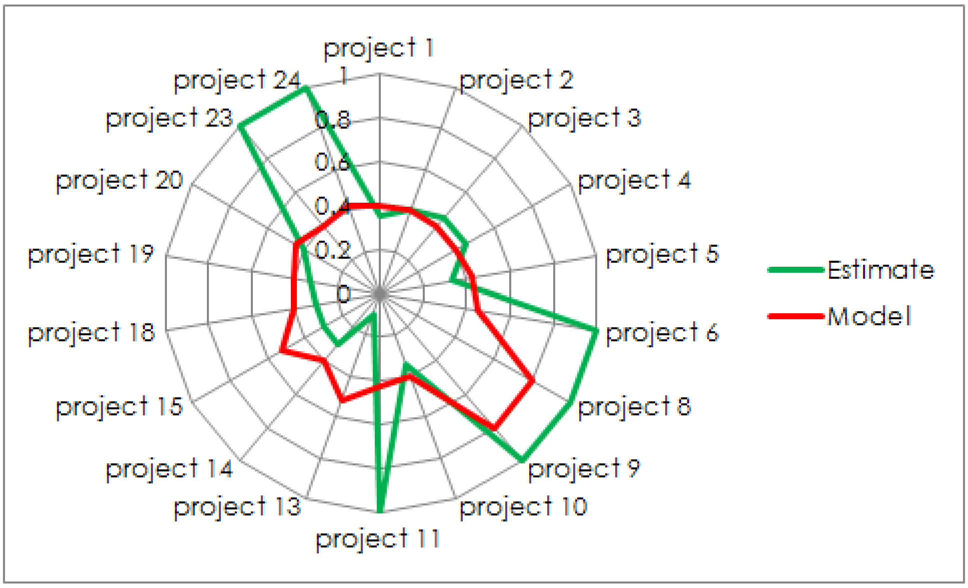


Figure 45 - Resource management predictions for Gate 3 – Gate 6: oriental estimates vs. predictive model.

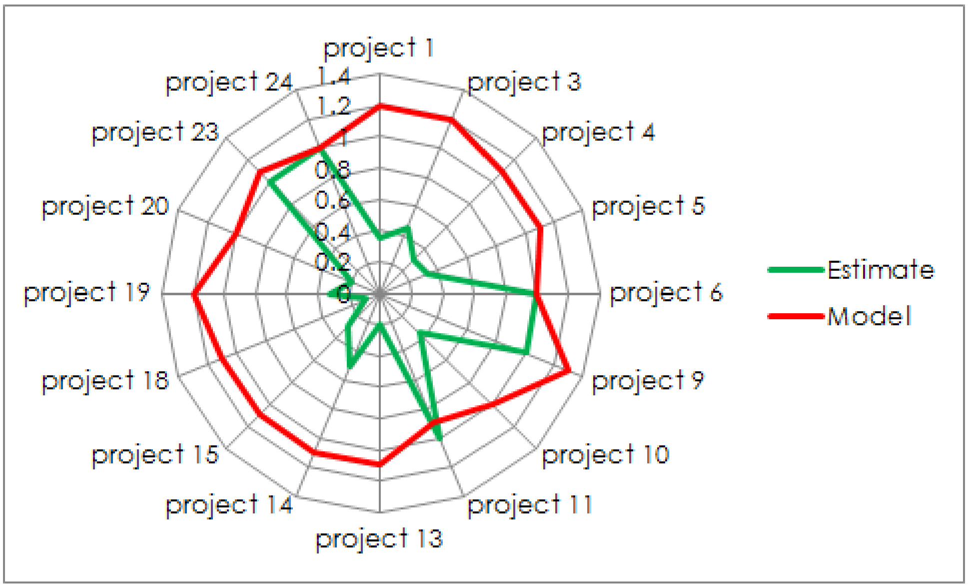


Figure 46 - Resource management predictions for Gate 6 – Gate 7: oriental estimates vs. predictive model.

Discussions with project managers suggest that the PM resource required on a project should not vary dramatically with "project type". Rather, the duration for which the PM resource is required will vary. From Figure 43 through to Figure 46 we can see that there is much more variation in each of the original resource estimates that there is in the model predictions. This suggests that the behaviour of the model is more in line with the resource required in reality than the original estimations. The variations could be attributed to a number of factors:

- **Estimations made by different managers** with different experiences, perceptions and biases are likely to account for a high proportion of the variation.
- **Changing role of project managers.** Perhaps the model reflects the current situation and each individual estimate reflected the roles and responsibilities

at the point in time the project was occurring. (Although this would not account for such extremes it might be a contributing factor).

- **The introduction of new initiative to improve planning.** Perhaps over time, the introduction of new planning tools has resulted in changes to the way resources are estimated. It is possible that if the original predictions were tracked for long enough, one might find that they become increasingly accurate.

5.3.6.2 VERIFICATION BIO-ENGINEERING

Only one model has been developed for Bio-Engineering as only one experimental survey response was received. The duration aspect of the model is reviewed before the resource element of the model is assessed.

Similar to project management, actual data is available for duration but not for resource.

5.3.6.2.1 VERIFYING BIO-ENGINEERING DURATION MODEL

The spider diagram in Figure 47 shows the zero error, the actual duration as the black line. Data series falling within the black line indicate under-predictions and data out with the black line suggest over predictions.

Again, as with project management it is clear that original predictions tend to underestimate the duration of projects. The original predictions for 3 of the 4 phases are of approximately equal accuracy to the model, only in the opposite direction. The model and estimates are comparable except between Gate 6 and Gate 7 where the estimates of managers are far superior. It is possible that with more respondents, a more accurate model for Gate 6 - Gate 7 could have been achieved.

Figure 479 illustrates the average error per Stage-Gate phase of both models. Totalling the average error can provide a quick view of which method, estimation or model prediction is most accurate overall. The total error for estimation is -201 for original estimations and 184 for the predictive model. The error is comparable in terms of scale but in opposite directions: the model over predicts whereas the original estimates under-predicts.

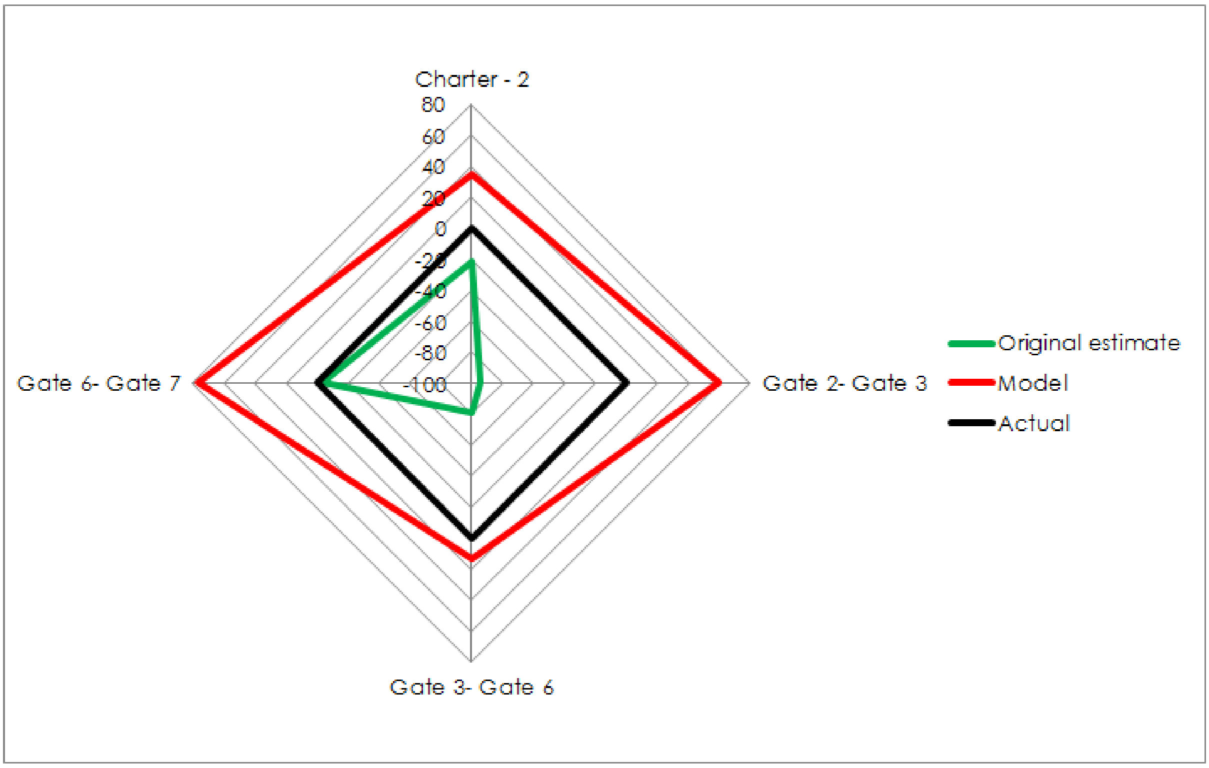


Figure 47 - Error (months) between Bio-Engineering predictive project duration model and actual data.

From Table 26 it is clear that although the model offers more accurate predictions on average, there is more variation in the predictions made. With error over a wider range, the over and under predictions of the model are cancelling each other out.

Table 26 –The standard deviation of error: comparing the model with original estimations.

	Std dev estimation	Std dev model	Number of projects
Charter - Gate 2	3.2	5.2	12
Gate 2 - Gate 3	14.9	18.3	12
Gate 3 - Gate 6	9.3	16.8	11
Gate 6 - Gate7	2.4	2.9	9

5.3.6.2.2 BIO-ENGINEERING RESOURCE MODEL VERIFICATION

Bio-Engineers design and develop implants. The nature of the project has an impact upon the amount of effort they are required to invest. This variation is reflected in both the model predictions and the original estimations. Comparisons between estimations and model predictions are presented in Figure 48, Figure 49, Figure 50, Figure 51 and Figure 52.

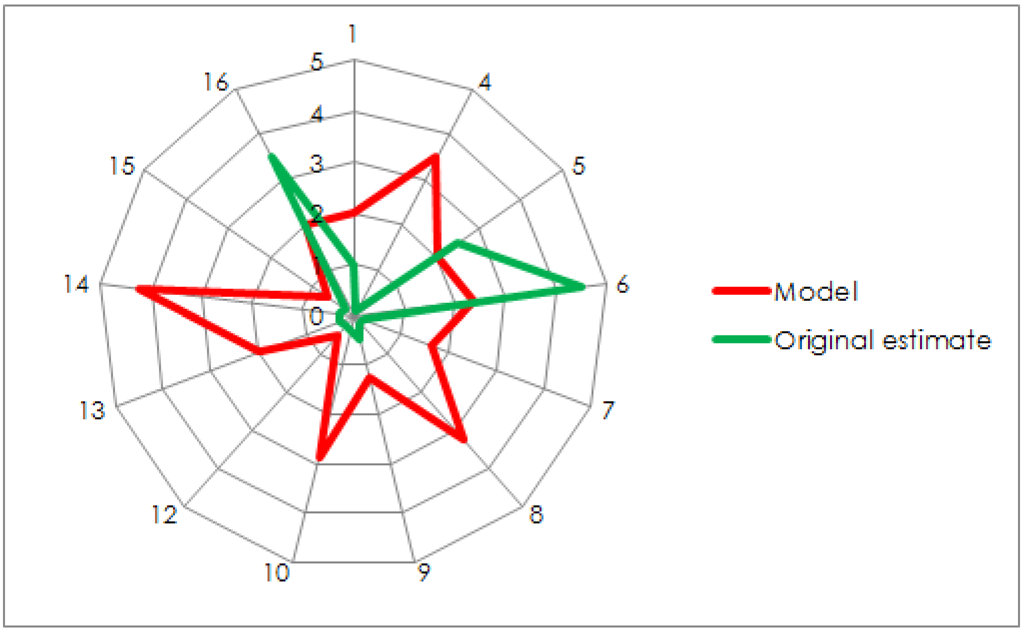


Figure 48 – Bio-Engineering resource predictions Charter – Gate 2

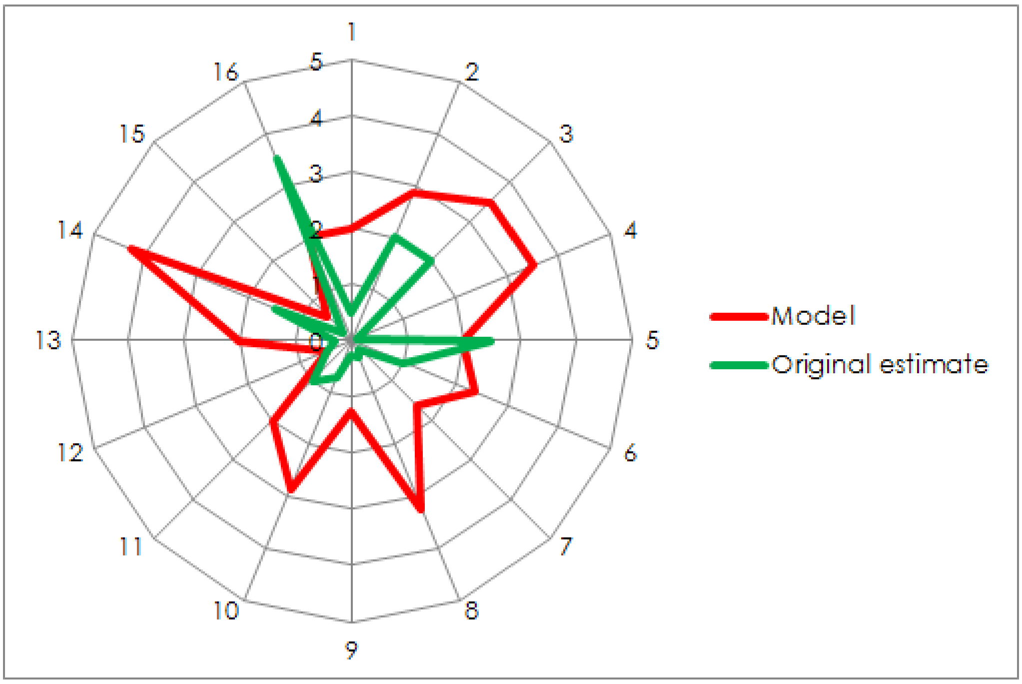


Figure 49 - Bio-Engineering resource predictions Gate 2 – Gate 3

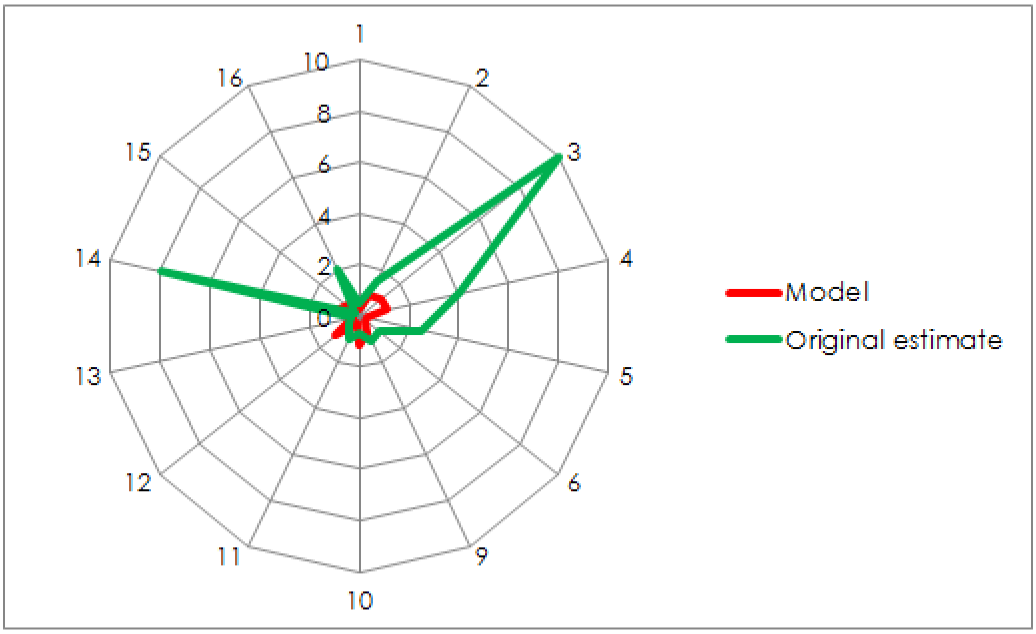


Figure 50 - Bio-Engineering resource predictions Gate 3 – Gate 6

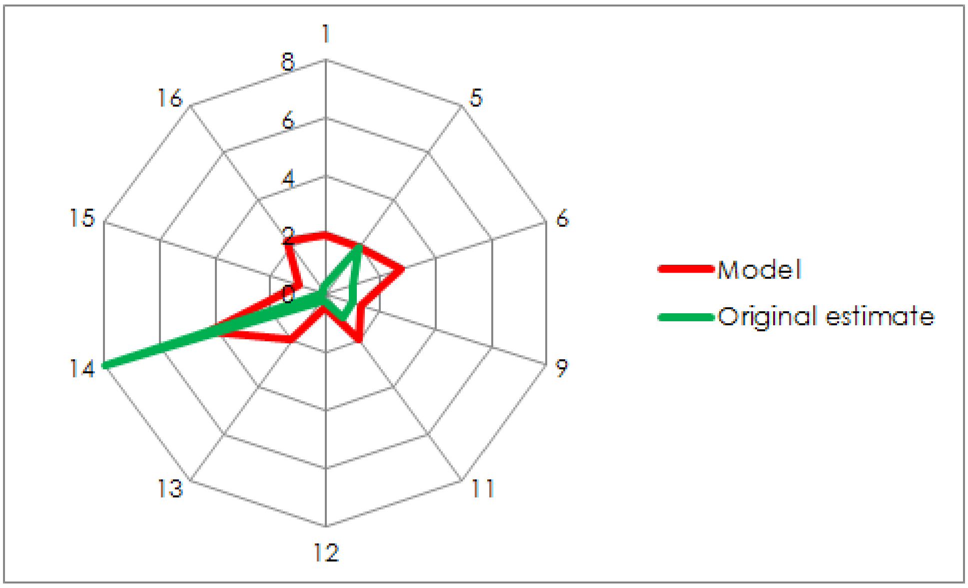


Figure 51 - Bio-Engineering resource predictions Gate 6 – Gate 7

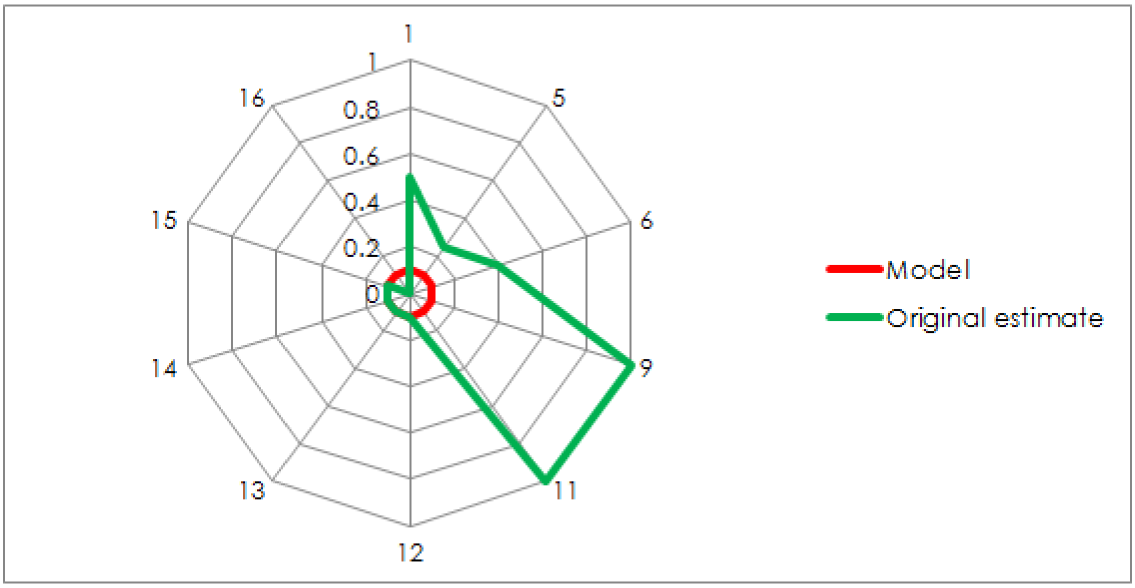


Figure 52 - Bio-Engineering resource predictions Gate 7 – Gate 8

Again, the original estimates suggest more extreme variation than the model predictions. The core pattern seems to remain the same: there are slight underestimations then sporadic breakouts of rough estimations (See projects 9 and 11 in Figure 52). Reassuringly, in some cases the breakouts are exaggerated echoes of underlying trends presented in the model data (See project 14, Figure 51; Project 3, Figure 49 and Project 6, Figure 48) suggesting that the model Design of Experiments indeed reflect patterns of cognition in estimation, although this is not always the case. In terms of accuracy, is not clear which forecasting method best predicts resource requirements: estimations or the predictive model. However, for comparable levels of accuracy the model Design of Experiments have significant benefits over the traditional estimation approach: results are available instantly rather than in months and the effort required to formulate estimations is greatly reduced; the results are consistent no matter which manager makes the estimations, and finally the factors impacting the predictions are transparent.

5.3.6.3 VERIFICATION REGULATORY

One model was developed for regulatory. This involved a singular response for duration and four combined responses for resource requirements. The duration model was only developed for one Stage-Gate phase. Resource models exist for all Stage-Gate phases although only two of the models required any analysis – Regulatory managers stipulated that the resource requirements for all gates other than Gate 3 to Gate 6 and Gate 6 to Gate 7 required consistent amounts of resource no matter what the nature of the project was.

5.3.6.3.1 VERIFICATION OF REGULATORY DURATION MODEL

A comparison between the duration model and the original estimations for the Gate 6 to Gate 7 regulatory duration model is presented in Figure 53. The model and original predictions follow largely the same pattern with a few exceptions (project 9, project 12 and project 13).

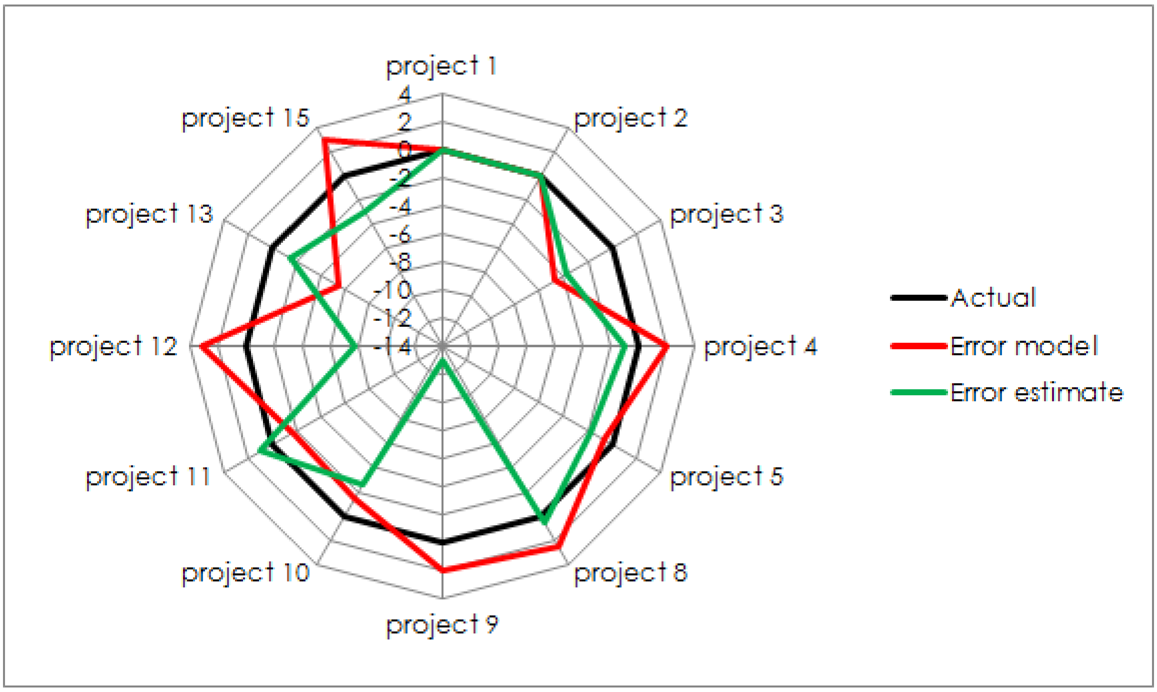


Figure 53 - Duration Gate 6 - 7 Regulatory models: comparing the error of the model with the error of estimations.

Again, there is a tendency for the original estimates to under predict resource required. On average, the original estimates were under by 33 months where as the model was out by just 2 months. If we remove project 9 as an outlier, the averages change to -20 and -4 months respectively. With project 9 removed, the standard deviation of the estimates is 2.5 where as the standard deviation of the model is 2.5 suggesting that the range of error of the model is slightly larger than that of estimations (although the model Design of Experiments not make significant errors, such as the original estimation for project 9).

5.3.6.3.2 VERIFICATION OF REGULATORY RESOURCE MODELS

Regulatory resource models suggest that resource requirements up to Gate 3 are consistent across all projects, no matter what characteristics the project has. Unusually (when compared to other functions), Figure 54 suggests show the model predicting lower resource requirements than estimations with exception of Project 11.

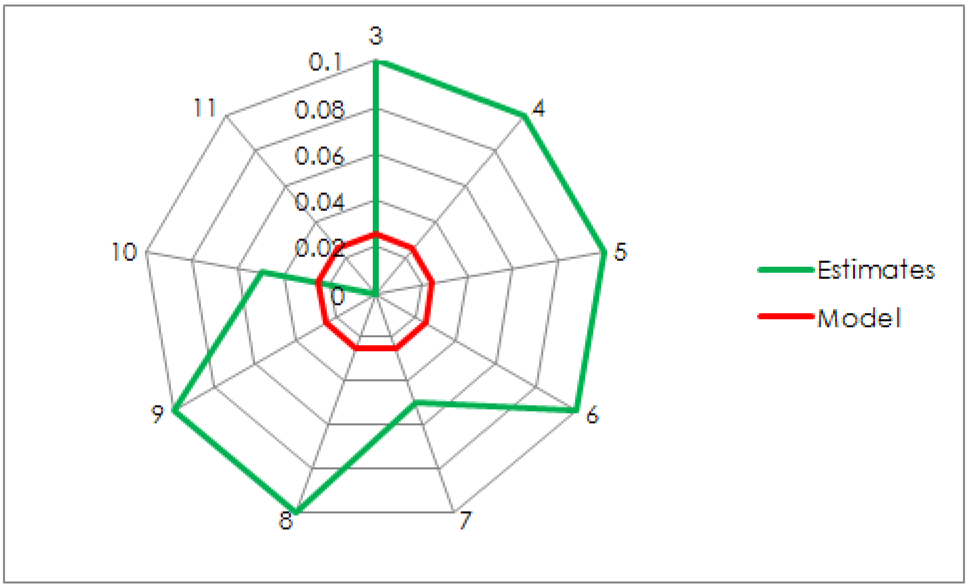


Figure 54 –Regulatory Resource models Charter – Gate 2 Comparison of model errors.

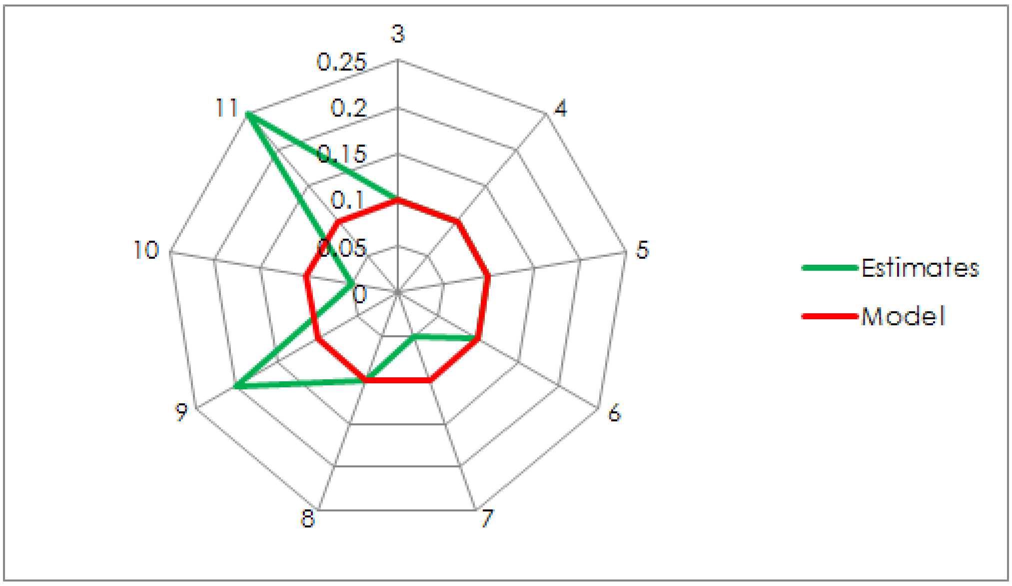


Figure 55 – Regulatory Resource models Gate 2 – Gate 3 Comparison of model errors.

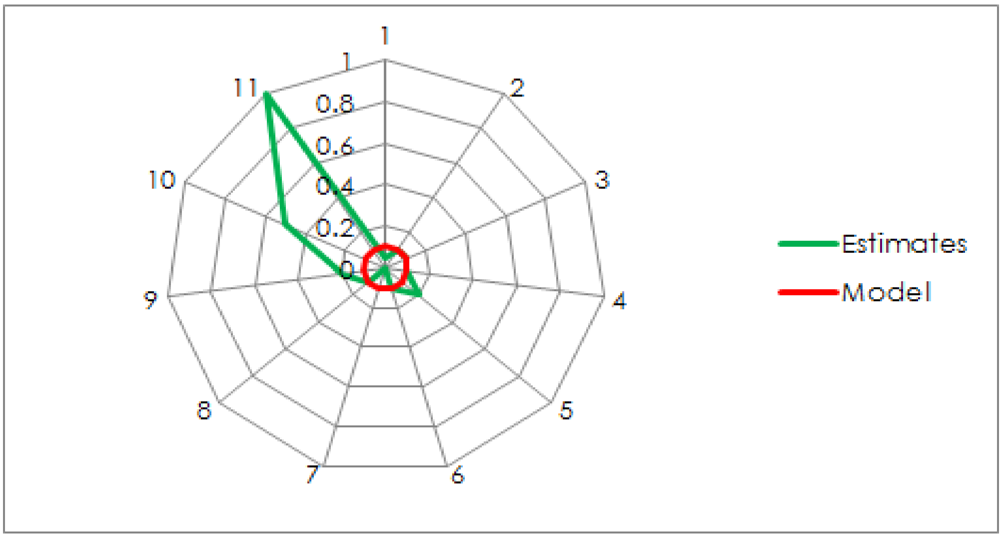


Figure 56 – Regulatory Resource models Gate 3 – Gate 6 Comparison of model errors.

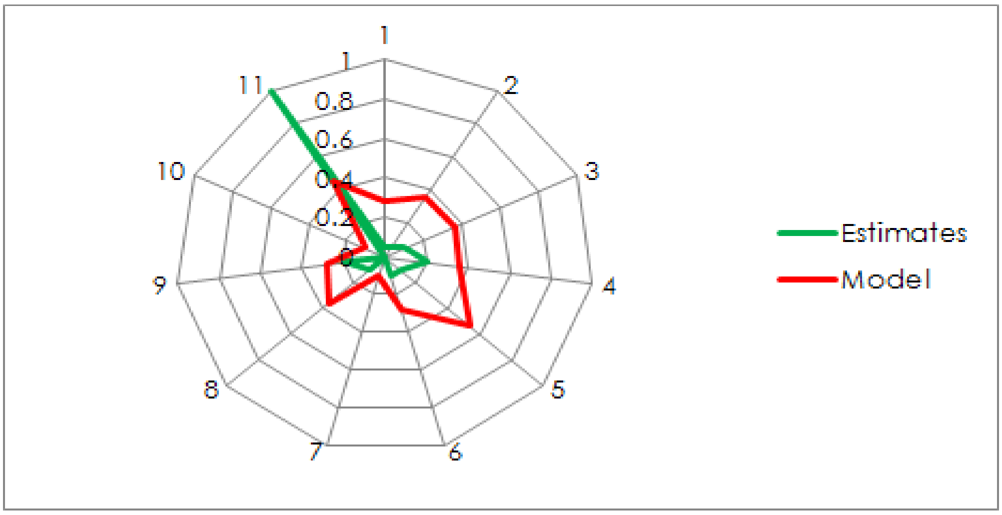


Figure 57 - Regulatory Resource models Gate 6 – Gate 7 Comparison of model errors.

With no actual past-project data for resource, it is impossible to conclusively establish which is more accurate: manager's estimations or the predictive model. However, the benefits of the model and the accuracy of the duration aspect make the predictive model a favourable option over estimations, especially in the early stages of a project or before a project exists.

The model and a report of results and verification data were submitted to the regulatory leader. A phone call was made several days later to two of the regulatory leaders to discuss results and gauge whether or not they would be happy to use the model in practice. Although they would be interested in seeing how it compares to actual resources used, they are happy to use the model in place of the current resource refresh process, at least as a default prediction.

5.3.6.4 VERIFICATION OF THE QUALITY MODEL

One duration model was created for Quality. This model was comprised of the estimations of four Quality managers. A model based upon a combined response was also created for resource however; no actual *or* estimated data could be collected.

5.3.6.4.1 VERIFICATION QUALITY DURATION MODEL

On first viewing, the spider diagram appears to show that the model is nowhere near as accurate as original estimates. On closer inspection, we can see that this is not actually the case. It is not as accurate as the other models but it is not that dramatically out either. Gate 3 to Gate 6 is the worst instance: however, in this case, the model over predicts by almost the same amount as the estimations under predict.

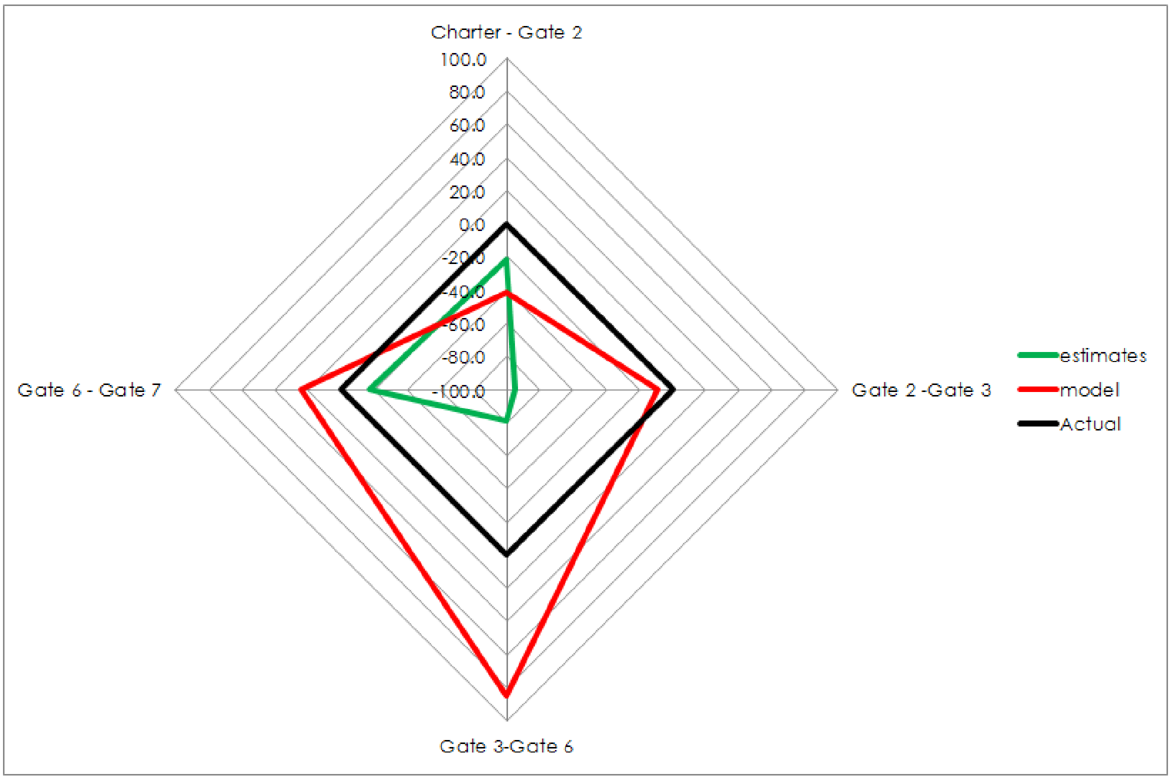


Figure 58 - actual error for quality duration model vs. original duration estimates

Table 27 - Standard deviation of

	Estimates	Model	Number of projects
Charter - Gate 2	-1.8	-3.5	12
Gate 2 -Gate 3	-7.9	-0.7	12
Gate 3-Gate 6	-6.7	7.1	12
Gate 6 - Gate 7	-1.6	2.2	11

5.3.7 FRACTIONAL FACTORIAL EVALUATION

The fractional factorial Design of Experiments approach to developing predictive models works well. The models developed consistently offer predictions comparable or better than the original estimates made by managers. With this method all project scenarios can be estimated quickly and easily whereas with the original method manager participation and consideration was required resulting in incomplete or delayed data. Additionally, this method removes all agendas and biases: the source of the data is transparent and no matter who is using the model, the same responses will be returned.

5.4 DEVIATIONS FROM THE DESIGNED PROCESS: TWO FURTHER CASE STUDIES

Models developed for Test Group and Design Engineering varied from the standard fractional factorial design. The process followed for each group will be discussed separately.

5.4.1. TEST GROUP RESOURCE MODELLING

The procedure for developing the Test Group model was very similar to the other four fractional factorial design described in 5.3. The key difference is that two types of models were developed: one describing resource required for implant development and one describing resource required for instruments development. The results of multiple models were summed to provide total resource requirements. The predictive model (6.4.1.3) demonstrates the key point of difference. This style of model also required a different verification process.

Test group leaders and managers were insistent that the factional factorial design would not work for their function. Managers felt that Test group resource requirements were "*more complex than the resource requirements of other functions and could not be categorised with a simplistic model*". As the support of managers is essential to this process and given that the process is experimental a compromised approach was sought. Managers were asked:

"If this is not how you consider resource, if these are not the factors you consider then how do you consider resource requirements for test? What would you think about?"

The Test group model explores resource prediction at a level deeper than the models described in section 5.3.

5.4.1.1 DEFINE AND DESIGN FOR TEST GROUP

Through discussion it emerged that instrument and implant resource should be considered separately: the descriptive characteristics (complexity, novelty etc.) can relate to instruments and implants separately. For example, instruments can be complex whilst implants are simple. To lump them all together under a "simple" or "complex" design project was [according to the managers] not an adequate approach although it had worked well for other functions. A model that removed number of implants and number of instruments from the factor list was required, allowing each individual project instrument and implant to be estimated separately. Although it is unlikely that this sort of information could be estimated at the outset of a project, there is chance that ballpark estimates could be made and with managers refusing to settle for the alternative, this is the approach that was taken.

The original factors for test group were derived from the survey using the logic demonstrated in Table 28.

Table 28 – Factors for original test group model.

Factors from survey	Are factor decomposable/ easily understood early in project?	Factors used in original design.	Factors used in final designs.
No. of Instruments **New or existing technology** **Project type** **Launch time pressure** **Technology acceptance** **Testing/ Validation required**	New or existing technology and technology acceptance are similar and can be replaced by design novelty and material tech novelty. Testing/ validation required can be replaced by design complexity.	No. instruments Design complexity Design novelty Material technology novelty	**Model 1: Implants** Implant novelty Implant complexity Man process novelty Core market? (yes or no) **Model 2: Instruments** Instrument novelty Instrument complexity Man process novelty Core market?

The survey design agreed upon is shown in Appendix 2.

5.4.1.2 COLLECT AND FIT

Test group responses were returned and analysed in the same manner as the standard fractional factorial designs except in this instance, there were two separate models: one for instruments and one for implants.

Test group models have been developed for Front end – Gate 1, Gate 2 – Gate 3, Gate 3 – Gate 6 and Gate 6 – Gate 7 for both resource and duration, for both instruments and implants.

16 models have been developed in total.

The R-squared (adjusted) values for each model are shown in Table 29. Documentation of the full analysis of data is available upon request.

Table 29 – R squared (adjusted) values for Implant test group model

	Front end – Gate 1	Gate 2-3	Gate 3-6	Gate 6-7
Duration	77.98	70.34	75.85	87.13
Resource	99.36	70.41	76.38	53.33

Table 30 – R-squared (adjusted) values for Instrument test group model

	Front end – Gate 1	Gate 2-3	Gate 3-6	Gate 6-7
Duration	72.66	65.57	100	65.57
Resource	94.28	71.35	70.30	100

The average R-squared (predicted) value is 78.16 %. 78.16 % of the variation in the hypothetical scenarios can be accounted for by the model. Theoretically, this model reflects just 3 % less variation than the project management model.

5.4.1.3 PREDICT

The process used to develop the predictive, user friendly, excel version of the regression models for test group was similar to the process documented in section 5.3.5. The key difference is that there were multiple models – one for each type of instrument and implant. The number of sub-models required depends upon the number of different types of instrument or implant in the project. The blue section at the top provides the prediction at a project level, the green section provides a prediction for Test resource for implants and the red sections provide predictions of Test resource required for each type of instrument in the project.

Figure 59 - Multiple sub-models for test group are combined to provide a project level prediction.

For the test group model, hidden cells in rows between models contain coefficients for each sub-model. Hidden cells in columns contain multipliers (1, 0 and -1) relating to the qualitative level selected.

For simplicity, the project level duration per-stage gate phase is assumed to be the maximum of any individual sub-model duration.

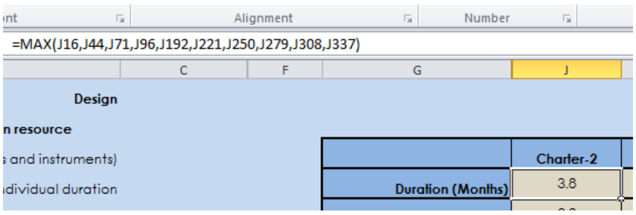


Figure 60 - Calculating project duration predictions from test group model

The total resource requirements for test group were calculated by summing the values predicted by each of the sub-models as is shown in Figure 61.

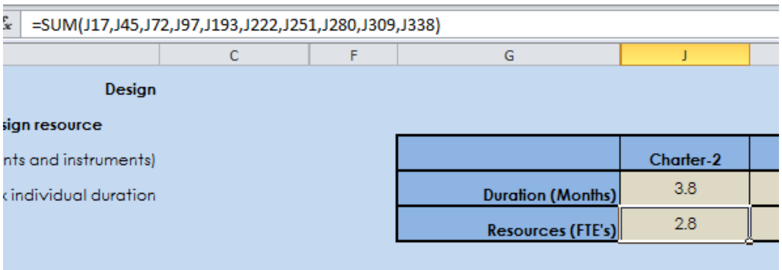


Figure 61 - Calculating total resource required for Test group

Predicting resource requirements for test group requires consideration of real project detail: consideration of the physical components that the project will deliver. This is not something that is considered pre-charter so this model would not be really useful prior to charter or before the project was underway unless very approximate estimations were made, which negates the need for such a level of detail.

5.4.1.4 VERIFYING THE TEST GROUP MODEL

Data at this level of detail was not readily available for past projects: although it was easy to establish the number of instruments or implants on a project, determining descriptions for each individual instrument and implant (there can be 100's per project) would require in-depth interviews with project core team members. With so much going on in the business, this was not feasible. However, experimenting with the model, it is clear that the results are not a reflection of reality: resource requirements are vastly overestimated.

Conservative estimates have been made regarding the instrument/ implant types that might be used in four different “project types” and estimations have been made accordingly. For experimentation/verification purposes, the project types have assumed the combinations shown in Table 31. It should be noted that the numbers of instruments and implants has been artificially reduced to allow reasonable estimations to be generated. In real-life projects, the numbers of instruments within one set can be in the order of hundreds.

Table 31 – Conservative estimations of possible instrument/ implant combinations per project type.

Project type	Instruments	Implants
Transformational	10 * complex, novel instruments with novel material technology 10 * simple instruments with some novel aspects and some novel aspects of material technology.	2 * implants – complex design, novelty design and novel material technology.
Substantial	10 *complex, some novel design aspects, some novel material aspects. 20 * standard complexity with some novel aspects of design and some novel aspects of material technology 10 * simple instruments with familiar design and familiar material technology	4 * implants – complex with some novel design aspects and some novel material technology.
Incremental	5 * standard instrument with some novel aspects of design and some novel aspects of material technology. 10 * simple instruments with familiar design and familiar material technology.	2 simple implants, with familiar design and familiar material technology.
Maintenance	2* simple instruments with familiar design and familiar material technology	1 simple implant with a familiar design, and familiar material technology

For each project type, the predictive test model generated the predictions shown in Table 32, Table 33, Table 34 and Table 35 . Bearing in mind that the way project types have been categorised is very conservative, the resource estimation seem excessively high. Predictions for one project can be as high as almost 80 full time people. For one conservatively estimated project this cannot possibly be a reflection of reality given that there are only 8 FTE's in Test Group in total. The model suggests that the business would only be able to cope with one project at a time when in reality dozens of projects run concurrently.

Table 32 - Transformational Test Group resource profile.

	Front end - Gate 1	Gate 1 - Charter	Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Gate 7-8
Duration (Months)	28.0	0.0	0.0	17.5	37.5	8.0	12.0
Resources (FTE's)	14.8	0.0	0.0	15.0	38.9	4.8	0.7

Table 33 - Substantial Test Group resource profile

	Front end - Gate 1	Gate 1 - Charter	Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Gate 7-8
Duration (Months)	24.8	0.0	0.0	13.5	29.0	8.0	12.0
Resources (FTE's)	29.6	0.0	0.0	30.1	77.7	9.9	0.8

Table 34 - Incremental Test Group resource profile

	Front end - Gate 1	Gate 1 - Charter	Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Gate 7-8
Duration (Months)	28.4	0.0	0.0	13.5	29.0	8.0	12.0
Resources (FTE's)	9.0	0.0	0.0	4.5	13.6	1.3	0.4

Table 35- Maintenance Test Group resource profile

	Front end - Gate 1	Gate 1 - Charter	Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Gate 7-8
Duration (Months)	28.4	0.0	0.0	13.5	29.0	8.0	12.0
Resources (FTE's)	2.0	0.0	0.0	1.9	5.7	0.9	0.2

The test group model becomes unreflective of reality when multiples of each type of instrument or implant is introduced. Although the model was not designed to be used at a project level, if we ignore the multiples of instruments and implants and just use the "type" we can reach more reasonable estimations by removing the term for the number of instruments and implants from each model – using just overall complexity and novelty instead. To generate some useful estimation at a high level and in the absence of better data, the high level "type" estimations can be used as a default.

5.4.2 DESIGN ENGINEERING RESOURCE MODELLING

Design engineering managers had the same complaints as Test group mangers. *"The modelling approach was too simple",* they had tried to make predictive models for resource before*, "there was no way this was going to work, and how could a model possibly work, design resource is so complex?"*

The situation with design- engineering was similar to the one found in test group: managers were not able to accept that a simple model might work and insisted upon complicating the design.

5.4.2.1 DEFINE AND DESIGN

Following proposition of the same question "...then how do you form resource estimates", the following compromised terms were reached:

- Instruments and implants must be modelled separately.
- Implants were of little consequence although the relationship between number of implants and resource required was not perceived to be linear: implants must be modelled at least 4 levels as neither 2-level fractional factorial or even 3 level were perceived to be an accurate enough measure.
- Instruments can be modelled in the same format as test group.

Design engineering model development demonstrates a completely different DoE approach. Owing to perceived complexities, Taguchi is used in the first instance to enable a selection of factors to be modelled at more than two levels without increasing the number of experiments required. Similar to Test Group, this approach also splits resource required for instruments and resource required for implants. Again, verification methods differ from those used for fractional factorial design as more detailed project descriptions are required.

Table 36- Factors impacting design resource

Factors from survey	Is each factor decomposable?	Is each factor determinable at the outset of a project	Factors used in design.
No. of SKU's **No. of instruments** **New or existing technology** **Core competency/ capability** **Launch time pressure**	Launch time pressure is not valid. No. of implant components and instrument components both though to have significance. New of existing technology and core competency replaced by design novelty and material tech novelty. "Complexity", "novelty" could refer to either instruments or implants independently…furthermore, within one set instruments could be both complex and simple. Argument for more granular categorisation.		**Implant model** No. of implant components Implant design complexity Implant design novelty Implant material technology novelty **Instrument model** Number of instruments (of each different type) Instrument design complexity Instrument design novelty Instrument material technology novelty.

The Design Engineering Survey can be found in Appendix 2.

When restricted to 8 runs, the only possible design option existing is an Orthogonal mixed level Taguchi model with a very low resolution. This design can only be expected to give a sketchy outline of the factors impacting design-engineering as confounding variables cannot be accounted for.

The design and test engineers both took a protective stance over their tacit knowledge claiming it was too intricate and complex to model. The implication that the complexities of their creativity could somehow be modelled simply seemed quite insulting. Through open questioning about exactly what they considered when estimating resource a compromise was reached. In retrospect, the compromise demonstrated that the process was in fact not so complex. If responses to the design resource survey could have been collected from non-designers then it is possible a fractional factorial design could have been used successfully.

5.4.2.2 COLLECT

Different people respondent to the survey as those involved in design were not willing to invest time in responding. The responses came from actual design engineers rather than managers. The people responding to the survey do not have a good project-wide view of resource requirements however, with no other alternative and time running out this was the only option. Three responses were received. Two respondents had collaborated, one had been completed the survey individually.

3 separate sets of models were developed. One for the two similar responses formed through collaboration, one model comprised of the three combined responses and one model based on the individual response.

5.4.2.3 FIT

The responses were analysed using the "analyse Taguchi design" feature in Minitab. It is unclear whether there was an issue with Minitab software or whether the granularity of the resolution was just too low to allow any sensible outcome but the results generated were contradictory. From Figure 62 we can see one of the main effect plots generated. The plots suggest a positive correlation between the factors and the resource required. Whereas, from Table 37 we can see that the coefficients are negative. Additionally, regression models formed through Taguchi analysis do not describe discrete points on the curve. Instead the line between the points is described: we have three coefficients to describe the four-point "number of implants" line. Deriving a regression model from the coefficients presented was not feasible.

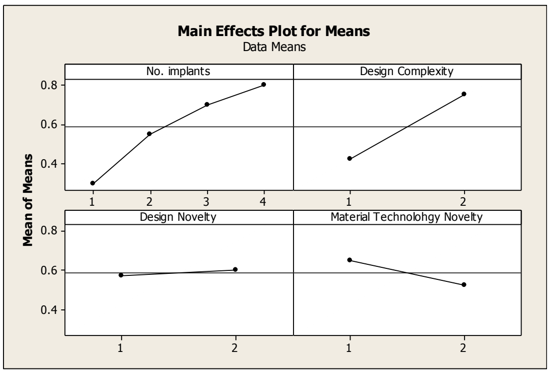


Figure 62 – Taguchi Analysis Main effects plot showing a positive correlation between no. implants and resource required.

Table 37 – Estimated coefficients relating to Figure 26. Note negative coefficients representing a positive correlation and the three terms used to describe no. implants.

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	0.58750	0.01250	47.000	0.014
No. impl 1	-0.28750	0.02165	-13.279	0.048
No. impl 2	-0.03750	0.02165	-1.732	0.333
No. impl 3	0.11250	0.02165	5.196	0.121
Design C 1	-0.16250	0.01250	-13.000	0.049
Design N 1	-0.01250	0.01250	-1.000	0.500
Material 1	0.06250	0.01250	5.000	0.126

S = 0.03536   R-Sq = 99.8%   R-Sq(adj) = 98.3%

In order to create a predictive model the "Taguchi predict" functionality in Minitab was utilised. This function could have been used to create predictions for any scenario described by the factors at any of the three levels (in a similar fashion to the excel model described previously). However, the goal of this research is to develop a predictive model that is easy to use and accessible within DePuy. To overcome this problem we reverted to the two level fractional factorial designs. As we could not go back and ask managers to provide more estimations (a manager's time is limited), the Taguchi predict function was used to generate the results for the fractional factorial templates. The fractional factorial templates were analysed using the standard procedure. The process applied is described in Figure 63 below.

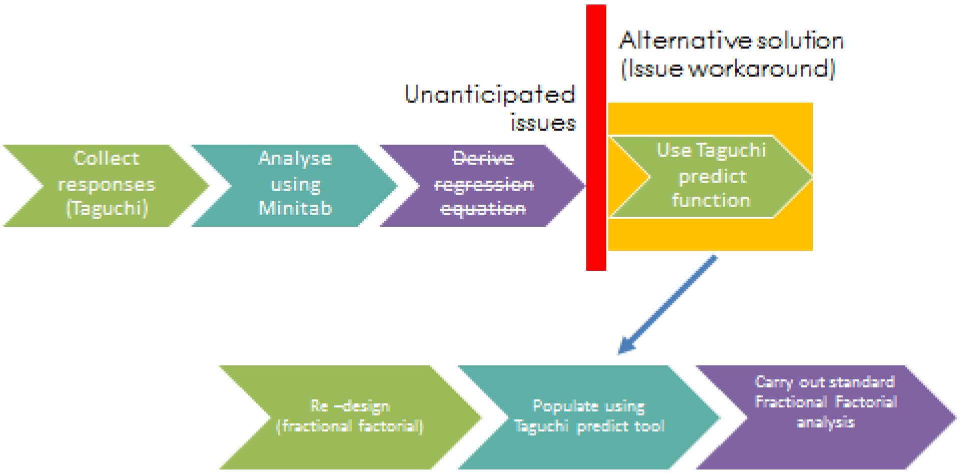


Figure 63 – The process followed to generate a regression equation for Design

5.4.2.4 PREDICT

The predictive model for design was laid out in a manner almost identical to the model for test group. The one difference (apart from the values of coefficients and constants) was the manner in which number of implants is selected. Rather than typing a number in a box, a level is selected from a drop down menu. As is shown in Figure 64.

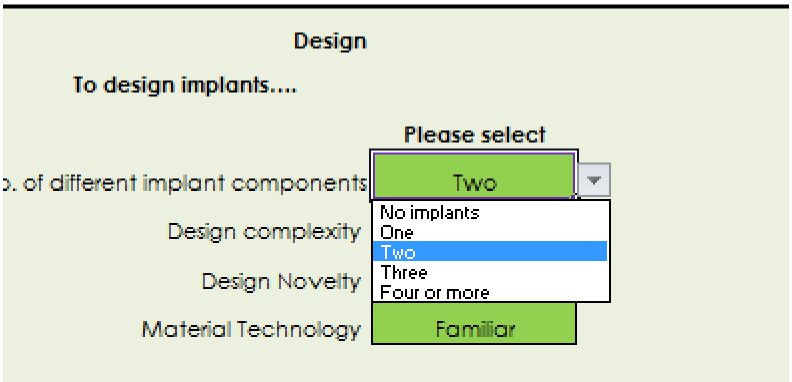


Figure 64 - Method for selecting number of implants

5.4.2.5 VERIFYING THE DESIGN ENGINEERING MODELS.

The same approach applied to Test group was used to assess the accuracy of the Design Engineering model. There are three different design models, so three different predictions are presented for each project type. Predictions per project type were as follows in Table 38 to Table 41.

Table 38 – Design Engineering: Model predictions for Transformational project

		Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Gate 7-8
Duration	**Model 1**	5.3	9.7		6.7	12.0
	Model 2	5.9	13.9		6.8	12
	Model 3	4.5	8.0		8.0	12
Resource	**Model 1**	3.2	8.7	3.6	6.5	1.2
	Model 2	2.5	6.1	7.7	6.9	2.2
	Model 3	4.8	9.2	6.6	8.5	1.2

Table 39 - Design Engineering: Model predictions for a Substantial project

		Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Gate 7-8
Duration	**Model 1**	6.2	9.0		7.2	12.0
	Model 2	6.0	12		7.4	12
	Model 3	7.5	7		8	12
Resources	**Model 1**	6.3	16.1	6.1	10.4	2.6
	Model 2	6	1	15.3	10.2	4.2
	Model 3	6.8	16.8	11.6	13	3.4

Table 40 - Design Engineering: Model predictions for an Incremental project

		Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Gate 7-8
Duration	**Model 1**	4.5	10.5		6.1	12
	Model 2	5	13.9		6.8	12
	Model 3	3.3.	4		3.8	12
Resource	**Model 1**	1.8	4.6	1.8	3.1	0.8
	Model 2	1.7	1.7	4	3.1	1.2
	Model 3	2.1	5.1	2.9	3.3	0.9

Table 41 - Design Engineering: Model predictions for a Maintenance project

		Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Gate 7-8
Duration	**Model 1**	4.5	11.3		6.4	12
	Model 2	6	13.9		6.8	12
	Model 3	3.3	1.7		3.3	12
Resource	**Model 1**	0.9	2.3	0.8	1.3	0.4
	Model 2	1	0.5	1.7	1.2	0.6
	Model 3	0.9	2.5	1	1	0.5

From the tables, without comparing with data Design Managers (the three respondents) and Project Managers noted that the duration predictions seem consistently low and the resource predictions consistently high. One manager suggested that if the relationship between resource and duration is inversely proportional then the model may provide more reasonable predictions. For example: If we look at the prediction for a "Transformational" project from the project management model (which we know is accurate) – See Table 42 below.

Table 42 – Project Management duration prediction for a Transformational type project

	Gate 0-1	Gate 1-Charter	Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Gate 7-8
Duration (Months)	3.0	9	9	20	21	5	12

If we assume that the relationship between resource and duration is inversely proportional, this allows flexibility in how we view the predictions. The 9 design engineers required over 10 months can be translated to a more reasonable 4.5 design engineers over 20 months. Despite the complexity of the process used to arrive at the model and the very course methods of analysis applied, the resultant model appears to derive reasonable conclusions although we do not have data to prove this conclusively.

5. 5 EXTERNAL VALIDATION - MODELLING PROJECT MANAGEMENT RESOURCE AT SCOTTISH WATER

Repeating the process in a different environment is an essential component of ensuring and demonstrating that the solution is not bespoke to DePuy and that it can also be applied to other types of business.

In looking for a suitable external case study company, the following considerations were made (in order of importance):

- Do they have past project data relating to project phase duration and/ or resource (preferably both)
- Is there a degree of uncertainty in predicting resource requirements? Are the company concerned about improving this?
- Design of Experiments the company have a matrix- structure: Do they run a variety of multiple, cross-functional projects simultaneously?

Looking for another company involved in NPD activities was not a priority. Given that the approach had already been applied to multiple NPD related functions within DePuy, a more stable environment with less uncertainty would provide the two key advantages:

1. Learning about the range of environments in which the approach could be applied. Potential to compare differences in results and suitability.
2. As a short case-study and with no in-depth understanding, a simpler and less uncertain project environment avoided complications would the approach to be followed exactly as it was in DePuy.

Scottish Water was selected as a suitable company. The have past-project data, and an active interest in improving resource predictions. In fact, several unsuccessful attempts to model resource requirements had already been made owing to the vast volumes of data required by conventional modelling approaches.

As Scottish Water is a utility company as opposed to a creative NPD business, they wish to minimise uncertainty in projects rather than accept it as an integral component. Uncertainty has no benefits for their business.

Additionally, Scottish water operates with a matrix structure, running tens of projects simultaneously. No single person has a clear view of the resource requirements across projects. Scottish water can identify with the same issues DePuy face with regards to resource information: accuracy, transparency, consistency and timeliness.

For simplicity, it was decided that resource modelling efforts would focus specifically on Project Management resource and specifically on Capital Investment Development projects. The process followed was identical to the process followed at DePuy and will be documented step-by step over the followings sections.

5.5.1 DESCRIBE

Before the researcher initiated contact with Scottish Water, they had already been looking into resource modelling using regression analysis and looking for trends in past project data. However, although they do have a wealth of data in comparison to DePuy, there are holes in the data and the volume of data is just not sufficient enough to create an accurate model.

Scottish Water had started efforts with a similar approach to the one taken in DePuy. A brainstorming session had been conducted with senior management in order to establish 38 factors driving Project management resource demand. The outcome of this session is included in Appendix 1b.

The researcher met with Scottish Water senior management and discussed the basis of the approach applied in DePuy and the need to focus upon project characteristics. The list of 38 factors was reduced to a shortlist of four. This was presented to a range of project managers for review. The project managers added a further two characteristics they considered to be significant. The six characteristics were:

1. Number of milestones
2. Meterage (number of meters of pipework to be laid)
3. Project value
4. Reputational standing
5. Complexity
6. Procurement timescales

5.5.2 DESIGN

Based upon learning derived through the DePuy pilot study a modelling experience, a decision was made to use an eight run, two level design. A quarter factorial design was selected. The Stage-Gate process in Scottish Water is simpler than the process at DePuy. Duration and resource responses were only required for three project phases. The designed survey for Scottish Water can be found in Appendix 3b.

5.5.3 COLLECT

Four Scottish Water project managers responded within a fortnight. Only two of the responses could be used. Two of the responses were not completed correctly: one respondent altered the scenarios (please see Figure 65) whilst the other respondent estimated resource requirements for Project Management, design and construction resource combined.

3	low	high	- change to H	low	high	low
4	high	high	- change to H	high	low	low
5	low	low	- change to	high	low	low
6	high	low - change	high	low	high	low

Figure 65 - Altered scenarios

Although the initial intention was to combine the responses using replicated corner points, the experiences in developing the project management model suggested that due to significant differences in prediction two separate models would produce better results. The average duration for one respondent was 161 weeks where as for the other; the average duration was 56 weeks.

5.5.4 FIT

To derive a regression model, the process followed was identical to the process followed for the four fractional factorial designs in DePuy (See section 5.3.4).

Coefficients for each Scottish Water Project Management model can be found in Appendix 5b.

Two separate models were created. The R-squared (Adjusted) values for each model can be found in Table 43.

Table 43 –R-squared adjusted values for both Scottish Water Project Management models.

Model		Capex 1-2	Capex 2-3	Capex 3-5
Respondent 1	Duration	66.25	41.25	92.25
	Resource	52,38	54.09	-
Respondent 2	Duration	38.23	63,58	56.35
	Resource	63.58	18.74	52.54

5.5.5 PREDICT

A predictive model was developed for Scottish Water using Excel™ in the same manner as the models developed for functions in DePuy. A screenshot of the model is featured in Figure 66Figure 66. Coefficients, constants and multipliers are in hidden cells.

INPUTS

Project characteristics	Please select...
no. milestones	low
meterage	high
Project value	medium
reputational standing	high
Project value	low
Compexity	high
Procurment timescales	high

OUTPUTS

	Duration capex 1-capex 2	Duration capex 2-capex 3	Duration capex 3-capex 5	Resouce capex 1-capex 2	Resource capex 2-capex 3	Resource capex 3-capex 5
Model 1 prediction	15.0	13.3	19.5	176.3	145.0	235.0
Model 2 prediction	3.8	3.8	14.4	25.2	34.7	147.4

Figure 66 - Screenshot of Scottish Water PM predictive model

5.5.6 VERIFY

Data for 14 past projects was collected from Scottish Water. Each of the past projects was categorised according to the 6 factors included in the model. Project managers were asked to categorise each project.

Scottish Water record actual project management resource used via timesheets, allowing the model to be compared to a more accurate view of reality. Although timesheets do not provide an absolute representation of reality, they represent retrospective estimations after the event based on what actually happened as opposed to forecasts or estimates made prior to the event. Estimated PM resource was not available so it is difficult to say conclusively whether the estimations of resource can be improved using the model. However, both estimated and actual information is available for duration data allowing a comparison to be made to the duration components of the models.

For each of the 15 past projects the categories were fed into the predictive model drop-down menu and predictions were made. The predictions were compared with original estimates and actual data.

5.5.6.1 VERIFYING THE DURATION ASPECT OF THE SCOTTISH WATER MODEL

Actual and forecast duration data was collected for 15 past projects. This data was compiled by a Scottish Water manager and sent to the researcher in the format shown in Figure 67.

Project ID	Project Name	Capex Approved Capex 1 Date	Capex Approved Capex 2 Date	Capex Approved Capex 3 Date	Capex Approved Capex 5 Date	
Confidential	Confidentail	02-Sep-10	23-Sep-10	05-Sep-11	30-May-12	ACTUAL
		Capex Forecast Capex 1 Date from Capex1 form	Forecast Capex 2 Date from Capex1 form	Forecast Capex 3 Date from Capex2 form	Forecast Capex 5 Date from Capex3 form	
		15-Sep-10	18-Apr-11	28-Nov-11	05-Jun-12	FORECAST
		PM Actual hours Cx1 to 2	PM Actual hours Cx2 to 3	PM Actual hours Cx3 to 5		
		23.5	78.25	14.5		ACTUAL
		PM Forecast hours Cx1 to 2	PM Forecast hours Cx2 to 3	PM Forecast hours Cx3 to 5		

Figure 67 - Example of data provided per project for 15 past projects by Scottish Water.

The actual duration of each stage gate phase and the forecast duration of each stage gate phase were calculated using an online date calculator application found using a Google search (**http://www.easysurf.cc/ndate2.htm**).

Each of the 15 projects was characterised according to the six factors at high, medium and low levels. This involved creating a template and contacting the PM for each project. The activity of contacting each manager and gathering responses was conducted by a senior manager within Scottish Water rather than the researcher. The template (created by the researcher) with responses from Managers is documented in Figure 68.

Project ID	Project name	No. of milestones	Meterage	Project value	Reputational standing	Complexity	Procurment timescales
4001190000		High	High	High	Medium	[illegible]	Medium
4008390000		Medium	Low	Low	Low	[illegible]	Short
4008520000		Low	Low	Low	Low	[illegible]	Short
4008530000		Low	Low	low	Low	[illegible]	Short
4008550000		Low	Low	Low	Medium	[illegible]	Medium
464150000		Medium	Medium	Low	Low	Standard	Medium
4002870000							
451820000		Medium	Medium	Medium	Low	Simple	Medium
462400000		Medium	Low	Low	Low	Simple	Medium
462670000		Medium	Low	Low	Low	Simple	Medium
466130000		Medium	Low	Medium	Medium	Simple	Medium
4003100000		Medium	Low	Medium	Low	Standard	Medium
4023460000		Medium	Low	Low	Low	Simple	Short
4009250000		Medium	Low	Medium	Low	Standard	Medium
4007180000		Medium	Low	Low	High	Simple	Medium

Should really be zero as

Should really be zero as

Should really be zero as no Lengths of pipe layed.

Figure 68 - Past project categorisation. A level for each factor (high, medium or low) was selected for each project.

A full collection of the data used to verify the Scottish Water models is available upon request.

For each project, the levels of each factor were entered into the predictive model to retrospectively predict the durations of each Stage-Gate phase. The predictions were compared with actuals. Figure 69 shows the difference between three predictive methods (managers estimation, model 1 and model 2) and the actual duration. Actual duration is shown as zero to provide a reference point for clarity.

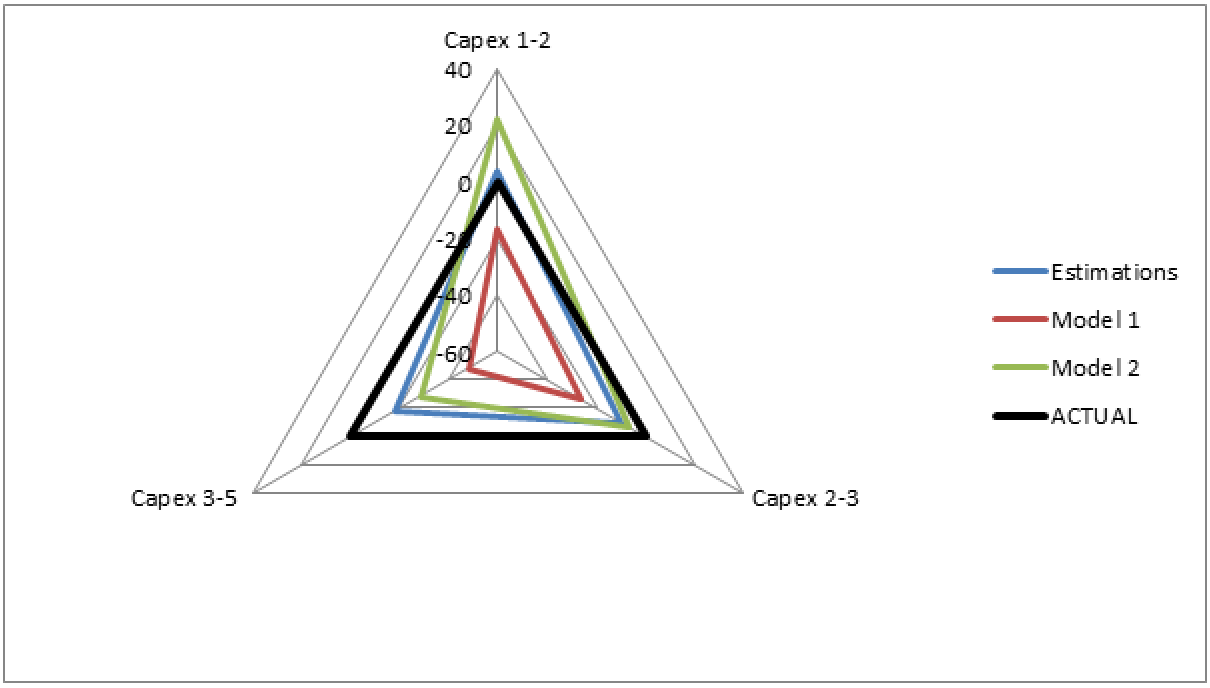


Figure 69 – Comparison of predictive methods with actuals. Estimations are close to actuals whilst model 1 consistently under predicts.

From Figure 69 it is clear that the manager's original estimates outperform the model: on average they provide a closer representation of what actually happened. However, we can also look at the patterns of errors for the models at each Stage-Gate phase. Figure 69 shows the errors across the 15 projects for Capex 1- Capex 2. We can see that there is not a clear pattern between the errors in the model and the errors in estimations, especially where Model 2 is concerned.

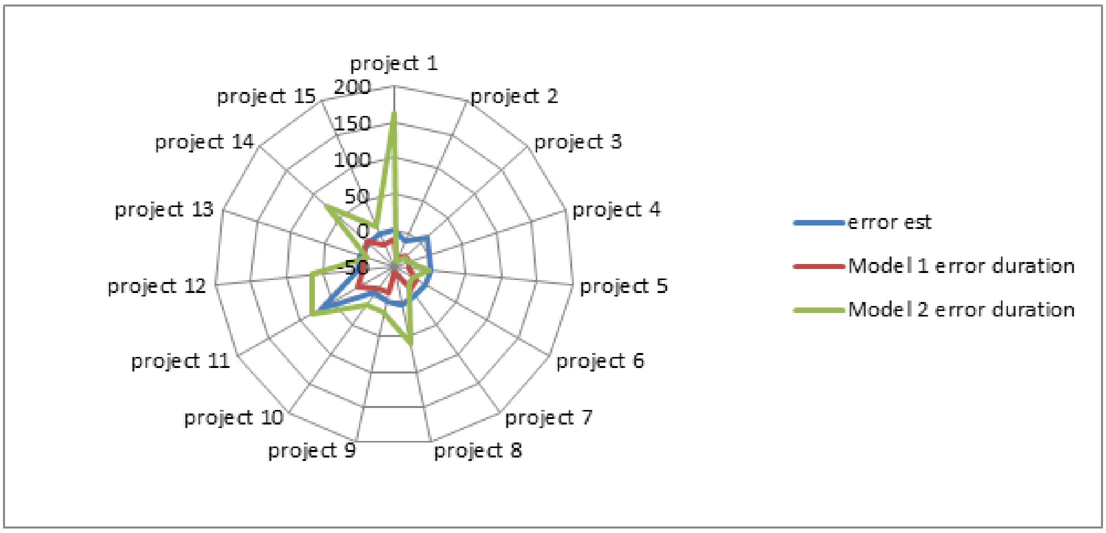


Figure 70 – Duration prediction errors Capex 1 – Capex 2

Model 2 can be removed from the comparison to allow closer examination of Model 1 and the original estimations. This is shown in Figure 71.

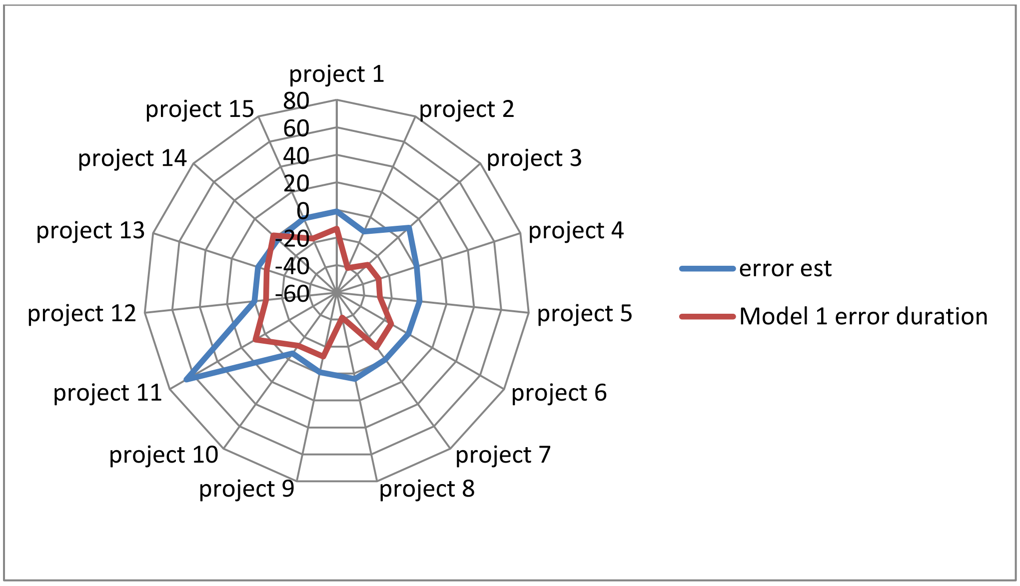


Figure 71 - Comparison between model 1 and estimation error for Capex 1 - Capex 2.

From Figure 71 we can see that there is actual very little error in the estimations. In cases where error is pronounced (Project 11), model 1 appears to echo the estimation error.

Moving on to Capex 2 – Capex 3, it is very clear that both Model 1 and Model 2 echo the estimation error. Although the estimations are more accurate, the models are essentially mimicking the tacit processes of managers. This is shown in Figure 72.

This indicates that the process set-out in this thesis is valid: Design of Experiments can be used to model tacit knowledge and can be used to generate a predictive model for project duration in the absence of past project data. With just 6 factors and 8 hypothetical project scenarios, the tacit processes of managers can be modelled.

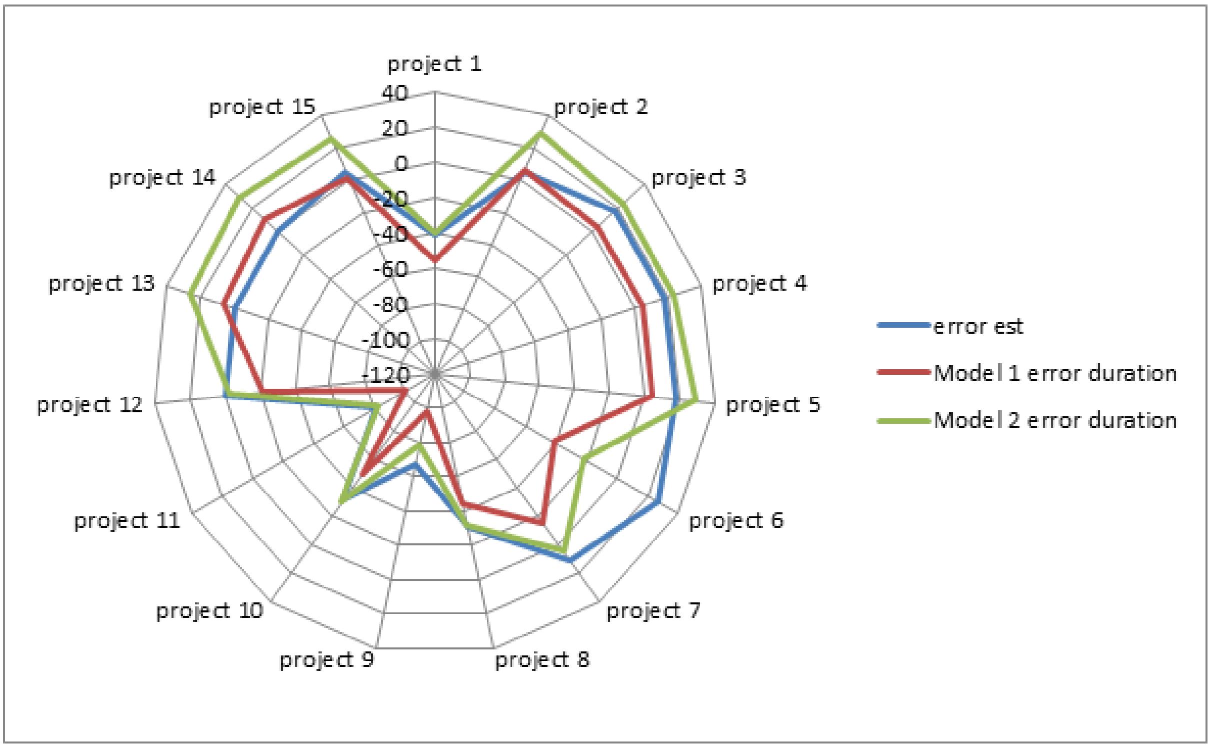


Figure 72 - Duration prediction errors Capex 1 – Capex 2

The results for Capex 3 – Capex 5, shown in Figure 73 present a similar story.

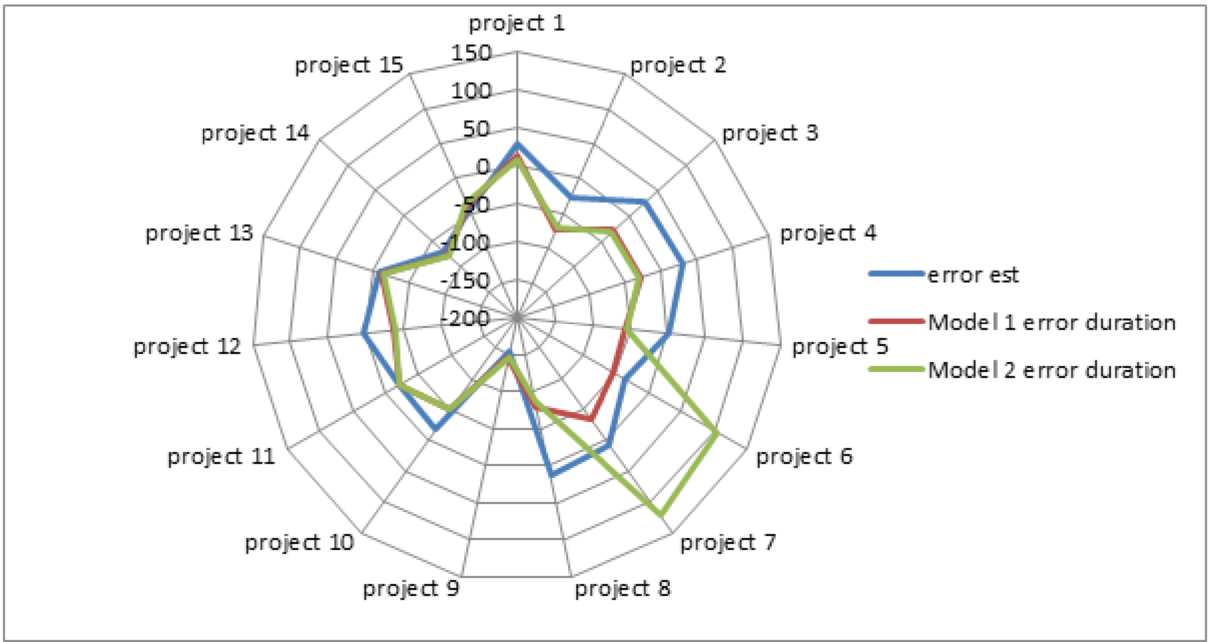


Figure 73 - Duration prediction errors Capex 1 – Capex 2

5.5.6.2 VERIFYING THE RESOURCE ASPECT OF THE SCOTTISH WATER MODELS.

For resource there are no manager's estimates to compare model predictions to. There is only have actual resource used (from timesheets) and model predictions.

Resource predictions from the models do not accurately represent time sheet data. The PM resource is more sensitive than the model. This could be due to factors associated with PM capacity, time-sheeting errors, or a combination of both. Figure 74 to Figure 76 present the comparisons between the actual resource and the model predictions.

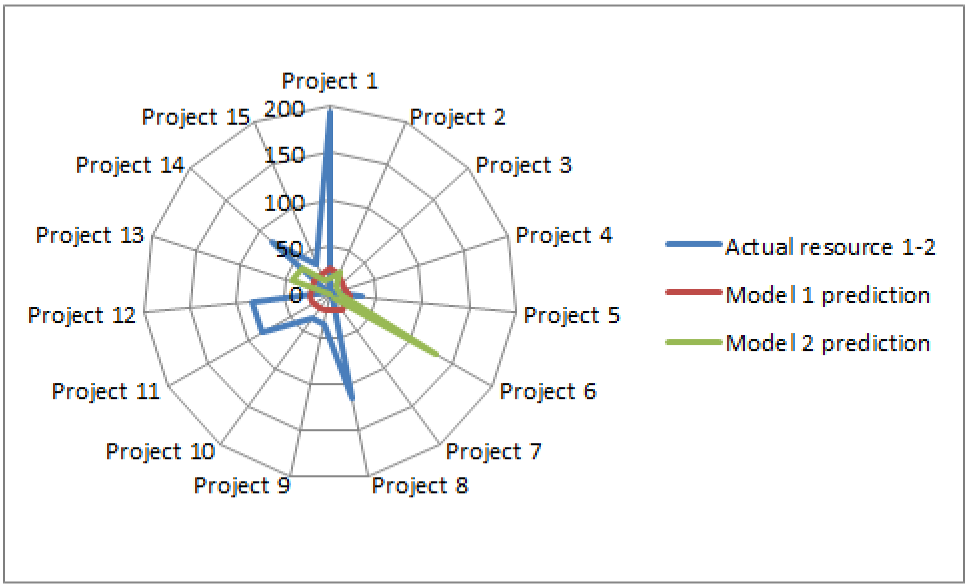


Figure 74 - Resource predictions comparison Capex 1 - Capex 2

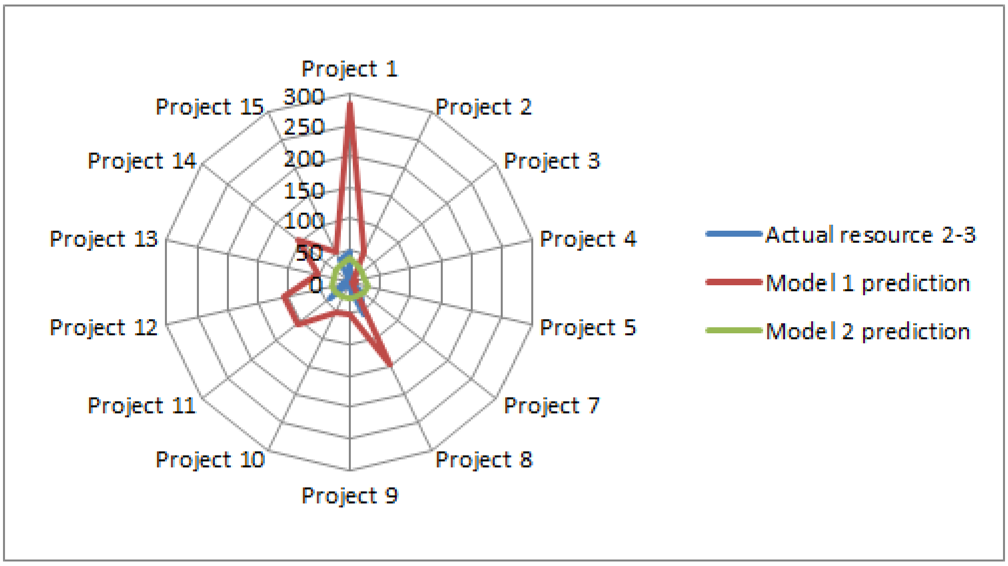


Figure 75 - Resource predictions comparison Capex 2 - Capex 3

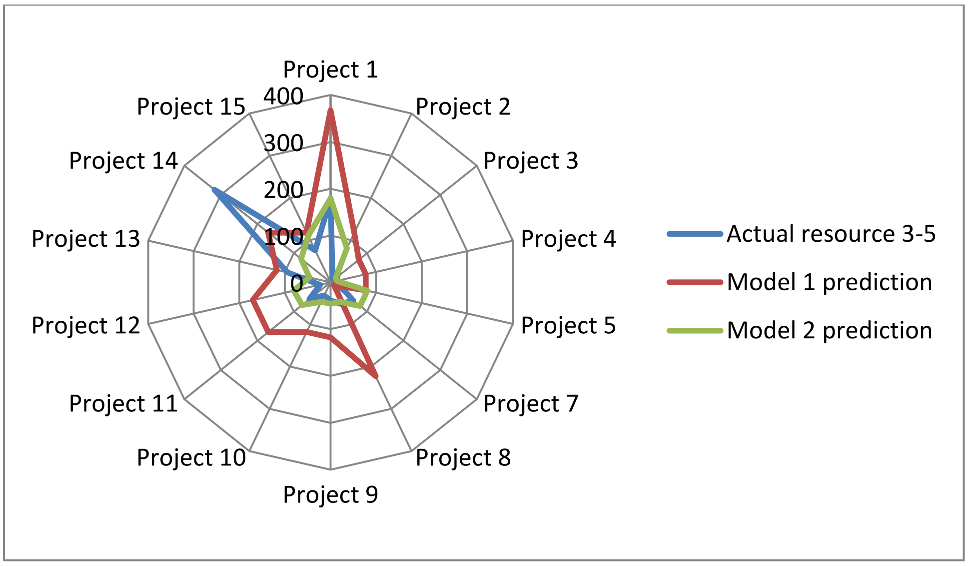


Figure 76 - Resource predictions comparison Capex 3 - Capex 5

5.5.6.3 SCOTTISH WATER VERIFICATION CONCLUSIONS

From the data we can see that the duration models work very well. They mimic the tacit considerations of managers. In DePuy the duration models are of comparable or even better accuracy. In Scottish Water, the patterns are reflected but the manager's estimations are more accurate – probably due to less underlying uncertainty. It is possible that more accurate models could be developed for Scottish Water with more experimental runs as this approximate estimation has been based on just 8 hypothetical scenarios.

The resource aspects of the Scottish Water models did not work as well as the duration aspect. There is no means of comparing the DePuy resource aspect as actual data Design of Experiments not exist. It would be interesting to compare the actual resource with the predicted resource for Scottish Water but this has not been possible. Comparing the actuals with original estimations and comparing the error with the accuracy of models would provide insight into whether the resource models echo the tacit considerations of managers or not. If the original estimations are accurate where the model is not then it would suggest that there are factors that can be established a priori that could but have not been included in the model. If the original estimates are inaccurate and following the trends in the model, it is possible that the tacit considerations have been modelled but the right factors are not being considered – perhaps factors relating to capacity need to be included (manger experience, number of concurrent projects etc.). If both the model nor estimates are accurate and there is no correlation between errors then the inference would be that either the timesheet data is not representative of reality or, that the resource cannot be modelled using project characteristics. This range of possible outcomes is presented in Table 44 below.

Table 44 - possible conclusions that could be drawn if original resource estimations were available

Scenario	Models	Estimates	Explanation (inferred)
1	Accurate	Accurate	This is not the case as models are not accurate. If they were the application of Design of Experiments in this context/ fashion would be valid regardless of the original estimations.
2	Accurate	Inaccurate	
3	Inaccurate	Accurate	This would suggest that it is possible to understand resource a priori and that the model has not included the right factors.
4	Inaccurate	Inaccurate	This could suggest one of two things: 1. The timesheet data Design of Experiments not represent reality. 2. Neither estimates nor the model consider the correct factors. It may or may not be possible to model resource using different factors (perhaps relating to capacity).

To develop Scottish Water models further, future work would begin with searching for a source of original resource estimation data then consideration of capacity factors when modelling resource requirements.

5.6 COMMENTS AND REFLECTION ON APPLICATION OF DESIGN OF EXPERIMENTS

This chapter has presented a novel application of Design of Experiments. Design of Experiments has been applied to model tacit, judgemental knowledge in order to develop several predictive models in environments where data was not available to enable the traditional data-based predictive modelling approaches.

The Scottish Water process is not a design process, there is less uncertainty therefore we would expect the managers original estimates to be more accurate and the process to be easier to replicate with a model. There is a lot of uncertainty in the DePuy process therefore it is harder for managers to be accurate (even a simple model outperforms them) however, because it is more complex/ not fully understood it is harder to replicate the tacit considerations with a model.

The approach involved the development of hypothetical project scenarios, the format of which was described by selectable designs. Resource requirement predictions were captured for each scenario based on subjective expert estimation rather than objective measurements. The limited verification available suggest that the model supersedes the unstructured estimations of managers by focusing upon only the few most significant factors (as opposed to pondering over a wide range of factors without *really* being sure of the effects of any) to provide an approximate, broadly accurate prediction.

Although the developed models are not based upon a wealth of real-life data and are not validated against extensive actual data, they do seem to provide a good quality forecasts which can be substituted for managers estimations. Results suggest that this process can provide a practical and useful solution. A summary of the results and learning derived is presented in Table 45 below.

Table 45 - Model results and summary of learning derived through Design of Experiments application

Model	Comparison with original estimations (where available).	Learning Derived	
Project Management	Significant accuracy improvements.	Design of Experiments can be applied successfully.	The quality of the responses is more important than the quantity of responses.
Bio-Engineering	Comparable, marginally better accuracy although wider range of error.	Perhaps more accurate models could have been developed with more responses.	
Regulatory	Significant accuracy improvements.	Although regulatory only impact one phase of the project, the model for this phase works well. An example of different functional behaviour (resource unaffected by variations in project characteristics…until later on in the project).	
Quality	Comparable	Similar to PM, a straight forward and successful model was developed. When respondents are on-board and committed, better models are produced.	
Test	No data	Too much granularity did not work well in this instance. Better to keep models 'high level'.	
Design	No data	Although leaders were convinced Design resource was complex and had non-linear relationships with project characteristics, survey responses show this is not necessarily the case.	Taguchi designs do not work well with minimal runs. Best to stick to simple fractional factorial designs (or increase no. of runs).
Scottish Water	Comparable accuracy Closely echo's the tacit processes of managers.	The process is valid for modelling project duration. More work needs to be done to establish whether or not it is suitable for modelling resource demand. It is likely that capacity must also be considered.	

Statistically, the application of Design of Experiments could be considered less robust than other approaches as only a few data points are considered. This is especially true in the case of the fractional factorial design used in this research. The more data points available, the more patterns can be understood. Although only 8 runs have been used, the data points that are used have been strategically chosen and positioned so maximum system information can be derived. One of the key advantages of the Design of Experiments approach is the ability of the analytical process to identify interactions between factors. The researcher's experiences and personal reflection upon particulars of the application of Design of Experiments in this context are discussed in the following sections.

5.6.1 PROCESS EVALUATION

The model results validate the application of Design of Experiments in this context. Design of Experiments can be used to echo the tacit considerations of managers and provides a means of modelling inexplicit knowledge.

Additionally, the process has developed models capable of addressing the key system requirements. The models provide approximate accuracy, they provide a timely alternative to the traditional estimation process (reducing time required from months to minutes), they are consistent no matter the experience of the tool user and the factors considered in producing the resource information are clear and transparent.

From a practical perspective, the model is most useful in environments with high uncertainty such as NPD.

The fundamental process is valid however; there are significant opportunities to explore the limitations and opportunities of process variations (tuning methods and designs) and environments.

5.6.2 TUNING PROCESS EVALUATION - ASSESSING ACCURACY USING R-SQUARED ADJUSTED

All of the models developed throughout this thesis have been tuned based on the assumption that a higher R-squared adjusted value is better. Models with a higher R-squared adjusted value should provide better predictability however; from Figure 77 we can see that in practice this is not the case. Models with lowered R-squared values on average have less error. Perhaps the low resolution of designs meant that when tuning factors that were of significance were unwittingly removed.

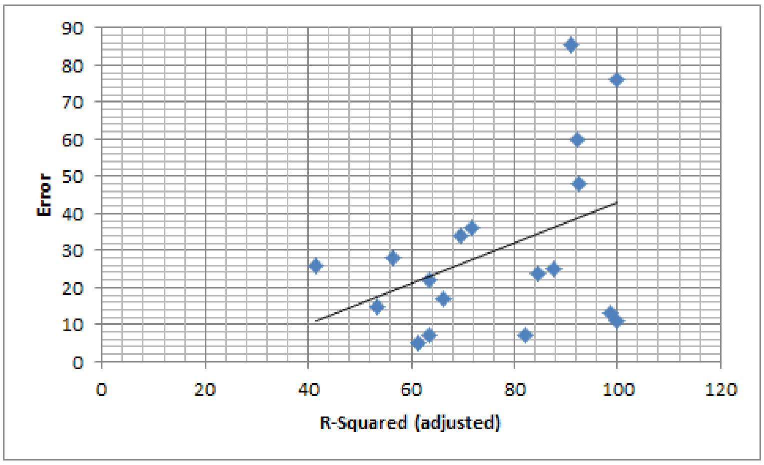


Figure 77 - R-squared (adjusted) values vs. model error

It would be interesting future work to repeat the study without tuning the model (to include all the terms) and compare the difference between the errors generated through a tuned and un-tuned models. In retrospect, perhaps tuning was not the best strategy for fractional factorial designs – perhaps tuning is best suited to full factorial or response surface models where confounding variables are accounted for.

6.0 EVALUATION AND IMPLEMENTATION

Chapter 5 documented the application of Design of Experiments to the development of seven different predictive models: six internal case studies and one external case study. This section documents the process of evaluating and implementing the six internal models.

First, the contexts of use are explored. Two different use environments are identified, each with slightly different needs. The original models are developed to suit the specific requirements of each context. The first context of use relates to strategic, rough-cut portfolio planning and the provision of default values. The second context of use relates to refining and updating the default values at a portfolio level of planning and also to generating early, tactical project plans. Contexts 1 and 2 are described in Table 46.

The requirements for context 1 were derived through discussion with portfolio managers and developers of a portfolio planning tool. Based on the requirements, a simple set of "resource profiles per project type" were developed.

The requirements for context 2 were derived from wider discussions about the implementation of the tool in context 1. These discussions included functional leaders in addition to the portfolio manager and portfolio tool developers. Functional leaders added to the original set of requirements and felt that they needed a more detailed model to suit their needs. This more detailed model was used as the basis for developing the resource profiles per project type used in context 1. A beta version of the context tool model was tested with members of DePuy project teams – user testing and evaluation is documented in Chapter 6.

Table 46 – Context 1 and context 2 requirements and model mechanics.

	Description	User requirements	Model mechanics
Context 1	Portfolio managers require estimated resource requirements for each project type. They may have very little information about the details of a project and would like to be able to quickly test scenarios autonomously.	Very high level estimations. Over a large portfolio it is likely errors will average out. The duration of stage – gate phases is important. Resources in FTE's.	Portfolio managers would like a simple resource profile per project type. 4 different project profiles that could be selected as default values.
Context 2	Functional managers require estimates per project type. They are likely to be concerned with projects that are "live" and actually happening/ consuming their resource. They want accurate estimates and some control of the predictions.	More accurate estimations, more detailed means of describing resource required i.e. through specific project characteristics. Resource requirements in ¼;s are well as Stage-Gates.	To be practical, each of the individual resource models must be combined under a master duration.

The context 2 model was developed first as this informed the project profiles used in project 1.

6. 1 MODEL USED IN CONTEXT 2

The model used in context 2 is a cross-functional version of the individual models developed in chapter 5. This section explains how the functional models were combined.

6.1.1 THE MECHANICS OF COMBINING FUNCTIONAL MODELS

The steps used to create combined cross-functional model are documented in Table 47.

Table 47 – Steps to combining the individual resource models.

Step	Purpose	Description
Create individual, duration and resource models per function.	Ability to predict resource per functional group for any type of project.	See chapter 7.
Find and select most accurate duration model components	Make sure that the models are coherent and that they are coherent in the most accurate way possible.	Based on verification data/model comparison with past projects.
Create predictive duration model	One duration.	Combine separate model components to get the most accurate duration overall.
Adjust resource per function to fit master duration.	Adjust resource proportionally to master fit duration.	Resource and duration are inversely proportional.

Steps 1 and 2: Select most accurate duration model

In order to combine all the models under a single duration, the most accurate duration model per-stage gate phase was selected. This was made up of components of different models. Based on a limited number of past projects Table 48 shows the most accurate model per Stage-Gate phase. The overall duration model was comprised off the most accurate model components.

Table 48 - Accuracy of each model per Stage-Gate phase

Function	Charter – Gate 2	Gate 2 – Gate 3	Gate 3 – Gate 6	Gate 6 – Gate 7
Project Management	-11	7	25	15
Bio-Engineering	34	60	13	76
Regulatory			5	
Quality	-48	22	-7	-28

As the project management model was on the whole, most accurate this was also used to predict pre-charter phases: Gate 0 - Gate 1 and Gate 1 – Charter. There was no data available to assess the accuracy of these phases as their introduction is relatively new.

Step 3: Create predictive duration model

The predictive duration model was created in the same way as the individual duration models. Coefficients and constants for each Stage-Gate phase duration from the respective functional analysis were arranged together.

The combined model contains all the factors included across the four models (rather than just a sub-set). Test and Design resource are included in separate work-sheets using the predictive models specific to their function. They could not be combined because the factors from Test and Design are not congruent with the factors describing the resource from the other functional groups. Test and Design are split into instrument/ implant model components.

Step 4: Adjust resource per function to fit master duration

An assumption has been made that the relationship between duration are resource is inversely proportional. As duration increases, resource required per period of time decreases at the same rate as it is spread out.

fx =(I11/R22)*R21

PREDICTIVE MODEL OUTP			
Front End – Gate 1	Gate 1– Charter	Charter - Gate 2	Gate 2– Gate 3
12.00	10.88	10.50	21.38
0.7	0.4	0.5	0.4
0.1	0.0	0.0	0.1
1.2	1.1	0.6	1.1
0.5	0.9	2.9	2.9
		17.0	3.6
2.3	2.7	2.9	3.3

Figure 78 - Adjusted resource per function= Master duration/ duration for function * resource prediction for function

6.1.2 BETA MODEL FOR CONTEXT 2

The beta model was developed by following step 1 to step 4. The model included each of the functional groups detailed in the thesis: project management, bio-engineering, regulatory, quality, test and design. The inputs: project characteristics (shown in Figure 79on the left hand side) are associated with a value (by making a selection from a drop down menu). Selecting various values drives a corresponding duration and demand prediction in FTE's required per Stage-Gate phase.

Project Characteristics	Please select approximate value for each characteristic from the drop down menus below...
The number of implants	two
The number of instruments	Medium
Design complexity	Complex
Design novelty	Novel
Regulatory pathway	Unapproved
Clinical trial requirements	Large
Material technology novelty	Novel
Manufacturing process novelty	Novel
Core market?	Yes
Location	Global
Surgeon team size	Medium
Strategic value	High
Production volume	Medium

	Front End - Gate 1	Gate 1- Charter	Charter - Gate 2	Gate 2- Gate 3	Gate 3- Gate 6	Gate 6- Gate7	Gate 7- Gate 8
Master Duration	3.00	10.88	10.50	21.38	21.00	23.06	12.00
PM FTE's	0.70	0.41	0.50	0.43	0.63	0.23	0.33
Reg FTE's	0.05	0.03	0.03	0.10	0.10	0.28	0.20
Design Quality FTE's	0.03	0.01	0.11	1.25	2.70	0.98	0.33
Marketing FTE's	0.50	0.88	2.50	2.50	2.50	2.50	0.88
Design FTE's			1.10	2.62	2.18	1.23	1.33
Development FTE's							
Clinical 2 FTE's							
Test 3 FTE's							
Function 4 FTE's							
Function 5 FTE's							
Function 6 FTE's							

Figure 79 - Beta model for context 2

The beta model was used to test the model usability and to gauge the response to the model before adjustments were made. Usability testing and results for the context 2 model are discussed in section 6.3.

6.2 CONTEXT 1 MODELS: RESOURCE PROFILES PER PROJECT TYPE

Concurrently, work was undertaken to understand the requirements for embedding the model in portfolio management tool (simultaneously being developed for DePuy be an external consultancy, in an effort to move away from the difficult to manage Excel™ spread-sheet approach).

Rather than include all variables in the model, it was decided that a resource profile per project type would be used to generate default resource predictions. Model 1 could then be used to update the default predictions as required. This approach requires minimal assumptions from the portfolio manager and should provide starting point even when minimal information in known.

The innovation manager defined the characteristics of each "type" of project. The level 1 model was used to create a resource profile based upon the characteristics selected. Characteristics for each type are shown in Table 49.

Table 49 - Project type scenarios

	Transformational	Substantial	Incremental	Maintenance
1. **The number of implants** (high, medium, low, none).	Medium	High	Medium	Low
2. **The number of instruments** (high, medium, low, none)	Medium	High	Medium	Low
3. **Design complexity** (Complex, standard, simple)	Complex	Complex	Standard	Simple
4. **Design novelty** (novel, some novel aspects, standard)	Novel	Some novel aspects	Standard	Standard
5. **Regulatory pathway** (approved, mixed, unapproved)	Unapproved	Mixed	Approved	Approved
6. **Clinical trial requirements** (large, medium, small).	Large	Large	Small	Small
7. **Material technology novelty** (novel, some novel aspects, stand	Novel	Some novel aspects	Standard	Standard
8. **Manufacturing process novelty** (novel, some novel aspects, sta	Novel	Some novel aspects	Standard	Standard
9. **Core market?** (yes, no)	No	Yes	Yes	Yes
10. **Location** (Global, specific to a region, specific to a country).	Global	Global	Specific to a region	Specific to a country
11. **Surgeon team size** (Large, medium, small)	Medium	Large	Small	Small
12. **Strategic value** (high, medium, low)	High	High	Medium	Low
13. **Production volume** (high, medium, low)	Medium	High	Medium	Low

The four resource profiles generated are shown below. These are Level One models: the highest level of prediction. The Level One models will be used as default predictions in the innovator portfolio management tool.

Table 50 - Transformation project resource profile. Charter – Launch 6.3 years

Transformational	Front End - Gate 1	Gate 1- Charter	Charter - Gate 2	Gate 2- Gate 3	Gate 3- Gate 6	Gate 6- Gate7	Gate 7- Gate 8
Master Duration	15.0	10.9	10.5	21.4	21.0	23.1	12.0
Project Management	0.7	0.4	0.5	0.4	0.6	1.0	0.3
Regulatory	0.1	0.0	0.0	0.1	0.1	0.3	0.2
QA	1.2	1.1	0.6	1.1	1.4	2.3	0.3
Marketing	0.5	0.9	2.9	2.9	2.9	2.9	0.9
Design			17.0	3.6	34.5	2.2	1.2
Development	2.3	2.7	2.9	3.3	0.0	7.7	0.1
Clinical							
Test	1.0	0.0	0.0	3.1	4.1	3.9	0.1
Function 4 FTE's							
Function 5 FTE's							
Function 6 FTE's							

Table 51 - Substantial project resource profile. Charter – Launch 5.9 years

Substantial	Front End - Gate 1	Gate 1- Charter	Charter - Gate 2	Gate 2- Gate 3	Gate 3- Gate 6	Gate 6- Gate7	Gate 7- Gate 8
Master Duration	12.00	10.50	12.38	21.75	22.88	13.26	12.00
Project Management	0.7	0.5	0.5	0.4	0.8	1.1	0.5
Regulatory	0.1	0.0	0.0	0.1	0.1	0.5	0.3
QA	1.2	1.1	0.5	1.5	2.2	1.6	0.5
Marketing	0.5	0.9	2.4	2.4	2.4	2.4	0.9
Design			36.5	5.7	59.4	2.4	2.2
Development	2.6	3.6	4.6	2.9	1.4	5.8	1.1
Clinical							
Test	1.0	0.0	0.0	2.7	4.3	1.8	0.1
Function 4 FTE's							
Function 5 FTE's							
Function 6 FTE's							

Table 52 - Incremental project resource profile. Charter - launch 3.8 years

Incremental	Front End - Gate 1	Gate 1- Charter	Charter - Gate 2	Gate 2- Gate 3	Gate 3- Gate 6	Gate 6- Gate7	Gate 7- Gate 8
Master Duration	9	6.75	7.125	16.875	17.8125	3.469	12
Project Management	0.7	0.4	0.5	0.4	0.5	1.2	0.3
Regulatory	0.1	0.0	0.0	0.1	0.1	0.5	0.3
QA	1.0	0.7	0.4	0.8	1.5	0.5	0.3
Marketing	0.4	0.6	0.2	0.2	0.2	0.2	0.6
Design			11.1	2.7	21.8	0.4	1.3
Development	2.5	2.7	1.7	1.6	3.9	0.9	0.1
Clinical							
Test	0.0	0.0	0.0	2.3	4.3	0.6	0.1
Function 4 FTE's							
Function 5 FTE's							
Function 6 FTE's							

Table 53 – Maintenance project resource profile. Charter – Launch 2.4 years

Maintenance							
	Front End - Gate 1	Gate 1- Charter	Charter - Gate 2	Gate 2- Gate 3	Gate 3- Gate 6	Gate 6- Gate7	Gate 7- Gate 8
Master Duration	1.00	6.56	2.81	12.38	9.94	3.47	12.00
Project Management	0.7	0.3	0.4	0.4	0.4	1.2	0.1
Regulatory	0.1	0.0	0.0	0.1	0.1	0.4	0.3
QA	0.6	0.7	0.2	0.4	0.4	0.8	0.1
Marketing	0.3	0.3	0.0	0.0	0.0	0.0	0.4
Design			2.1	1.4	6.1	0.2	0.7
Development	2.3	3.3	0.4	0.9	1.6	0.4	0.0
Clinical							
Test	0.3	0.0	0.0	0.0	0.8	1.5	0.1
Function 4 FTE's							
Function 5 FTE's							
Function 6 FTE's							

Overall, the duration across Stage-Gates per project type can be viewed in Figure 80.

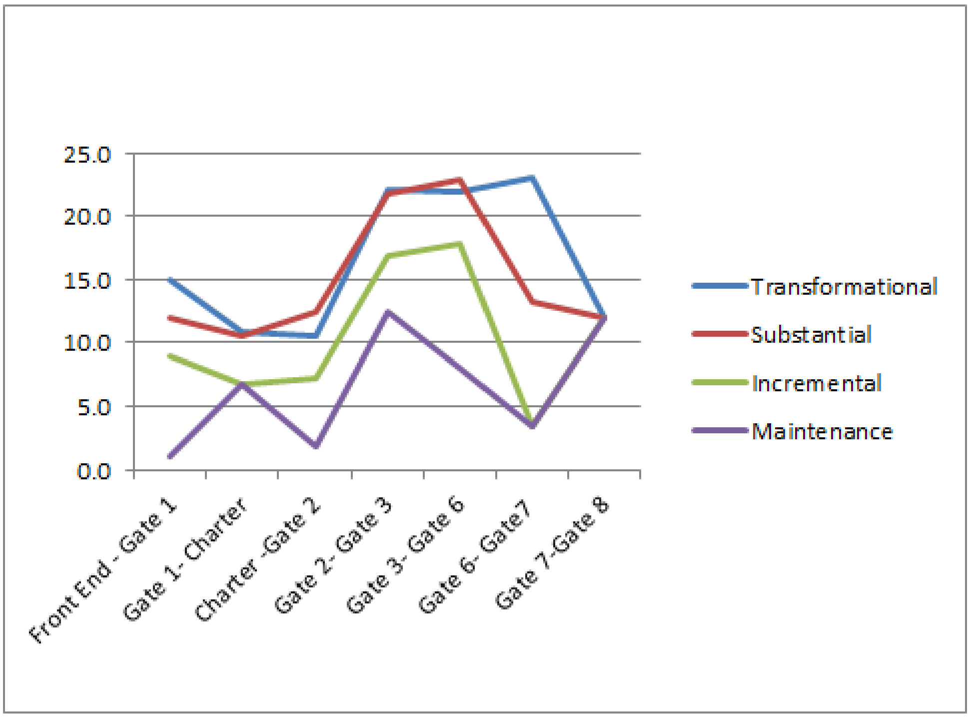


Figure 80 – Duration profile per project type across Stage-Gate phases.

Figure 81 compares the total duration and "total" resource required per project.

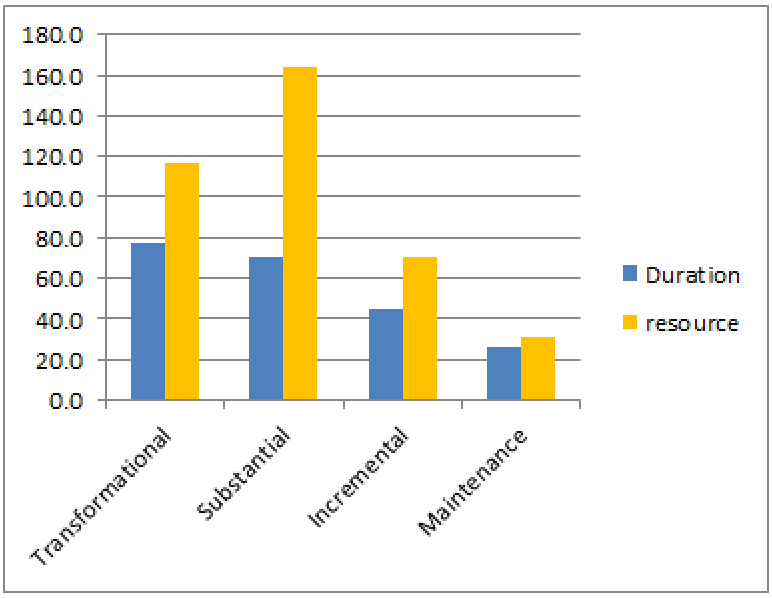


Figure 81 - Total duration and total resource per project type

For the benefit of DePuy, a workbook of brief instructions for creating the Excel™ versions of predictive models was created. This is included in Appendix 6aa.

6.2.1 IMPLEMENTING AND USING THE MODEL IN PRACTICE

Context one models are currently being applied in DePuy through integration with a portfolio management tool. Default values per project are provided by the tool in the first instance as per the recommendation by Anderson and Joglekar (2005).

- Default values can then be adjusted by the portfolio manager or front-end team using the context two models if more descriptive project information is available. There are no current plans to apply Context two models to project planning. Additionally, once project plans have been established it is likely that the default values will be updated using traditional methods until such time that the accuracy of the model can be validated and confidence in predictions gained. It is noteworthy that the accuracy of the model can only be established through comparison with actual resource data. With a reluctance to gather such data DePuy remain unable to establish the accuracy of the model and the accuracy of their estimates. Without actual resource data, DePuy will remain unable to defend or verify their ability to meet the criteria specified in Worldwide Quality Policy (QSP-100000 Revision 5, Appendix 4) described presented earlier on Page 23 namely: "***Optimising our internal resources, both human and technological".*** *It is impossible to optimise the resource if there is no understanding of the reality of the demand and capacity.*

The predictive models developed are most useful in the early stages of a development project, before detailed project information is known. Once a project plan has been developed and work is underway, the accuracy of the predictive model is likely to be lower than that of managers or the project team. Although the prediction is made in the early stages, it will be made for the whole project duration.

6.3 USABILITY TESTING FOR CONTEXT 2 MODEL

The model developed in section 6.1 was subjected to testing. The model was presented at a Quarterly "R&D Science Fair" in the DePuy design office, Leeds. The purpose of the science fair is to allow ideas and innovations to be shared between projects and initiatives and to update those who are interested or who have invested time with progress and results. The science fair is open to all DePuy NPD project team members, managers and business leaders.

The model was presented for anyone who wished to "have a shot" to test. Testing required "inputting" the relevant levels of each project characteristics via the drop down menu. Participants were asked to input characteristics for a project they were familiar with. A range of DePuy employees responded over the 3 hour science fair: from project team members to project managers. Twelve employees responded in total.

Although project team members are not likely to be required to use the model, they were familiar with overall aims of the research and had sufficient project experience to describe a past or current project using the levels and be familiar with the durations.

Following the user test, respondents were asked to complete a short survey about their experiences and perceptions of the model.

Generally, comments were positive. All participants could see benefits in the model. Establishing realistic milestones including launch dates was widely regarded to be a key benefit. When asked to comment on the model overall. Specific comments relating to this include:

- *"Will be brilliant for NPI launches"*
- *"useful marker of milestones"*
- *"If this becomes standard in determining realistic timelines would be a great asset to managing market expectations"*

This aspect of the model relates to predicting durations rather than resource. Having this alone, without the resource aspect of the model offers significant improvements. Too much pressure around launch dates and unrealistic milestones is a business-wide issue. Additionally, this aspect of modeling can be related to both early project plans (tactical planning) and portfolio level planning (at a strategic level). The same data could be used for both, increasing consistency in terms of the way workload is considered system-wide. All participants felt that the output of the tool was reasonable. However, remarks were made regarding the need for actual data to back-up the predictions and instill confidence. The key concern here is that actual data is not available and currently DePuy do not have plans to gather any on the scale required. Actual data is the only way that the model (or any type) of forecast can be thoroughly assessed for accuracy. Without quantifiable evidence of the benefits, traction to implement the tool at a project level is poor. As the project life-cycle is so long, gathering sufficient data to instill confidence may take years and a consistent, well organized data gathering approach. There is no instant, easy fix to this issue.

The suitability of the tool to portfolio level planning remarked upon. The quickness of the estimation process was particularly beneficial. It was noted that for project planning purposes, resources per quarter (from a specifiable start date) would be preferable to resource per Stage-Gate. The duration aspect of the model means that adding this functionality should not be difficult.

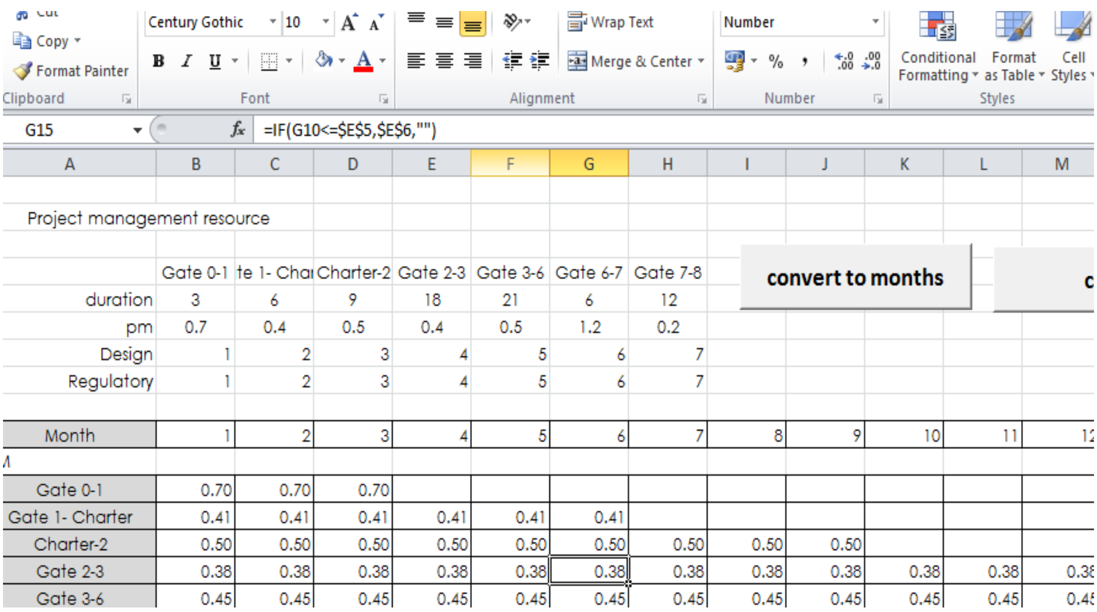
One participant didn't notice the definitions of inputs (hidden in cell comments) and remarked that they ought to be better defined. This is something that can easily be made more explicit in future versions. Whilst one person remarked that the interface was clear and well laid out, another remarked that it ought to be clearer. This is an area that would benefit from further investigation prior to the tool being launched in practice.

In summary, although the tool has scope to be useful, the collection of actual resource data remains critical for successful, system-wide implementation. Without actual data and supporting evidence, the application of the tool is limited.

6.1.4 COMBINED MODEL REFINEMENT

Feedback from the evaluation survey suggests that the model would be more useful at a project planning level if the Stage-Gates were represented in quarters. Stage-Gates are of very little consequence to project team members. This is also required for a portfolio model as the managers and functional leaders will be the ones approving the predictions, accepting and updating the defaults.

Transferring predictions from Stage-Gates to quarters required the use of the "IF" function and a simple macro as is shown in Figure 82.



A	B	C	D	E	F	G	H	I	J	K	L	M
	Gate 0-1	te 1- Chai	Charter-2	Gate 2-3	Gate 3-6	Gate 6-7	Gate 7-8					
duration	3	6	9	18	21	6	12					
pm	0.7	0.4	0.5	0.4	0.5	1.2	0.2					
Design	1	2	3	4	5	6	7					
Regulatory	1	2	3	4	5	6	7					
Month	1	2	3	4	5	6	7	8	9	10	11	12
Gate 0-1	0.70	0.70	0.70									
Gate 1- Charter	0.41	0.41	0.41	0.41	0.41	0.41						
Charter-2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50			
Gate 2-3	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Gate 3-6	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45

Figure 82 - Converting resource per Stage-Gate into months requires the use of the IF function and a macro

Another issues communicated through feedback was general model clarity. The model lay out has been colour coordinated and tidied up to make completion simpler. Unfortunately, due to the inherent complexities Test and Design models require a separate sheet to generate predictions. Ideally predictions for all functions could be generated from a single drop-down menu. The new layout is shown in Figure 83.

Assumptions: resource and duration are inversely proportional.
FTE = Full Time Equivelent: 1 FTE = 100 % of one persons time.

PREDICTIVE MODEL INPUTS ...

Project Characteristics	Please select approximate value for each characteristic from the drop down menus below...
The number of implants	two
The number of instruments	Medium
Design complexity	Complex
Design novelty	Novel
Regulatory pathway	Unapproved
Clinical trial requirements	Large
Material technology novelty	Novel
Manufacturing process novelty	Novel
Core market?	No
Location	Global
Surgeon team size	Large
Strategic value	High
Production volume	Medium

PREDICTIVE MODEL OUTPUTS ...

		Front End - Gate 1	Gate 1- Charter	Charter - Gate 2	Gate 2- Gate 3	Gate 3- Gate 6	Gate 6- Gate7	Gate 7- Gate 8
	Master Duration	12.00	10.88	10.50	21.38	21.00	23.06	12.00
Resource (FTE's)	Project Management	0.7	0.4	0.5	0.4	0.6	1.0	0.3
	Regulatory	0.1	0.0	0.0	0.1	0.1	0.3	0.2
	QA	1.2	1.1	0.6	1.1	1.4	2.3	0.3
	Marketing	0.5	0.9	2.9	2.9	2.9	2.9	0.9
	Design			17.0	3.6	34.5	2.2	1.2
	Development	2.3	2.7	2.9	3.3	0.0	7.7	0.1
	Clinical							
	Test	1.0	0.0	0.0	3.1	4.1	3.9	0.1
	Function A							
	Function B							
	Function C							

Figure 83 – Final model for context 2

7.0 CONCLUSIONS

"Experience is what you get when you didn't get what you wanted"

Randy Pausch

The final chapter of the thesis concludes the research work presented. An overview of the work completed is offered with the original objectives (section 1.2.2) as a point of reference. This is followed by a summary of the novel contributions to theory and practice resulting from the work. The quality of the research is considered using the criteria set out in section 2.2.2. The limitations of the research and areas of future work are discussed before the thesis closes with a final personal reflection upon the research experience.

7.1OVERVIEW OF THE THESIS

The aim of this thesis is to provide an improved approach to resource planning in NPD. By applying systems thinking to the process, the fundamental under-lying issue was uncovered: resource information. Existing literature relating to resource information was reviewed. Through this review of literature and observations and experiences derived through the sponsoring company the requirements of good resource planning information were established. The possibility of using existing predictive modelling methods was explored with regression analysis and categorisation as the main contenders. Due to a lack of past project data neither method was capable of producing a useful predictive resource model. This provoked the need to apply a novel modelling method which resulted in the significant contribution to knowledge. Design of Experiments has been applied to model the tacit considerations of resource estimators and to develop an accurate, timely, consistent and transparent predictive model. The solution developed is reliable and offers significant contributions to knowledge and to practice. There are possibilities of developing this approach further and applying the process in a wider variety of contexts.

The main stages of this research work were:

- ✓ Working with DePuy, the researcher established a broad understanding of the range of practical issues surrounding resource planning in NPD. This was complimented by a comprehensive review of the literature. (O1 & O2)
- ✓ Systems' thinking was employed to consider the problem from a variety of perspectives in order to encourage the development of a robust and useful solution. This led to the realisation that resource information was critical at all levels of NPD planning and an unresolved issue in theory and practice. (O3)
- ✓ A methodology corresponding to the need to further investigate resource planning was developed. In designing the research approach particular attention was paid to establishing a range of problem perspectives: construct validity, external validity, internal validity and reliability were used to ensure high quality research outputs. (O4 & O5)
- ✓ A more focused investigation ensued to explore the as-is resource information situation from the perspective of literature and practice. The processes and issues associated with the development of resource information were explored from Material, Social and Personal perspectives at all decision making levels (strategic, tactical, and operational). Key requirements of good resource information were realised: accuracy, timeliness, transparency and consistency.

- ✓ A decision was made to explore the possibility of meeting the resource information requirements using a predictive model. Various modelling methods were assessed. Regression analysis and categorisation were employed without success: DePuy did not have enough past project data.
- ✓ Rather than adjusting the research focus, the researcher sought an alternative method. Design of Experiments was identified as a possible contender. A systematic literature review was conducted into applications specific to prediction.
- ✓ The opportunity to adapt Design of Experiments was identified. The process of exploring this adapted application is the main contribution of this thesis. The process was applied to 6 different functional groups within DePuy by following the process described in Chapter 5. (O7)
- ✓ The process of applying Design of Experiments to resource planning predictive model development was repeated in an external company: Scottish Water
- ✓ Finally, the quality of the research was assessed against the criteria specified in the research approach section 2.2.2. This is documented in section 7.2 (O8)

A summary of the research process is presented in Figure 84.

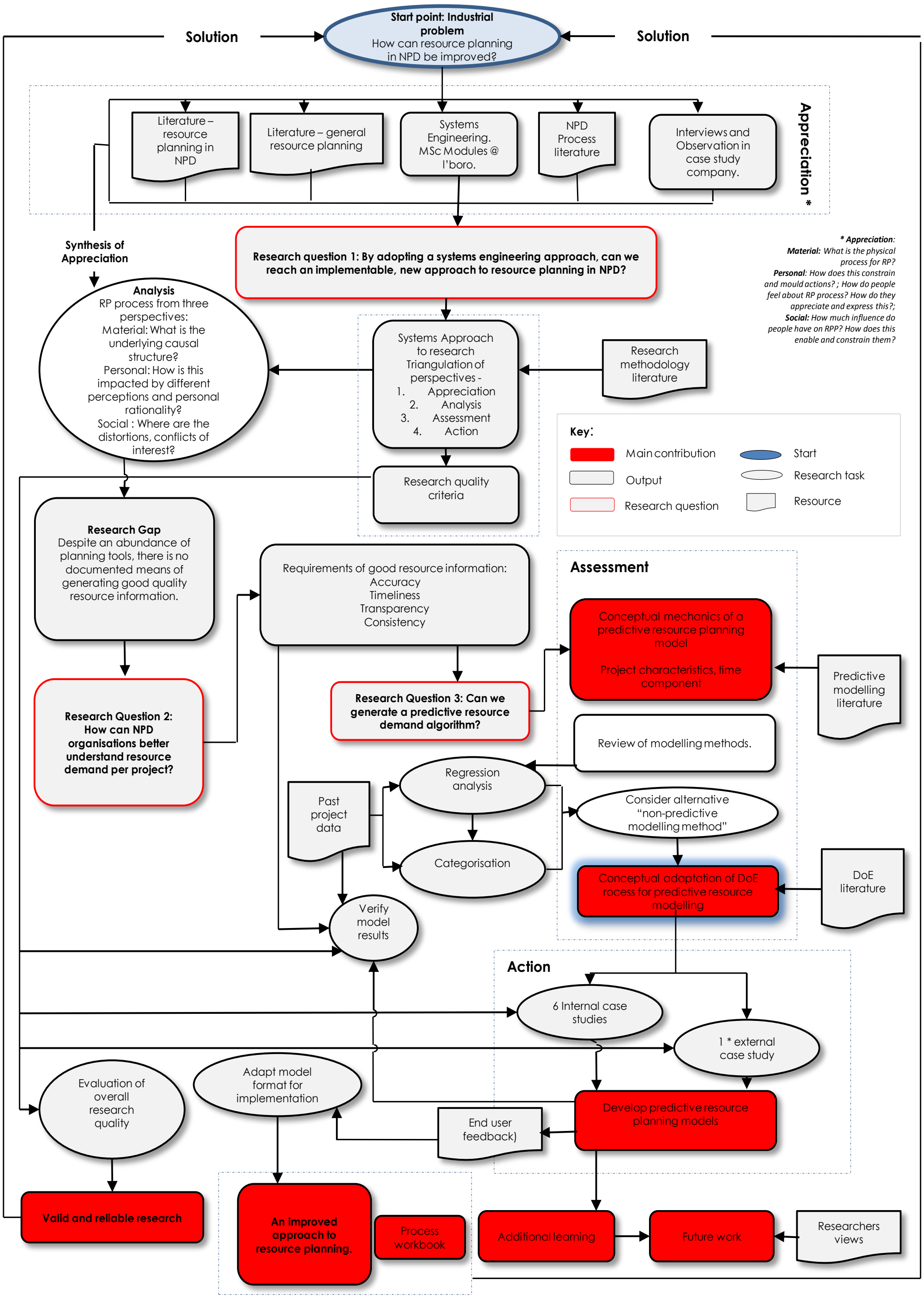


Figure 84 – Summary of research process

7.1 CONTRIBUTION OF THE RESEARCH

The main aim of this project is to make a significant contribution to knowledge. An important component of this thesis has been relating the findings with existing work in order to demonstrate novelty and advancement in knowledge and practice.

This research has broadened the applicability and usefulness of existing resource planning techniques as well as presenting a resource planning technique in its own right. Additionally, and perhaps more significantly a new method for predictive modelling and a new application of Design of Experiments has been documented.

The project began with an industrial problem: resource planning in New Product Development (i.e. how to plan resource requirements in an environment characterised by uncertainty). In addition to making a significant contribution to knowledge, an additional objective has been to deliver a practical solution for industry.

The following sections describe the contributions to both theory and practice on resource planning in NPD provided by this research work.

7.1.1 CONTRIBUTION TO THEORY

Three main contributions to theory are claimed. Each of the main contributions relates to research questions 2 and 3. Investigation of the first research question provided direction for the research and resulted in a contribution in the form of a fresh understanding of the problem area generated though the analysis of three systems perspectives: material, social and personal. The systems perspective lead to the realisation that resource information is a system wide issue: tacking resource information provides an opportunity to realise system wide improvements. In this sense, the first research question has been answered through the identification and successful resolution of the second and third questions. A systems approach has allowed us to reach an implementable and improved solution to resource planning in NPD. Had a systems approach not been used, it is less likely that the same essential issue would have been identified, that the same avenues would have been investigated and that the end-result would have been as implementable or would have had system-wide benefits.

7.1.1 CONTRIBUTION 1:

The development of a process for applying Design of Experiments (Design of Experiments) to modelling the tacit considerations used by managers to make resource estimations.

This contribution is a result of answering research question 2 and builds upon the notion that resource requirements per “project type” should be known as a matter of course (Anderson and Joglekar, 2005). Resource estimations are a critical input for sophisticated portfolio planning approach (in addition to standard project management tools). Existing literature cites the resource component of planning as a weakness that needs to be addressed (Cooper and Kleinschmidt 1993; Cooper 2003; Smith and Reinertsen 1998; kavadias and Loch, 2004). Predictive modelling approaches documented in existing literature (Armstrong, 1985; Field, 1999; Witten, 2001) do not meet the requirements imposed by the NPD environment. This research sets out a new improved means of generating resource information, such that the outputs of existing tools will be improved.

Attempts were made to create a predictive planning model following a standard, well established approach using past project data. Although even at the outset there was an understanding that the volume of data was not sufficient for creating a robust model, it was thought that the case study company had reasonable data for 400 past projects. Once investigations ensued, it emerged that this was not the case and that data was in fact only available for around 30 past projects. This was not enough to provide any insight into resource information using traditional analysis methods (Field, 1999). Re-evaluation of the research approach was required and a more innovative solution was sought through necessity. As no data was available, the only other option was to gather the estimations of managers to create the predictive model. Design of Experiments provided a structured and logical framework upon which a process for doing so could be developed. No evidence could be found of Design of Experiment being used to model tacit knowledge or estimations. In fact, all literature reviewed discussed Design of Experiments that was informed using either physical measurements or simulated data.

7.1.2 CONTRIBUTION 2:

Design of Experiments is applied in a novel way to develop a predictive model of resource demand per project. The novel method features estimations rather than actual data and hypothetical project scenarios in place of experiments.

The specific combinations of data required for the application of Design of Experiments means retrospective data is unlikely to be available – hence the need to conduct planned experiments or simulate data. In this instance estimates were used in place of actual data and designed hypothetical project scenarios in place of designed experiments.

Creating a predictive model for resource information in this way has not been documented in existing literature. Hockman (1993) and Sreenivas (1998) describe the limited application of Design of Experiments and call for wider adoption of this powerful method.

7.1.3 CONTRIBUTION 3:

This research explores the link between project characteristics and resource demand.

This contribution relates to research question 2 and the mechanics driving the predictive model. This relates to predictive resource modelling in NPD irrespective of the method used. Existing methods are based upon either product characteristics (Madachy and Brown, 2000; Boehm et al., 2000; Boehm and Valerdi 2008.), or events and activities (Kerzner, 2009). Neither of which are suitable in an NPD context. The characteristics of a project are in fact, the main resource demand driver. Project type (Anderson and Joglekar, 2005) is an assimilation of project characteristics into stereotypes or groups but not an accurate or robust reflection of the effect of changes in combinations of characteristics upon resource requirements.

Existing predictive models are based on correlations between product characteristics and resource demand/ project duration however, in the context of this research the physical characteristics of properties were not a valid start point for exploring correlations. (This would also be true in any other NPD environment when the physical qualities of the product do not differ greatly between one offering and another or they are simply unknown).

With product characteristics unsuitable, events and activities are often used to plan resource requirements in practice however, these require careful thought in their own right and are associated with more detailed project knowledge than is available at the very outset. The very process of creating an activities and events based plan and resource profile requires exploring some of the creative possibilities.

Project characteristics are refers to only as project type in the literature, with no in-depth discussions about what this really means or looks like in terms of generating resource profiles. The approach developed through this thesis provides a means of really exploring the project characteristics driving resource demand and takes things to a more detailed level than a very general "project type".

7.2.1CONTRIBUTION TO PRACTICE

This research has provided industry with an implementable solution to the resource planning problem in NPD in the form of a process for creating a predictive resource planning model. The output of the process will provide superior resource information than that of the process currently used when compared on four different metrics documented in Table 54.

Table 54 – The resource information derived from the new modelling process compared to the original process

Criteria	Original process	New approach
Accuracy	Unknown accuracy. No traceability to learn from or correct mistakes.	Results suggest that the new approach is comparable to the estimations of managers. In DePuy where original estimates were inaccurate the model offers improved accuracy, In Scottish Water where accuracy of original estimations was high, the model Design of Experiments not perform quite as well.
Timeliness	3 – 6 months to gather cross functional resource data.	Seconds to estimate resource for each project in portfolio. Estimates across functions generated instantaneously.
Transparency	None – unclear what was driving the estimations.	In addition to the facility to predict, there is a much better

	Perceived to be agendas and biases in the decision making process.	understanding of the factors driving resource demand per functional group. The Scottish Water results show how well the modelling process employed captures the considerations of managers.
Consistency	Different managers making estimations each cycle, different assumptions and perceptions.	The model produces the same results no matter who is controlling it. Portfolio managers will be able to freely run "what-if" scenarios without relying upon project managers and functional leaders for input. The standard deviation of errors in predictions is comparable to the spread of errors in original estimations.

Although the predictive model developed is specific to DePuy or Scottish Water, the process demonstrated has potential to be applied with similar success in other business environments.

The model is currently being applied at a portfolio planning level rather than a project planning level. At a project planning level, more information is known, more experts are involved. Consequently the benefits of the model and confidence in the model (without past project data to support) are decreased whilst the resistance to the model (as a barrier to political influence) is increased. Without actual data, no convincing argument can developed for or against using the model at a project planning level.

On complex projects with unfamiliar or undefined scope, the model could be used to provide some guidelines or to inform the estimation process. The transparency of the model and the influence of each of the factors lend itself well to this sort of application. As the project progresses and the scope are defined the model may become less useful. In the case of complex projects, it is likely to be most useful at the early stages and for portfolio level planning.

On routine projects with familiar and defined scope the model could be used to provide an outline project plan or to provide a reasonably accurate estimate valid throughout the duration of the project. This would have the benefit of saving planning time and introducing consistency.

In addition to generating new estimates, the process of developing the model could also be used to assess the abilities of existing estimators. Who provides good, bad, indifferent estimates consistently and which factors do they consider? Once a "good" estimator has been identified, the model could be used as a training aid to provide guidance for less experienced estimators.

7.2 RESEARCH QUALITY

Thus far, this chapter has discussed the contributions of the research work however, if these contributions are to be given merit it is important that they are critically assessed and shown to be valid and of quality.

During the development of the research approach criteria were established to evaluate the output. The criteria selected were chosen from case-study research. The contribution of this work will be assessed according to four criteria: construct validity, internal validity, external validity and reliability.

7.2.1 CONSTRUCT VALIDITY

Construct validity determines how well a test or experiment lives up to its claims: the extent to which the study relates to an accurate observation of reality (Denzin and Lincoln 2011).

Several methods can be used to ensure construct validity. One method frequently used in management research is tying the research construct to existing literature. This research departs from traditional approaches to resource planning and as such, this method Design of Experiments not serve to validate the construct. Other means of validating the construct which have proved more achievable are:

- ✓ **Establishing a chain of evidence** (Yin, 2008) although literature cannot support the construct, a logical argument moving away from existing research is presented. Existing methods have been "disproven" through logical arguments.
- ✓ **Using multiple sources of evidence** (Denzin and Lincoln 2011; Stake 1995) - A positivist research stance supported by interpretivist and constructivist stances is the one way to ensure construct validity. Actual data, estimations, statistical analysis of estimations and qualitative data have been used to describe the relationship between project characteristics and resource demand.
- ✓ **Thick descriptions** – The development of the modelling process has been discussed in detail including detailed descriptions of how failed attempts using traditional methods spurred on the development of a new process.

7.2.1.2 INTERNAL VALIDITY

Internal validity is the logical testing of the relationships between variables in the research. Based on ideas by Popper (1956) rather than trying to provide the hypothesis, the researcher can attempt to disprove all alternatives (Silverman, 2005). Techniques such as cross case analysis and open discussion regarding the assumptions can help establish internal validity. Deviant cases should also be included in the analysis of the hypothesis (Silverman 2009).

- ✓ **Disproving alternatives** - The alternative possible constructs for models are discussed in detail (events and activities and product characteristics).
- ✓ **Cross case analysis** - multiple case studies were conducted. The duration aspects of the model have been shown to work across all cases.
- ✓ **Reporting deviant results** - all case studies worked well. Design and Test are two deviant examples. Additionally, the Scottish Water models suggest that the resource aspects of the models may be missing some factors or that the wrong factors have been explored.
- ✓ **Open discussion regarding assumptions** - Throughout the research process, findings, assumptions and plans were reported to key industry stakeholders on a weekly basis via a project update email. This allowed any discrepancies in opinion or assumptions to be quickly highlighted and brought to the fore for discussion. Findings from each method and case study were given to participants who were encouraged to feedback questions and comments at each stage. This helped inform and strengthen the research process. For example when the results of the "which project characteristics impact resource demand" were discussed with respondents it emerged that there were likely to be interactions between characteristics: something that the researcher had not initially considered. Ultimately this type of feedback helped develop a more robust solution as the correct issues could be addressed.

7.2.1.3 EXTERNAL VALIDITY

External validity is concerned with the applicability of the research findings beyond the immediate case. Although case study research is usually applied to study the effects of phenomenon within the context of a particular case (Coughlan and Coghlan 2002), it is important that the domain in which the findings can be generalised is clear (Yin, 2008). In the context of this research, the specific relationships described in each model are very specific to the functional group within DePuy (and perhaps only valid at a certain point in time. As the business changes the specific relationships between variables may change). What is very generalizable is the method is used to establish the nature of the relationships. Such a method could be used in any conceivable context to develop a predictive model providing expert opinion is available to provide estimates and hypothetical project scenarios can be described.

This research process has been applied in two very different contexts with positive results in each. Although the Scottish Water model is not quite as useful (it is not as accurate as manager's estimates) it Design of Experiments serve other purposes in that it provides insight into the factors driving resource demand.

Although the process may not yield an accurate model each time it is applied, it will provide information about the perceived impact of the factors included: an indication of whether the factors are significant or otherwise.

7.2.1.4 RELIABILITY

Reliability is concerned with the repeatability of the research process. Research is reliable when the process of the study can be repeated at different points in time, by different researchers in the same environment and the same conclusions can still be drawn (Yin, 2008). It is unlikely that exactly the same correlations would be found a month from now, a year from now or two years from now if the study were to be conducted again in DePuy. It is expected that approximately the same results would be achieved in the short term although in the longer term, as the business changes it is expected that results would change.

The process followed has been documented step-by-step. Both simple process instructions and in-depth analysis have been provided to enable repeatability by other researchers in other environments and by employees of DePuy should they wish to extend the model to other functional groups.

7.2.1.5 SUMMARY OF QUALITY EVALUATION

Table 55 summaries the evaluation of this research against each of the criteria described in section 7.2. The research has been shown to meet each of the criteria. This leads to the conclusion is that the research is reliable and valid.

Table 55 – Summary of quality evaluation

Quality criteria	Was it satisfied?	How?
Contribution to knowledge	Yes	The development of a process for applying Design of Experiments (Design of Experiments) to modelling the tacit, considerations used by managers to make resource estimations. Design of Experiments is applied in a novel way to develop a predictive model of resource demand per project. The novel method features estimations rather than actual data and hypothetical project scenarios in place of experiments. This research explores the link between project characteristics and resource demand.
Contribution to practice	Yes	Predictive resource planning model that produces resource information that offers potential for improvements on four measures: Accuracy, timeliness, consistency, transparency. A process of developing the model. (Step-by-step instructions).
Rigorous research design	Yes	Through demonstration of construct validity, internal validity, external validity and reliability.
Construct validity	Yes	Triangulation of perspectives Chain of evidence established Structured reporting
Internal validity	Yes	Cross case-study analysis Developing a research framework Subjecting assumptions to public testing Comparison with past project data.
External validity	Yes	External case study Comparison with past project data
Reliability	Yes	Cross case analysis Structured reporting

7.3 REFLECTION UPON METHODOLOGICAL APPROACH

Mingers and Brocklesby provide a framework for developing a methodology to facilitate research about or involving an "intervention" rather than a specific methodology. However, existing pragmatic methodologies are similar in that they do not force a singular perspective but instead encourage consideration of multiple viewpoints. Examples of such methodologies are: Action Research (Coughlan and Coglan, 2002); Procedural Action Research (Platts 1993); and Design Research Methodology (DSM) (Blessing, 2009).

There are links and differences between each of the methods described and the approach adopted. Each methodological approach and the links to Mingers and Brocklesbys framework will be discussed in turn.

7.3.1 ACTION RESEARCH

Action research has four key aspects.

1. **Action research is about research in action, rather than research about action**. This aspect is applicable to the research methodology being employed: We are not interested in observing a company implement a change or action, rather we are interested in informing and researching the nature of the action and the process of developing the action.
2. **Action research is participative.** Although this research project requires the input of people within the company through surveys, interviews and data collection. They are not involved in the plan, act, and evaluate cycle. Although the researcher adopted the role of planner at one point (with the sole purpose of deepening understanding) they are not part of the process being studied. Similarly, company employees do not have the breadth of perspective necessary to understand the various nuances of planning issues at each level.

3. **Research is concurrent with action.** Rather than work with a plan, act, evaluate cycle this research work choose to get to the root of the problem and make one larger over-riding change. Due to time constraints, the effects of this change have not been evaluated. Resource planning in DePuy is quite emotive. Incremental improvements or small and improvement initiatives have been attempted previously on numerous occasions creating imitative fatigue and general scepticism. To take any action in an experimental manner, without evidence of the benefits would be a high risk strategy for DePuy.
4. **A sequence of events and an approach to problem solving.** Although key, over-riding phases were adhered to; no specific sequence of events could be prescribed a priori, especially early on. Perhaps later in the research when various predicting modelling methods were applied the action research cycle could be said to have occurred. A plan was made to apply each method, the method was attempted and results were evaluated before a plan to attempt a new method was derived and the cycle repeated.

Although the approach taken has some similarities to action research, the non-participatory aspect and the lack of concurrency with action conflict with the action research approach.

Action research methodology has potential to be applied to the later stage of the Mingers and Brocklesby framework. At this stage participation is imperative, the research would be concurrent with action and the action and development of approach would be simultaneously evolving. The Mingers and Brocklesby framework could conceivably be applied to each cycle of the action research plan, act process although evaluation is not a feature and would have to be conducted separately.

7.3.2 PROCEDURAL ACTION RESEARCH

Procedural Action Research (PAR) is a research methodology used to develop strategic formulations. Where other approaches may not be theoretically or philosophically sound, PAR links the processes with existing theoretical frameworks, encourages adequate empirical testing and promotes useable research results. The methodology described by Platts (1997) is comprised of three stages:

1. Creating the strategy formulation process (through literature review, interviews with industry and consultants, report back).
2. Testing and refining the process through application in a small number of companies. Three things need to be considered in this phase: the involvement of the researcher, the consistency of the process and the choice of sites to be studied.
3. Investigating the wider applicability through survey.

PAR is in some senses very similar to the approach adopted through this research work. The methods used in steps one and two are similar to those employed through the framework derived from Mingers and Brocklesby's work. The key difference is that PAR is used specifically to help develop strategy whereas the nature of the output or research goal in this research work was less specific and more uncertain at the outset. What is useful and relevant are the considerations that must be given during stage 2. The consistency of the process and the choice of sites to be studied will be considered during the case-study phase documented in Chapter 5. The involvement of the researcher is already defined at this point. Surveying wider industry for the applicability of the approach has not been carried out as part of this thesis work. However, to further verify the generalizability of the approach, it could be a useful "future work" step.

7.3.3 DESIGN RESEARCH METHODOLOGY

Design Research Methodology (DRM) is a methodology for research to improve design. That is, where there is a need to develop knowledge regarding improving design or to support design (i.e. how to proceed with design in an efficient and effective way) (Blessing, 2009). Although this research centres on planning the NPD process, it is not the intention that it is exclusively applicable to NPD environments. Success criteria for DRM centre on the notion of a successful or unsuccessful product being created. Although product success is undoubtedly linked to the resource planning process in development environments, the link could be said to be tenuous and at best difficult to measure due to the vast number of other factors involved.

DRM differs from the action research methods in that it specifically sets out to uncover the research areas most likely to be practically and academically worthwhile and realistic. It is similar to Mingers and Brocklesby's framework in that it accommodates the use of different methods and encourages both qualitative and quantitative perspectives. The DRM framework is presented in Figure 86.

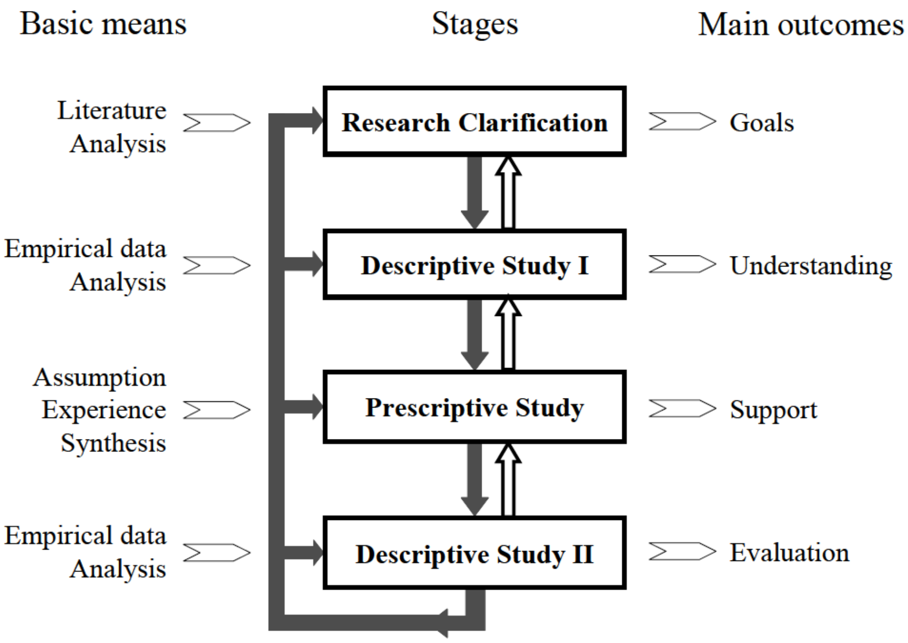


Figure 85 – The DRM framework

The framework shown in Figure 86 echoes the cycles of iteration that were employed in this research work. Specifically, the cycles between literature and understanding of the as-is situation in the business although this early work was primarily based upon assumptions, experience and synthesis rather than empirical data analysis. The one component included here which is lacking in the action research methodologies is prescribed room to understand the problem situation. Research clarification involves searching the literature for factors that:

> *"Influence task clarification and product success, in particular those factors that link the two together. Based on the findings, an initial description of the existing situation is developed, as well as a description of the desired situation, in order to make the assumptions underlying each of the descriptions explicit".*

(Blessing, 2009).

This short stage of DRM covers the first three stages of the Mingers and Brocklesby Framework. This first stage is conducted prior to forming a goal and followed by investigation of designers at work. It seems much reasonable to form the goal and a vision of the "to-be" situation once the subtleties of the problem are understood. Especially given the lack of practical relevance of what is reported in literature. However, upon reflection one weakness of the way in which the Mingers and Brocklesby approach has been applied and an action that would be recommended should the work be carried out again would be to provide greater clarification and separation of insights from literature and insights from industrial observation thus allowing clearer traceability of arguments and evidence rooting the new approach in existing theory. However, caution would be advised as completely separating the two approaches could result in diluted or blinkered insights or insights of less practical value.

In the prescriptive study stage of DRM, factors in the environment are manipulated and the effect observed. This concept Design of Experiments not have any bearing upon the research approach taken. Perhaps in the final "action" stage this may be of relevance but other important stages have been missed, namely the development of the solution or analysis and assessment of the various options.

Although DRM may be a suitable methodology for design research, in this context it is not a suitable option. One key, useful concept is the notion of describing the "as-is" and "to-be" situations although the researcher feels that a full understanding of the system form a theoretical and practical point of view needs to be established before decisions are made regarding the best course of action.

7.3 LIMITATIONS

Due to resource and time constraints there are natural limitations to what can be achieved within a research process. Recognising the limitations strengthens the validity of the findings and the reliability of the process. Limitations in this work relate to the results and the methodology. Each is discussed separately.

7.3.1 LIMITATIONS OF THE RESEARCH RESULTS

The contribution offered by this research is novel and moves away from traditional approaches to resource planning in a number of ways. The experimental approach taken is both a strength and weakness of the research: a strength because it has provided insights into resource information generation and a practical solution. Furthermore it has demonstrated potential of a new predictive method which could be used in contexts outside NPD resource planning. However, it also makes it difficult to relate the findings of the work with existing literature.

Necessity is the mother of invention and it was necessity that drove the researcher to apply Design of Experiments in this context. The researcher is not an expert in statistics and had only very limited experience of Design of Experiments. Consequently, in some instances the approach taken was naïve and did not demonstrate considered knowledge of the method (for example applying Taguchi with only 8 runs). This did serve to show the limitations of the approach for example – if the relationship between project characteristics and resource is thought to be non-linear and more than three levels are used then more than 8 hypothetical project scenarios will be required. Perhaps this seems obvious but it was only through testing that the researcher could be sure. This research merely indicates that Design of Experiments is a valid process; it Design of Experiments not suggest that the process of analysis is the optimal one. There are a number of process variables that could have an effect upon the accuracy of the model. A limitation of the research is that it is unclear what constitutes an optimal process for model development. Potential variations for each process step are described in Table 56.

Table 56 – Process variables. A limitation of work is the lack of clarity about which process variables provide the best models.

Variable	Potential variations
Describe – factors included	A number of experiments could be used. A screening design followed by more in-depth designs with fewer factors.
Design - Experimental design	More runs could potentially be more accurate although it is possible that concentration could fade with more runs.
Collect	Number of respondents Multiple corner points How to select best respondents How best to get respondents on board
Fit	Tuning method

The second limitation of the work is the lack of past project data against which to verify the model. A larger volume of data would have provided more reliable indication of the accuracy of the model and validity of the process.

A third limitation is the lack of time to observe and report the implications of implementing the improved resource information generation method upon the resource planning process as a whole.

7.3.2 LIMITATIONS OF THE RESEARCH METHODOLOGY

A key limitation of the study is the lack of "actual" resource data for model verification. With the exception of the external case study company, no such data existed. A long-term data gathering process is required to verify this aspect of the model fully. The data from Scottish Water served to show that the resource aspect of the model is perhaps not accurate. A limitation of the methodology, forced through limited resources is the focus upon demand rather than a combination of or separate views of demand and capacity.

The process was repeated with just one external case study company; ideally for triangulation at least one further case-study company would be used. Additionally, the case study company was from a very different industry, although this shows the range of environments the process could be applied in it Design of Experiments not provide depth of understanding about NPD specific contexts.

7.3 FUTURE WORK

As this research describes how an existing tool can be applied in a new way there are a range of opportunities for future work. These can be broadly categorised as: work exploring the optimisation of the Design of Experiments predictive modelling process as is described in this research; work exploring the contexts the process could be applied in and limitations and finally; work exploring how Design of Experiments models could be adapted and used in practice.

7.3.1 OPTIMISATION OF THE DESIGN OF EXPERIMENTS PROCESS

Various aspects of the Design of Experiments process described in Chapter 5 could be better understood. Applying the process with different designs and factors, using different numbers of respondents perhaps arranged in different ways and alternative tuning mechanisms all provide opportunities for optimising the statistical aspects. There is also an opportunity to explore how the process is viewed by managers and business leaders: how to engage them early on and how to ensure that they understand and buy-into the process. This seems to have an impact upon the consideration they give to responses and the accuracy of the estimations they provide.

7.3.2 WORK EXPLORING CONTEXTS FOR APPLICATION

The next logical steps are to develop a model based upon factors impacting capacity and to find sources of actual data to verify models against.

It is possible that the verified duration aspect of the model can be applied in a number of planning contexts for example construction or shipbuilding.

7.3.3 WORK EXPLORING PRACTICAL USE

The effects of the new approach to resource information generation upon the resource planning process still remain unobserved.

Once the model has been implemented in DePuy, it is possible that the business will change over time. The factors considered significant just now may not have the same significance in years to come, different factors may become important. One possibility solution would be to use the Design of Experiments model to train an Artificial Neural Network (ANN) and update the network (once trained) with actual project data. This could potentially be a learning model with ever increasing accuracy.

7.4 REFLECTION ON THE RESEARCH PROCESS

The experience of this research project has been stretching, challenging and interesting. It has helped immensely that I have enjoyed the systems engineering aspects of the research, the subject matter, the challenges of conducting research in industry and working with the people in DePuy.

7.4.1 RESEARCH IN INDUSTRY

Conducting research in industry provided the most rewarding and challenging dimension of the work. Managing the balance between industry's expectations for fast, implementable results and the academic pressures for theoretically sound approaches was at times difficult.

Managing expectations was challenging but not quite as difficult as understanding and managing politics within DePuy, something I was completely naïve to until I realised I was handling it all incredibly badly. In retrospect and with lessons learnt the cogs of the whole process could have been aided with a little more political savvy on my part. One of the major lesson was telling people they are wrong (*even when they are*) Design of Experiments not help.

7.4.2 ACADEMIC CHALLENGES

Having made the decision to develop a predictive model at such a late stage in the project and being so convicted that it would provide the best route forward gave me little room for turning back. When the data was not available to make regression analysis work, there was a degree of panic and disappointment. But, strangely enough this turned out to be the best thing that could have happened. Necessity drove the project in a more innovative, interesting and useful direction.

7.4.3 PERSONAL CHALLENGE

By far the most profound lessons have been personal. I feel I have been challenged and stretched. Rather than becoming brittle with the various testing times, it is testament to the gracious patience and example of the people around me that I managed to learn valuable lessons.

If there has been one key theme to the research experience it is this: adversity and tough times are to be embraced rather than cowered away from. With a bit of patience, reflection and perseverance they can produce growth and better results. And they make life more interesting.

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APPENDICES FOR THE ENG.DOC THESIS

"A SYSTEMS APPROACH TO RESOURCE PLANNING IN NEW PRODUCT DEVELOPMENT"

By

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A thesis submitted to the University of Strathclyde

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November 2012

GUIDE TO READING APPENDICES

SIX APPENDICES ACCOMPANY THE ENG. DOC THESIS "A SYSTEMS APPROACH TO RESOURCE PLANNING IN NPD". THE APPENDICES ALL RELATE SPECIFICALLY TO THE NOVEL PROCESS OF APPLYING DOE TO THE DEVELOPEMNT OF A PREDICTIVE RESOURCE MODEL. THE PROCESS IS DIVIDED INTO SEVEN PHASES: DESCRIBE, DESIGN, COLLECT, FIT, PREDICT, VERIFY AND IMPLEMENT.

THE NUMBER OF EACH APPENDIX, THE PHASE IT REFERS TO, AND A BRIEF DESCRIPTION OF THE CONTENT IS PRESENTED IN TABLE 1 BELOW.

APPENDICES ARE NUMBERED CHRONOLOGICALLY, DEPENDING WHERE IN THE PROCESS THEY REFER TO (WHERE IN THE THESIS THEY APPEAR FIRST). "A" AND "B" LABELS HAVE BEEN ASSIGNED. "A" REFERS TO APPEDICES RELATING TO DEPUY AND "B" REFERS TO SCOTTISH WATER.

TABLE 57 - APPENDIX NUMBERS AND DESCRIPTION

PHASE	APPENDIX NUMBER(S)	DESCRIPTION OF CONTENT
DESCRIBE	1A, 1B.	FACTORS IMPACTING RESOURCE DEMAND/ PROJECT DURATION PER FUNCTIONAL GROUP.
DESIGN	2A, 2B	DESIGNED SURVEYS PER FUCNTION.
COLLECT	3A 3B	SURVEY RESPONSES
FIT	4	FULL ANALYSIS OF PROJECT MANAGEMENT MODEL
	5A 5B	COEFFICENTS PER FUNCTION
PREDICT	6A, 6AA	MODEL BUILDING GUIDEANCE SLIDES, CREATING AN EXCEL VERSION OF THE MODEL
VERIFY	UPON REQUEST ONLY.	PROJECT CATAGORISATION AND VERIFICATION DATA ELECTRONIC COPY AVAILABLE UPON REQUEST.

APPENDIX 1 – FACTORS IMPACTING RESOURCE DEMAND/ PROJECT DURATION PER FUNCTIONAL GROUP

1A - RESULTS FOR DEPUY

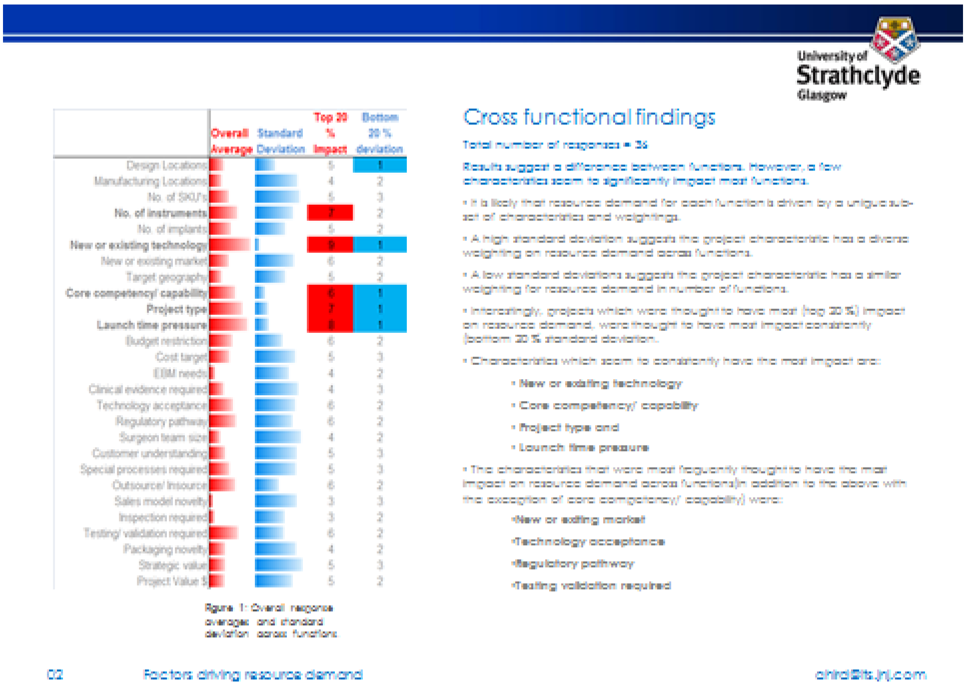

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Figure 2: Averages per function contributing to the overall cross-functional average.

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Operations

Total number of responses = 11

- Characteristics which seem to have the most impact (top 20 %) upon resource demand in Operations are:
  - No. of SKU's
  - No. of implants
  - New or existing technology
  - Project type
  - Launch time pressure and
  - Special Processes required
- The characteristics that were most frequently thought to have the most impact on Operations resource (addition to the above) were:
  - Manufacturing locations
  - No. of instruments
  - Budget restriction
  - In source/ Outsource
  - Testing/ Validation required and
  - Packaging novelty
- There was most variation in results for manufacturing location , no. of instruments, core competency/capability, budget restriction and regulatory pathway. This could indicate that there are likely to be interactions between these characteristics and others.
- Other factors that were suggest to influence resource demand in operations were 1)the quality/quantity of front end work and 2) project management use across the project. Both were ranked as having a high impact.

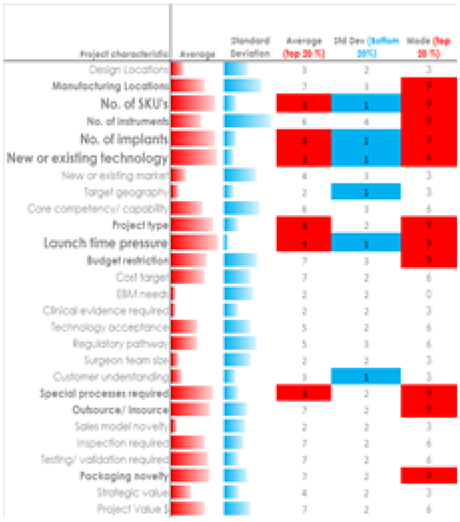

Figure 3: Factors affecting Operations resource demand

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Testing

Number of responses =2

Project characteristic	Respondent 1	Respondent 2	Average	std dev	Top 20 %
Design Locations	3	3			3
Manufacturing Locations	3	3			3
No. of SKU's	6	3			4.5
No. of Instruments	9	9			9
No. of Implants	6	3			4.5
New or existing technology	9	9			9
New or existing market	3	6			4.5
Target geography	6	3			4.5
Core competency/ capability	6	6			6
Project type	9	9			9
Launch time pressure	9	9			9
Budget restriction	6	6			6
Cost target	6	6			6
EBM needs	3	3			3
Clinical evidence required	3	3			3
Technology acceptance	9	9			9
Regulatory pathway	6	9			7.5
Surgeon team size	6	9			7.5
Customer understanding	6	9			7.5
Special processes required	6	9			7.5
Outsource/ Insource	6	6			6
Sales model novelty	3	3			3
Inspection required	3	6			4.5
Testing/ validation required	9	9			9
Packaging novelty	3	3			3
Strategic value	6	6			6
Project Value $	6	6			6

Figure 4: Factors affecting Testing resource demand

• Characteristics which seem to have the most impact (top 20 %) upon resource demand in Testing are:

- **No. of Instruments**
- **New or existing technology**
- **Project type**
- **Launch time pressure**
- **Technology acceptance**
- **Testing/ Validation required**

•All factors that ranked in the top 20 % in terms of there impact upon resource planning were considered to have the same level of impact by both respondents.

• Regulatory pathway, Surgeon team size, Customer understanding and special processes all ranked in the top 30 % of characteristics impacting resource demand. However there was less agreement about these factors between the two respondents.

• Overall, between the two respondents there was no dramatic difference in scores. Scores only differed by one level. The differences could be down to interactions existing between factors and different weightings being required in different situations.

• Other suggested factors that may influence Testing resource demand :

- Business team/ mgmt priority
- Urgent regulatory response required
- Potential field action
- Urgent production issue

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Marketing

Number of responses =2

Project characteristic	Respondent 1	Respondent 2	Average	Standard dev	Top 20 %
Design Locations	6	6			6
Manufacturing Locations	0	3			2
No. of SKU's	3	3			3
No. of Instruments	6	3			5
No. of Implants	6	3			5
New or existing technology	9	9			9
New or existing market	9	6			8
Target geography	6	3			5
Core competency/ capability	3	6			5
Project type	9	6			8
Launch time pressure	9	9			9
Budget restriction	6	9			8
Cost target	6	3			5
EBM needs	3	3			3
Clinical evidence required	3	3			3
Technology acceptance	3	3			3
Regulatory pathway	3	6			5
Surgeon team size	6	9			8
Customer understanding	3	9			6
Special processes required	3	0			2
Outsource/ Insource	3	3			3
Sales model novelty	3	6			5
Inspection required	3	3			3
Testing/ validation required	3	3			3
Packaging novelty	3	3			3
Strategic value	9	6			8
Project Value $	3	9			6

Figure 5: Factors affecting Marketing resource demand

• Characteristics which seem to have the most impact (top 20 %) upon resource demand in marketing are:

- **New or existing technology**
- **New or existing market**
- **Project type**
- **Launch time pressure**
- **Budget restriction**
- **Surgeon team size**
- **Strategic value**

•There is some variation between responses from the two respondents. This is true for both significant and non significant characteristics.

• This could point towards high levels of interaction between project characteristics in terms of the way they impact resource demand.

• Design location, Customer understanding and Project Value were in the top 30 % of project characteristics impacting marketing resource demand.

• There was more agreement between respondents about which factors had low impact upon resource demand.

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Design

Number of responses =7

- Characteristics which seem to have the most impact (top 20 %) upon resource demand in Design are:
  - **No. of SKU's**
  - **No. of Instruments**
  - **New or existing technology**
  - **Core competency/ capability**
  - **Launch time pressure**
- In addition to the above, **Design locations** and **No. of implants** were the characteristics most frequently considered to have "high impact" on design resource demand.
- There was a wide variety of responses from the 7 participants suggesting that there are high levels of interaction between project characteristics.
- The no. of implants, the project type and the decision to in source/outsource were in the top 30 % of project characteristics impacting resource demand.
- Technology acceptance, Regulatory pathway and Testing/ validation required were in the top 40 % of project characteristics impacting resource demand.
- Other suggested factors that were suggested to impact resource demand in design include:
  - Design Verification
  - Resource support from management
  - Scope Change
  - Team member understanding of project priority
  - Realistic timeline support from management

Project characteristic	Average	Standard deviation	Average (top 20 %)	Std dev (bottom 20 %)	Mode (Top 20%)
Design Locations			6	3	9
Manufacturing Locations			3	3	3
No. of SKU's			7	3	9
No. of instruments			7	3	9
No. of implants			6	4	9
New or existing technology			7	2	9
New or existing market			4	2	3
Target geography			3	2	3
Core competency/ capability			8	1	9
Project type			6	2	6
Launch time pressure			8	2	9
Budget restriction			5	3	6
Cost target			5	3	6
EBM needs			3	2	3
Clinical evidence required			4	3	3
Technology acceptance			6	2	3
Regulatory pathway			6	2	3
Surgeon team size			3	3	3
Customer understanding			3	2	3
Special processes required			5	1	6
Outsource/ Insource			6	2	6
Sales model novelty			3	2	3
Inspection required			4	1	3
Testing/ validation required			6	2	3
Packaging novelty			3	2	3
Strategic value			4	2	3
Project Value $			4	2	3

Figure 6: Factors affecting Design resource demand

07 Factors driving resource demand ahird@its.jnj.com

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Development

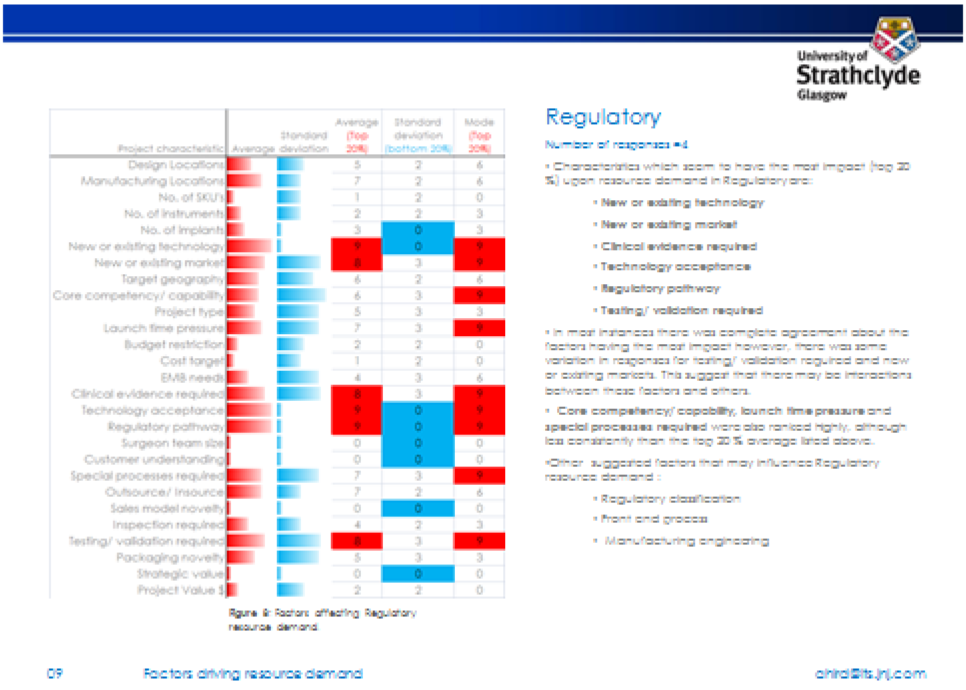
Number of responses =6

- Characteristics which seem to have the most impact (top 20 %) upon resource demand in Development are:
  - **No. of Instruments**
  - **New or existing technology**
  - **Core competency/ capability**
  - **Project type**
  - **Launch time pressure**
  - **Regulatory pathway**
- **No. of implants** was also frequently ranked as having high impact upon development resource demand.
- Overall, there was general agreement about the factors having the most impact.
- Overall, there was a wide variety of responses from the 6 participants suggesting that there are high levels of interaction between project characteristics.
- Special process required and testing/validation required were in the top 30 % of project characteristics impacting resource demand.
- No. of SKU's and Clinical evidence required were in the top 40 % of project characteristics impacting resource demand.
- Other suggested factors that may influence Development resource demand :
  - Scope Change
  - Resource support from management
  - Team member understanding of project priority
  - Realistic timeline support from management

Project characteristic	Average	Standard deviation	Average (top 20%)	Std dev (bottom 20 %)	Mode (Top 20 %)
Design Locations			5	3	3
Manufacturing Locations			4	3	6
No. of SKU's			6	3	6
No. of instruments			7	3	9
No. of implants			5	3	9
New or existing technology			7	3	9
New or existing market			5	2	6
Target geography			3	2	3
Core competency/ capability			6	3	9
Project type			7	3	9
Launch time pressure			8	3	9
Budget restriction			4	3	3
Cost target			4	2	6
EMB needs			4	2	3
Clinical evidence required			6	3	3
Technology acceptance			5	2	3
Regulatory pathway			6	3	9
Surgeon team size			4	2	6
Customer understanding			4	2	6
Special processes required			6	2	6
Outsource/ Insource			5	2	6
Sales model novelty			3	2	3
Inspection required			3	1	3
Testing/ validation required			6	2	6
Packaging novelty			4	2	6
Strategic value			4	2	6
Project Value $			4	2	6

Figure 7: Factors affecting Development resource demand

08 Factors driving resource demand ahird@its.jnj.com



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Regulatory

Number of responses =4

- Characteristics which seem to have the most impact (top 20 %) upon resource demand in Regulatory are:
  - New or existing technology
  - New or existing market
  - Clinical evidence required
  - Technology acceptance
  - Regulatory pathway
  - Testing/ validation required
- In most instances there was complete agreement about the factors having the most impact however, there was some variation in responses for testing/ validation required and new or existing markets. This suggest that there may be interactions between these factors and others.
- **Core competency/ capability, launch time pressure** and **special processes required** were also ranked highly, although less consistently than the top 20 % average listed above.
- Other suggested factors that may influence Regulatory resource demand :
  - Regulatory classification
  - Front end process
  - Manufacturing engineering

Project characteristic	Average	Standard deviation	Average (Top 20%)	Standard deviation (bottom 20%)	Mode (Top 20%)
Design Locations			5	2	6
Manufacturing Locations			7	2	6
No. of SKU's			1	2	0
No. of Instruments			2	2	3
No. of Implants			3	0	3
New or existing technology			9	0	9
New or existing market			8	3	9
Target geography			6	2	6
Core competency/ capability			6	3	9
Project type			5	3	3
Launch time pressure			7	3	9
Budget restriction			2	2	0
Cost target			1	2	0
EMB needs			4	3	6
Clinical evidence required			8	3	9
Technology acceptance			9	0	9
Regulatory pathway			9	0	9
Surgeon team size			0	0	0
Customer understanding			0	0	0
Special processes required			7	3	9
Outsource/ Insource			7	2	6
Sales model novelty			0	0	0
Inspection required			4	2	3
Testing/ validation required			8	3	9
Packaging novelty			5	3	3
Strategic value			0	0	0
Project Value $			2	2	0

Figure 8: Factors affecting Regulatory resource demand

09 Factors driving resource demand ahird@its.jnj.com

1B – SCOTTISH WATER

PM resource factors (1of 3)

Project cost – LBE
Project cost – design
Project cost – construction
PMO geographical location
Construction Site geographical location
Procurement method
Feasibility process
Development process
Commissioning process
Stakeholder liaison
Environmental factors
Land factors

Scottish Water
Always serving Scotland

PM resource factors (2 of 3)

Health safety and welfare factors
Project complexity (e.g. black box design)
Planning factors
Resource availability
Resource competency
Role of project planners
Role of commercial (quantity surveyors)
Site Investigation
Framework Suppliers
Mini –competition procurement
Project reporting
Project steering group

Scottish Water
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PM resource factors (3 of 3)

Stage & gate process
PM competency
PM workload
PM portfolio
PMO
Contractor selection
Contractor competency
Designer Competency
Staff costs
Overhead costs
Seven stage process
Project delays / on hold
Change of scope
Project documentation (ISO 9001)

Scottish Water
Always serving Scotland

APPENDIX 2 A– SURVEY DESIGN

TABLE 58 – SURVEY DESIGN FOR PROJECT MANAGEMENT AND BIO-ENGINEERING

SCENARIO	NUMBER OF IMPLANTS	NUMBER OF INSTRUMENTS	DESIGN COMPLEXITY	DESIGN NOVELTY	MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	FRONT END - GATE 1	GATE 1- CHARTER	CHARTER -GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7- GATE 8
1	LOW	LOW	SIMPLE	HIGH	NOVEL	DURATION (MONTHS)	*N MONTHS*						
						RESOURCE (FTE'S)	*N FTE'S*						
2	HIGH	LOW	SIMPLE	LOW	STANDARD	DURATION (MONTHS)							
						RESOURCE (FTE'S)							
3	NONE	HIGH	SIMPLE	LOW	NOVEL	DURATION (MONTHS)							
						RESOURCE (FTE'S)							
4	HIGH	HIGH	SIMPLE	HIGH	STANDARD	DURATION (MONTHS)							
						RESOURCE (FTE'S)							
5	LOW	LOW	COMPLEX	HIGH	STANDARD	DURATION (MONTHS)							
						RESOURCE (FTE'S)							
6	HIGH	LOW	COMPLEX	LOW	NOVEL	DURATION (MONTHS)							
						RESOURCE (FTE'S)							
7	NONE	HIGH	COMPLEX	LOW	STANDARD	DURATION (MONTHS)							
						RESOURCE (FTE'S)							

8	HIGH	HIGH	COMPLEX	HIGH	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)							

TABLE 59 – SURVEY DESIGN FOR REGULATORY

SCENARIO	NO. IMPLANTS	MANUFACTURING PROCESS NOVELTY	DESIGN COMPLEXITY	DESIGN NOVELTY	MATERIAL TECHNOLOGY	PLEASE ESTIMATE….	FRONT END 0 - GATE 1	GATE 1- CHARTER	CHARTER -GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7- GATE 8
1	LOW	STANDARD	SIMPLE	HIGH	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)	*N MONTHS* *N FTE'S*						
2	HIGH	STANDARD	SIMPLE	LOW	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)							
3	NONE	NOVEL	SIMPLE	LOW	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)							
4	HIGH	NOVEL	SIMPLE	HIGH	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)							
5	LOW	STANDARD	COMPLEX	HIGH	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)							
6	HIGH	STANDARD	COMPLEX	LOW	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)							
7	NONE	NOVEL	COMPLEX	LOW	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)							
8	HIGH	NOVEL	COMPLEX	HIGH	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)							

TABLE 60 - SURVEY DESIGN FOR MARKETING

SCENARIO	STRATEGIC VALUE	DESIGN COMPLEXITY	DESIGN NOVELTY	SURGEON TEAM SIZE	PLEASE ESTIMATE....	FRONT END - GATE 1	GATE 1 - CHARTER	CHARTER -GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7-GATE 8
1	HIGH	COMPLEX	HIGH	LARGE	DURATION (MONTHS) RESOURCE (FTE'S)	*N MONTHS* *N FTE'S*						
2	HIGH	COMPLEX	LOW	SMALL	DURATION (MONTHS) RESOURCE (FTE'S)							
3	HIGH	SIMPLE	HIGH	SMALL	DURATION (MONTHS) RESOURCE (FTE'S)							
4	LOW	SIMPLE	HIGH	LARGE	DURATION (MONTHS) RESOURCE (FTE'S)							
5	LOW	COMPLEX	HIGH	SMALL	DURATION (MONTHS) RESOURCE (FTE'S)							
6	LOW	SIMPLE	LOW	SMALL	DURATION (MONTHS) RESOURCE (FTE'S)							
7	LOW	COMPLEX	LOW	LARGE	DURATION (MONTHS) RESOURCE (FTE'S)							
8	HIGH	SIMPLE	LOW	LARGE	DURATION (MONTHS) RESOURCE (FTE'S)							

TABLE 61 - SURVEY DESIGN FOR QUALITY

SCENARIO	NUMBER OF IMPLANTS	NUMBER OF INSTRUMENTS	DESIGN COMPLEXITY	MANUFACTURING PROCESS NOVELTY	PRODUCTION VOLUME	PLEASE ESTIMATE....	FRONT END - GATE 1	GATE 1- CHARTER	CHARTER -GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7- GATE 8
1	LOW	LOW	SIMPLE	NOVEL	HIGH	DURATION (MONTHS)	*N MONTHS*						
						RESOURCE (FTE'S)	*N FTE'S*						
2	HIGH	LOW	SIMPLE	STANDARD	LOW	DURATION (MONTHS)							
						RESOURCE (FTE'S)							
3	NONE	HIGH	SIMPLE	STANDARD	HIGH	DURATION (MONTHS)							
						RESOURCE (FTE'S)							
4	HIGH	HIGH	SIMPLE	NOVEL	LOW	DURATION (MONTHS)							
						RESOURCE (FTE'S)							
5	LOW	LOW	COMPLEX	NOVEL	LOW	DURATION (MONTHS)							
						RESOURCE (FTE'S)							
6	HIGH	LOW	COMPLEX	STANDARD	HIGH	DURATION (MONTHS)							
						RESOURCE (FTE'S)							
7	NONE	HIGH	COMPLEX	STANDARD	LOW	DURATION (MONTHS)							
						RESOURCE (FTE'S)							
8	HIGH	HIGH	COMPLEX	NOVEL	HIGH	DURATION (MONTHS)							
						RESOURCE (FTE'S)							

FOR EACH IMPLANT COMPONENT OF THE TYPE DESCRIBED IN THE SCENARIOS PLEASE CONSIDER THE RESOURCES REQUIRED AND THE ASSOCIATED DURATION.

SCENARIO	IMPLANT NOVELTY	IMPLANT COMPLEXITY	MAN PROCESS NOVELTY	CORE MARKET?	PLEASE ESTIMATE....	**FRONT END - GATE 1**	**GATE 1- CHARTER**	**CHARTER - GATE 2**	**GATE 2- GATE 3**	**GATE 3- GATE 6**	**GATE 6- GATE7**	**GATE 7- GATE 8**
1	STANDARD	SIMPLE	STANDARD	YES	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
2	NOVEL	SIMPLE	STANDARD	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
3	STANDARD	COMPLEX	STANDARD	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
4	NOVEL	COMPLEX	STANDARD	YES	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
5	STANDARD	SIMPLE	NOVEL	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
6	NOVEL	SIMPLE	NOVEL	YES	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
7	STANDARD	COMPLEX	NOVEL	YES	DURATION (MONTHS)							

					RESOURCE (FTE'S)							
8	NOVEL	COMPLEX	NOVEL	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							

FOR EACH INSTRUMENT OF THE TYPE DESCRIBED IN THE SCENARIOS PLEASE CONSIDER THE RESOURCES REQUIRED AND THE ASSOCIATED DURATION.

SCENARIO	INSTRUMENT NOVELTY	INSTRUMENT COMPLEXITY	MAN PROCESS NOVELTY	CORE MARKET?	PLEASE ESTIMATE....	**FRONT END - GATE 1**	**GATE 1- CHARTER**	**CHARTER -GATE 2**	**GATE 2- GATE 3**	**GATE 3- GATE 6**	**GATE 6- GATE7**	**GATE 7- GATE 8**
1	STANDARD	SIMPLE	STANDARD	YES	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
2	NOVEL	SIMPLE	STANDARD	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
3	STANDARD	COMPLEX	STANDAR	NO	DURATIO							

			D		N (MONTHS) RESOURCE (FTE'S)							
4	NOVEL	COMPLEX	STANDARD	YES	DURATION (MONTHS) RESOURCE (FTE'S)							
5	STANDARD	SIMPLE	NOVEL	NO	DURATION (MONTHS) RESOURCE (FTE'S)							
6	NOVEL	SIMPLE	NOVEL	YES	DURATION (MONTHS) RESOURCE (FTE'S)							
7	STANDARD	COMPLEX	NOVEL	YES	DURATION (MONTHS) RESOURCE (FTE'S)							
8	NOVEL	COMPLEX	NOVEL	NO	DURATION (MONTHS) RESOURCE (FTE'S)							

TABLE 62 – SURVEY DESIGN FOR DESIGN ENGINEERING

DESIGN RESOURCE REQUIRED FOR IMPLANT DESIGN PER PROJECT WITH THE FOLLOWING CHARACTERISTICS

SCENARIO	NUMBER OF IMPLANT COMPONENTS	IMPLANT DESIGN COMPLEXITY	IMPLANT DESIGN NOVELTY	IMPLANT MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	CHARTER -GATE 2	GATE 2- GATE 3	GATE 3- GATE 6
1	ONE	SIMPLE	STANDARD	STANDARD	DURATION (MONTHS)			
					RESOURCE (FTE'S)			
2	ONE	COMPLEX	NOVEL	NOVEL	DURATION (MONTHS)			
					RESOURCE (FTE'S)			
3	TWO	SIMPLE	STANDARD	NOVEL	DURATION (MONTHS)			
					RESOURCE (FTE'S)			
4	TWO	COMPLEX	NOVEL	STANDARD	DURATION (MONTHS)			
					RESOURCE (FTE'S)			
5	THREE	SIMPLE	NOVEL	STANDARD	DURATION (MONTHS)			
					RESOURCE (FTE'S)			
6	THREE	COMPLEX	STANDARD	NOVEL	DURATION (MONTHS)			
					RESOURCE (FTE'S)			
7	FOUR PLUS	SIMPLE	NOVEL	NOVEL	DURATION (MONTHS)			
					RESOURCE (FTE'S)			
8	FOUR PLUS	COMPLEX	STANDARD	STANDARD	DURATION (MONTHS)			

		RESOURCE (FTE'S)			

DESIGN RESOURCE REQUIRED FOR EACH INSTRUMENT WITH THE FOLLOWING CHARACTERISTICS

SCENARIO	INSTRUMENT DESIGN COMPLEXITY	INSTRUMENT DESIGN NOVELTY	INSTRUMENT MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	CHARTER -GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE7	GATE 7-GATE 8
1	COMPLEX	NOVEL	NOVEL	DURATION (MONTHS)					
				RESOURCE (FTE'S)					
2	SIMPLE	STANDARD	NOVEL	DURATION (MONTHS)					
				RESOURCE (FTE'S)					
3	COMPLEX	STANDARD	STANDARD	DURATION (MONTHS)					
				RESOURCE (FTE'S)					
4	SIMPLE	NOVEL	STANDARD	DURATION (MONTHS)					
				RESOURCE (FTE'S)					

TABLE 63 – REVISED SURVEY FOR TEST GROUP PART A

FOR EACH IMPLANT COMPONENT OF THE TYPE DESCRIBED IN THE SCENARIOS PLEASE CONSIDER THE RESOURCES REQUIRED AND THE ASSOCIATED DURATION.

SCENARIO	IMPLANT NOVELTY	IMPLANT COMPLEXITY	MAN PROCESS NOVELTY	CORE MARKET?	PLEASE ESTIMATE….	**FRONT END - GATE 1**	**GATE 1-CHARTER**	**CHARTER -GATE 2**	**GATE 2-GATE 3**	**GATE 3-GATE 6**	**GATE 6-GATE7**	**GATE 7-GATE 8**
1	STANDARD	SIMPLE	STANDARD	YES	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
2	NOVEL	SIMPLE	STANDARD	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
3	STANDARD	COMPLEX	STANDARD	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
4	NOVEL	COMPLEX	STANDARD	YES	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
5	STANDARD	SIMPLE	NOVEL	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
6	NOVEL	SIMPLE	NOVEL	YES	DURATION (MONTHS)							
					RESOURCE (FTE'S)							

7	STANDARD	COMPLEX	NOVEL	YES	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
8	NOVEL	COMPLEX	NOVEL	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							

TABLE 64 - REVISED SURVEY FOR TEST GROUP PART B

FOR EACH INSTRUMENT OF THE TYPE DESCRIBED IN THE SCENARIOS PLEASE CONSIDER THE RESOURCES REQUIRED AND THE ASSOCIATED DURATION.

SCENARIO	INSTRUMENT NOVELTY	INSTRUMENT COMPLEXITY	MAN PROCESS NOVELTY	CORE MARKET?	PLEASE ESTIMATE....	**FRONT END - GATE 1**	**GATE 1- CHARTER**	**CHARTER -GATE 2**	**GATE 2- GATE 3**	**GATE 3- GATE 6**	**GATE 6- GATE7**	**GATE 7-GATE 8**
1	STANDARD	SIMPLE	STANDARD	YES	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
2	NOVEL	SIMPLE	STANDARD	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
3	STANDARD	COMPLEX	STANDARD	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
4	NOVEL	COMPLEX	STANDARD	YES	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
5	STANDARD	SIMPLE	NOVEL	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
6	NOVEL	SIMPLE	NOVEL	YES	DURATION (MONTHS)							

					RESOURCE (FTE'S)							
7	STANDARD	COMPLEX	NOVEL	YES	DURATION (MONTHS)							
					RESOURCE (FTE'S)							
8	NOVEL	COMPLEX	NOVEL	NO	DURATION (MONTHS)							
					RESOURCE (FTE'S)							

TABLE 65 - REVISED SURVEY DESIGN FOR DESIGN ENGINEERING PART A

DESIGN RESOURCE REQUIRED FOR IMPLANT DESIGN PER PROJECT WITH THE FOLLOWING CHARACTERISTICS

SCENARIO	NUMBER OF IMPLANT COMPONENTS	IMPLANT DESIGN COMPLEXITY	IMPLANT DESIGN NOVELTY	IMPLANT MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	CHARTER -GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE7	GATE 7-GATE 8	PROJECT TYPE
1	ONE	SIMPLE	STANDARD	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)						
2	ONE	COMPLEX	NOVEL	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)						
3	TWO	SIMPLE	STANDARD	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)						
4	TWO	COMPLEX	NOVEL	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)						
5	THREE	SIMPLE	NOVEL	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)						
6	THREE	COMPLEX	STANDARD	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)						
7	FOUR PLUS	SIMPLE	NOVEL	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)						
8	FOUR PLUS	COMPLEX	STANDARD	STANDARD	DURATION (MONTHS)						

		RESOURCE (FTE'S)						

TABLE 66 - REVISED SURVEY FOR DESIGN ENGINEERING PART B

DESIGN RESOURCE REQUIRED FOR EACH INSTRUMENT WITH THE FOLLOWING CHARACTERISTICS

SCENARIO	INSTRUMENT DESIGN COMPLEXITY	INSTRUMENT DESIGN NOVELTY	INSTRUMENT MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	CHARTER -GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE 7	GATE 7-GATE 8	PROJECT TYPE
1	COMPLEX	NOVEL	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)						
2	SIMPLE	STANDARD	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)						
3	COMPLEX	STANDARD	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)						
4	SIMPLE	NOVEL	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)						

Appendix 2 B- Scottish water survey design

Scenario	No. of milestones	Meterage	Project Value	Reputatonal standing	Complexity	Procurement Timescales	Please estimate…	Capex 1 to Capex 2	Capex 2 to Capex 3	Capex 3 to Capex 5
1	low	low	low	high	high	high	Duration	*Weeks*		
							Resource	*Man hours*		
2	high	low	low	low	low	high	Duration			
							Resource			
3	low	high	low	low	high	low	Duration			
							Resource			
4	high	high	low	high	low	low	Duration			
							Resource			
5	low	low	high	high	low	low	Duration			
							Resource			
6	high	low	high	low	high	low	Duration			
							Resource			
7	low	high	high	low	low	high	Duration			
							Resource			
8	high	high	high	high	high	high	Duration			
							Resource			

APPENDIX 3 A – SURVEY RESPONSES

TABLE 67 - PROJECT MANAGEMENT RESPONSE 1

SCENARIO	NUMBER OF IMPLANTS	NUMBER OF INSTRUMENTS	DESIGN COMPLEXITY	DESIGN NOVELTY	MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	FRONT END - GATE 1	GATE 1- CHARTER	CHARTER -GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7 - GATE 8
1	LOW	LOW	SIMPLE	HIGH	NOVEL	DURATION (MONTHS)	*1*	12	1	12	6	3	12
						RESOURCE (FTE'S)	*0.5*	0.2	0.4	0.4	0.4	1	0.1
2	HIGH	LOW	SIMPLE	LOW	STANDARD	DURATION (MONTHS)	1	15	2	24	12	6	12
						RESOURCE (FTE'S)	0.7	0.3	0.4	0.3	0.4	1	0.2
3	NONE	HIGH	SIMPLE	LOW	NOVEL	DURATION (MONTHS)	3	12	3	12	24	24	12
						RESOURCE (FTE'S)	0.7	0.5	0.4	0.3	0.7	1.3	0.2
4	HIGH	HIGH	SIMPLE	HIGH	STANDARD	DURATION (MONTHS)	3	12	2	24	12	12	12
						RESOURCE (FTE'S)	0.7	0.5	0.5	0.5	0.5	1	0.3
5	LOW	LOW	COMPLEX	HIGH	STANDARD	DURATION (MONTHS)	3	12	3	24	24	12	12

						RESOURCE (FTE'S)	0.7	0.5	0.5	0.5	0.5	1	0.2
6	HIGH	LOW	COMPLEX	LOW	NOVEL	DURATION (MONTHS)	3	15	3	24	24	18	12
						RESOURCE (FTE'S)	0.7	0.5	0.5	0.5	0.7	1	0.3
7	NONE	HIGH	COMPLEX	LOW	STANDARD	DURATION (MONTHS)	3	18	12	24	30	30	12
						RESOURCE (FTE'S)	0.7	0.5	0.5	0.5	1	1.5	0.3
8	HIGH	HIGH	COMPLEX	HIGH	NOVEL	DURATION (MONTHS)	3	24	6	36	18	12	12
						RESOURCE (FTE'S)	0.7	0.5	0.5	0.5	0.7	1	0.5

TABLE 68 - PROJECT MANAGEMENT RESPONSE 2

SCENARIO	NUMBER OF IMPLANTS	NUMBER OF INSTRUMENTS	DESIGN COMPLEXITY	DESIGN NOVELTY	MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	FRONT END - GATE 1	GATE 1- CHARTER	CHARTER -GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE 7	GATE 7- GATE 8
1	LOW	LOW	SIMPLE	HIGH	NOVEL	DURATION (MONTHS)	*N MONTHS*						
						RESOURCE (FTE'S)	*N FTE'S*						
2	HIGH	LOW	SIMPLE	LOW	STANDARD	DURATION (MONTHS)	1	6	2	9	12	6	12
						RESOURCE (FTE'S)	0.7	0.3	0.4	0.3	0.4	1	0.2
3	NONE	HIGH	SIMPLE	LOW	NOVEL	DURATION (MONTHS)	1	9	6	12	18	6	12

						RESOURCE (FTE'S)	0.7	0.3	0.4	0.5	0.5	1	0.2
4	HIGH	HIGH	SIMPLE	HIGH	STANDARD	DURATION (MONTHS)	1	6	6	9	15	6	12
						RESOURCE (FTE'S)	0.7	0.3	0.4	0.3	0.4	1	0.2
5	LOW	LOW	COMPLEX	HIGH	STANDARD	DURATION (MONTHS)	1	6	6	18	18	6	12
						RESOURCE (FTE'S)	0.7	0.3	0.4	0.3	0.5	1	0.2
6	HIGH	LOW	COMPLEX	LOW	NOVEL	DURATION (MONTHS)	1	9	12	12	24	6	12
						RESOURCE (FTE'S)	0.7	0.5	0.4	0.3	0.4	1	0.2
7	NONE	HIGH	COMPLEX	LOW	STANDARD	DURATION (MONTHS)	1	9	12	12	18	6	12
						RESOURCE (FTE'S)	0.7	0.5	0.4	0.3	0.8	1	0.2
8	HIGH	HIGH	COMPLEX	HIGH	NOVEL	DURATION (MONTHS)	1	12	12	12	24	6	12
						RESOURCE (FTE'S)	0.7	0.5	0.4	0.3	0.8	1	0.2

TABLE 69 - BIO-ENGINEERING SURVEY RESPONSE

SCENARIO	NUMBER OF IMPLANTS	NUMBER OF INSTRUMENTS	DESIGN COMPLEXITY	DESIGN NOVELTY	MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	FRONT END - GATE 1	GATE 1-CHARTER	CHARTER -GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE 7	GATE 7-GATE 8
1	LOW	LOW	SIMPLE	HIGH	NOVEL	DURATION (MONTHS)	3	6	12	12	36	12	12
						RESOURCE (FTE'S)	1	1	1	1	0.2	1	0.1
2	HIGH	NONE	SIMPLE	LOW	STANDARD	DURATION (MONTHS)	3	3	6	24	3	6	12
						RESOURCE (FTE'S)	1	1	1	1	1	1	0.1
3	NONE	HIGH	SIMPLE	LOW	NOVEL	DURATION (MONTHS)	3	3	6	24	6	12	12
						RESOURCE (FTE'S)	2	2	2	2	2	2	0.1
4	HIGH	HIGH	SIMPLE	HIGH	STANDARD	DURATION (MONTHS)	24	12	12	36	36	12	12
						RESOURCE (FTE'S)	3	3	5	5	0.5	5	0.1
5	LOW	LOW	COMPLEX	HIGH	STANDARD	DURATION (MONTHS)	6	6	12	12	36	12	12
						RESOURCE (FTE'S)	1	1	1	1	0.2	1	0.1
6	HIGH	NONE	COMPLEX	LOW	NOVEL	DURATION (MONTHS)	6	6	18	30	0	12	12
						RESOURCE (FTE'S)	1	1	1	1	0	2	0.1
7	NONE	HIGH	COMPLEX	LOW	STANDARD	DURATION (MONTHS)	3	3	12	18	6	12	12
						RESOURCE (FTE'S)	2	2	2	2	2	1	0.1
8	HIGH	HIGH	COMPLEX	HIGH	NOVEL	DURATION	24	12	12	36	36	12	12

		(MONTHS)							
		RESOURCE (FTE'S)	3	3	5	5	0.5	5	0.1

TABLE 70- REGULATORY RESPONSE 1

SCENARIO	NO. IMPLANTS	MANUFACTURING PROCESS NOVELTY	DESIGN COMPLEXITY	DESIGN NOVELTY	MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	FRONT END 0 - GATE 1	GATE 1- CHARTER	CHARTER - GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7-GATE 8
1	LOW	STANDARD	SIMPLE	HIGH	NOVEL	DURATION (MONTHS)						12-24 MONTHS	
						RESOURCE (FTE'S)	*0.05*	0.025	0.025	0.1	0.1	.3-.6	0.3
2	HIGH	STANDARD	SIMPLE	LOW	STANDARD	DURATION (MONTHS)						3-6 MONTHS	
						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	.3-.6	0.3
3	NONE	NOVEL	SIMPLE	LOW	NOVEL	DURATION (MONTHS)						2 WEEKS	
						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	0.1	0.1
4	HIGH	NOVEL	SIMPLE	HIGH	STANDARD	DURATION (MONTHS)						6-12 MONTHS	
						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	.3-.6	0.3
5	LOW	STANDARD	COMPLEX	HIGH	STANDARD	DURATION (MONTHS)						6-12 MONTHS	
						RESOURCE (FTE'S)	*0.05*	0.025	0.025	0.1	0.1	.3-.6	0.3
6	HIGH	STANDARD	COMPLEX	LOW	NOVEL	DURATION (MONTHS)						6-12 MONTHS	
						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	.3-.6	0.3
7	NONE	NOVEL	COMPLEX	LOW	STANDARD	DURATION (MONTHS)						2 WEEKS	

						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	0.1	0.1
8	HIGH	NOVEL	COMPLEX	HIGH	NOVEL	DURATION (MONTHS)						5-7 YEARS	
						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	.3-.6	0.3

TABLE 71 - REGULATORY RESPONSE 2

SCENARIO	NO. IMPLANTS	MANUFACTURING PROCESS NOVELTY	DESIGN COMPLEXITY	DESIGN NOVELTY	MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	FRONT END 0 - GATE 1	GATE 1 - CHARTER	CHARTER - GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE7	GATE 7-GATE 8
1	LOW	STANDARD	SIMPLE	HIGH	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)	*N MONTHS* *N FTE'S*					US 150 DAYS EU 120 DAYS	
2	HIGH	STANDARD	SIMPLE	LOW	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)						US 120 DAYS EU 120 DAYS	
3	NONE	NOVEL	SIMPLE	LOW	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)						US 0 DAYS EU 10 DAYS	
4	HIGH	NOVEL	SIMPLE	HIGH	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)						US 120 DAYS EU 120 DAYS	
5	LOW	STANDARD	COMPLEX	HIGH	STANDARD	DURATION (MONTHS) RESOURCE (FTE'S)						US 180 DAYS EU 150 DAYS	
6	HIGH	STANDARD	COMPLEX	LOW	NOVEL	DURATION (MONTHS) RESOURCE (FTE'S)						US 180 DAYS EU 150 DAYS	
7	NONE	NOVEL	COMPLEX	LOW	STANDARD	DURATION (MONTHS)						US 270	

												DAYS	
						RESOURCE (FTE'S)						EU 180 DAYS	
8	HIGH	NOVEL	COMPLEX	HIGH	NOVEL	DURATION (MONTHS)						US 2555 DAYS	
						RESOURCE (FTE'S)						EU 1500 DAYS	

TABLE 72 - REGULATORY RESPONSE 3

SCENARIO	NO. IMPLANTS	MANUFACTURING PROCESS NOVELTY	DESIGN COMPLEXITY	DESIGN NOVELTY	MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	FRONT END 0 - GATE 1	GATE 1- CHARTER	CHARTER - GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7- GATE 8
1	LOW	STANDARD	SIMPLE	HIGH	NOVEL	DURATION (MONTHS)						3-6 MONTHS	
						RESOURCE (FTE'S)	*0.05*	0.025	0.025	0.1	0.1	.3-.6	0.3
2	HIGH	STANDARD	SIMPLE	LOW	STANDARD	DURATION (MONTHS)						3-6 MONTHS	
						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	.3-.6	0.3
3	NONE	NOVEL	SIMPLE	LOW	NOVEL	DURATION (MONTHS)						1-2 WEEKS	
						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	0.1	0.1
4	HIGH	NOVEL	SIMPLE	HIGH	STANDARD	DURATION (MONTHS)						3-6 MONTHS	
						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	.3-.6	0.3
5	LOW	STANDARD	COMPLEX	HIGH	STANDARD	DURATION (MONTHS)						6-12 MONTHS	
						RESOURCE (FTE'S)	*0.05*	0.025	0.025	0.1	0.1	.3-.6	0.3
6	HIGH	STANDARD	COMPLEX	LOW	NOVEL	DURATION (MONTHS)						6-12 MONTHS	
						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	.3-.6	0.3
7	NONE	NOVEL	COMPLEX	LOW	STANDARD	DURATION (MONTHS)						1-2 WEEKS	

						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	0.1	0.1
8	HIGH	NOVEL	COMPLEX	HIGH	NOVEL	DURATION (MONTHS)						YEARS	
						RESOURCE (FTE'S)	0.05	0.025	0.025	0.1	0.1	.3-.6	0.3

TABLE 73 - REGULATORY RESPONSE 4

SCENARIO	NO. IMPLANTS	MANUFACTURING PROCESS NOVELTY	DESIGN COMPLEXITY	DESIGN NOVELTY	MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	FRONT END 0 - GATE 1	GATE 1- CHARTER	CHARTER - GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7- GATE 8
1	LOW	STANDARD	SIMPLE	HIGH	NOVEL	DURATION (MONTHS)	*N MONTHS*					3-4 MONTHS	
						RESOURCE (FTE'S)	*N FTE'S*						
2	HIGH	STANDARD	SIMPLE	LOW	STANDARD	DURATION (MONTHS)						3-4 MONTHS	
						RESOURCE (FTE'S)							
3	NONE	NOVEL	SIMPLE	LOW	NOVEL	DURATION (MONTHS)						2 WEEKS	
						RESOURCE (FTE'S)							
4	HIGH	NOVEL	SIMPLE	HIGH	STANDARD	DURATION (MONTHS)						3-4 MONTHS	
						RESOURCE (FTE'S)							
5	LOW	STANDARD	COMPLEX	HIGH	STANDARD	DURATION (MONTHS)						3-4 MONTHS	
						RESOURCE (FTE'S)							

6	HIGH	STANDARD	COMPLEX	LOW	NOVEL	DURATION (MONTHS)						3-4 MONTHS	
						RESOURCE (FTE'S)							
7	NONE	NOVEL	COMPLEX	LOW	STANDARD	DURATION (MONTHS)						2 WEEKS	
						RESOURCE (FTE'S)							
8	HIGH	NOVEL	COMPLEX	HIGH	NOVEL	DURATION (MONTHS)						3-4 MONTHS	
						RESOURCE (FTE'S)							

TABLE 74 - QUALITY RESPONSE

SCENARIO	NUMBER OF IMPLANTS	NUMBER OF INSTRUMENTS	DESIGN COMPLEXITY	DESIGN NOVELTY	MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	FRONT END - GATE 1	GATE 1-CHARTER	CHARTER -GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE 7	GATE 7-GATE 8
1	LOW	LOW	SIMPLE	HIGH	NOVEL	DURATION (MONTHS)	*1*	1	3	12	18	3	12
						RESOURCE (FTE'S)	*0.1*	0.1	0.25	0.5	0.5	1	0.1
2	HIGH	LOW	SIMPLE	LOW	STANDARD	DURATION (MONTHS)	1	1	3	12	12	6	12
						RESOURCE (FTE'S)	0.1	0.1	0.25	0.75	0.75	1.5	0.2
3	NONE	HIGH	SIMPLE	LOW	NOVEL	DURATION (MONTHS)	1	1	3	12	24	12	12
						RESOURCE (FTE'S)	0.1	0.1	0.25	0.5	1	1	0.2
4	HIGH	HIGH	SIMPLE	HIGH	STANDARD	DURATION (MONTHS)	1	1	6	18	18	12	12
						RESOURCE (FTE'S)	0.1	0.1	0.25	1	2	2	0.3
5	LOW	LOW	COMPLEX	HIGH	STANDARD	DURATION (MONTHS)	1	1	3	18	18	12	12
						RESOURCE (FTE'S)	0.1	0.1	0.25	0.5	0.75	1	0.2
6	HIGH	LOW	COMPLEX	LOW	NOVEL	DURATION (MONTHS)	1	1	3	24	24	18	12
						RESOURCE (FTE'S)	0.1	0.1	0.25	0.75	1.5	1.5	0.3
7	NONE	HIGH	COMPLEX	LOW	STANDARD	DURATION (MONTHS)	1	1	6	24	24	12	12
						RESOURCE (FTE'S)	0.1	0.1	0.25	1	2	2	0.3
8	HIGH	HIGH	COMPLEX	HIGH	NOVEL	DURATION (MONTHS)	1	1	6	24	36	18	12

		RESOURCE (FTE'S)	0.1	0.1	0.25	2	3	2	0.5

TABLE 75 - TEST GROUP RESPONSE

SCENARIO	IMPLANT NOVELTY	IMPLANT COMPLEXITY	MAN PROCESS NOVELTY	CORE MARKET?	PLEASE ESTIMATE….	**FRONT END - GATE 1**	**GATE 1-CHARTER**	**CHARTER -GATE 2**	**GATE 2-GATE 3**	**GATE 3-GATE 6**	**GATE 6-GATE7**	**GATE 7-GATE 8**
1	STANDARD	SIMPLE	STANDARD	YES	DURATION (MONTHS)	0			3	3	2	
					RESOURCE (FTE'S)	0			0.1	0.8	0.5	
2	NOVEL	SIMPLE	STANDARD	NO	DURATION (MONTHS)	18			1	3	2	3
					RESOURCE (FTE'S)	0.6			0.1	0.75	0.5	0.25
3	STANDARD	COMPLEX	STANDARD	NO	DURATION (MONTHS)	0			0	6	2	
					RESOURCE (FTE'S)	0			0	0.5	0.5	
4	NOVEL	COMPLEX	STANDARD	YES	DURATION (MONTHS)	40			18	36	4	3
					RESOURCE (FTE'S)	0.5			0.5	2.5	0.5	0.25
5	STANDARD	SIMPLE	NOVEL	NO	DURATION (MONTHS)	35			18	46	9	3
					RESOURCE (FTE'S)	1			0.5	3.5	0.5	0.25
6	NOVEL	SIMPLE	NOVEL	YES	DURATION (MONTHS)	35			18	40	15	3
					RESOURCE (FTE'S)	1			0.5	3.1	0.75	0.25
7	STANDARD	COMPLEX	NOVEL	YES	DURATION (MONTHS)	35			25	48	15	3
					RESOURCE (FTE'S)	1			0.75	3.5	0.75	0.25
8	NOVEL	COMPLEX	NOVEL	NO	DURATION (MONTHS)	35			25	50	15	3
					RESOURCE (FTE'S)	1			0.75	3.75	0.75	0.25

FOR EACH INSTRUMENT OF THE TYPE DESCRIBED IN THE SCENARIOS PLEASE CONSIDER THE RESOURCES REQUIRED AND THE ASSOCIATED DURATION.

SCENARIO	INSTRUMENT NOVELTY	INSTRUMENT COMPLEXITY	MAN PROCESS NOVELTY	CORE MARKET?	PLEASE ESTIMATE….	**FRONT END - GATE 1**	**GATE 1- CHARTER**	**CHARTER -GATE 2**	**GATE 2- GATE 3**	**GATE 3- GATE 6**	**GATE 6- GATE7**	**GATE 7- GATE 8**
1	STANDARD	SIMPLE	STANDARD	YES	DURATION (MONTHS)	*0*			3	3	2	
					RESOURCE (FTE'S)	*0*			0.1	0.1	0.75	
2	NOVEL	SIMPLE	STANDARD	NO	DURATION (MONTHS)	3			3	3	2	
					RESOURCE (FTE'S)	1			0.1	0.1	0.75	
3	STANDARD	COMPLEX	STANDARD	NO	DURATION (MONTHS)	0			3	3	2	
					RESOURCE (FTE'S)	0			0.1	0.1	0.75	
4	NOVEL	COMPLEX	STANDARD	YES	DURATION (MONTHS)	6			9	6	6	8
					RESOURCE (FTE'S)	2			1.75	4	1	1
~~5~~	~~STANDARD~~	~~SIMPLE~~	~~NOVEL~~	~~NO~~	DURATION (MONTHS)	9			9	3	6	
					RESOURCE (FTE'S)	0.4			0.75	2	0.8	
6	NOVEL	SIMPLE	NOVEL	YES	DURATION (MONTHS)	9			9	3	6	9
					RESOURCE (FTE'S)	0.4			0.75	2	0.8	0.5
~~7~~	~~STANDARD~~	~~COMPLEX~~	~~NOVEL~~	~~YES~~	DURATION (MONTHS)	18			18	6	12	
					RESOURCE (FTE'S)	2			3.5	8	2	
8	NOVEL	COMPLEX	NOVEL	NO	DURATION (MONTHS)	18			18	6	12	18
					RESOURCE (FTE'S)	2			3.5	8	2	1.5

TABLE 76- DESIGN ENGINEERING RESPONSE 1

SCENARIO	NUMBER OF IMPLANT COMPONENTS	IMPLANT DESIGN COMPLEXITY	IMPLANT DESIGN NOVELTY	IMPLANT MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	CHARTER -GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE7
1	ONE	SIMPLE	STANDARD	STANDARD	DURATION (MONTHS)	3	4		3
					RESOURCE (FTE'S)	0.25	0.75	0.2	0.5
2	ONE	COMPLEX	NOVEL	NOVEL	DURATION (MONTHS)	6	9		5
					RESOURCE (FTE'S)	0.5	0.75	0.2	0.5
3	TWO	SIMPLE	STANDARD	NOVEL	DURATION (MONTHS)	3	7		3
					RESOURCE (FTE'S)	0.4	0.75	0.2	0.5
4	TWO	COMPLEX	NOVEL	STANDARD	DURATION (MONTHS)	6	9		6
					RESOURCE (FTE'S)	0.5	0.75	0.2	0.5
5	THREE	SIMPLE	NOVEL	STANDARD	DURATION (MONTHS)	6	9		5
					RESOURCE (FTE'S)	0.5	0.75	0.3	0.5
6	THREE	COMPLEX	STANDARD	NOVEL	DURATION (MONTHS)	4	9		5
					RESOURCE (FTE'S)	0.5	75	0.3	0.5
7	FOUR PLUS	SIMPLE	NOVEL	NOVEL	DURATION (MONTHS)	6	10		6
					RESOURCE (FTE'S)	0.4	0.75	0.3	0.5
8	FOUR PLUS	COMPLEX	STANDARD	STANDARD	DURATION (MONTHS)	4	10		6
					RESOURCE (FTE'S)	0.4	0.75	0.3	0.5

DESIGN RESOURCE REQUIRED FOR <u>EACH INSTRUMENT</u> WITH THE FOLLOWING CHARACTERISTICS

SCENARIO	INSTRUMENT DESIGN COMPLEXITY	INSTRUMENT DESIGN NOVELTY	INSTRUMENT MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	CHARTER -GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE7	GATE 7-GATE 8
1	COMPLEX	NOVEL	NOVEL	DURATION (MONTHS)	6	18		8	
				RESOURCE (FTE'S)	0.3	0.75	0.3	0.75	0.1
2	SIMPLE	STANDARD	NOVEL	DURATION (MONTHS)	3	9		4	
				RESOURCE (FTE'S)	0.2	0.75	0.1	0.3	0.1
3	COMPLEX	STANDARD	STANDARD	DURATION (MONTHS)	4	12		6	
				RESOURCE (FTE'S)	0.3	0.75	0.2	0.6	0.1
4	SIMPLE	NOVEL	STANDARD	DURATION (MONTHS)	4	12		6	
				RESOURCE (FTE'S)	0.2	0.75	0.2	0.6	0.1

TABLE 77- DESIGN ENGINEERING RESPONSE 2

SCENARIO	NUMBER OF IMPLANT COMPONENTS	IMPLANT DESIGN COMPLEXITY	IMPLANT DESIGN NOVELTY	IMPLANT MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	CHARTER -GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE7	GATE 7-GATE 8
1	ONE	SIMPLE	STANDARD	STANDARD	DURATION (MONTHS)	4	5		3	
					RESOURCE (FTE'S)	0.25	0.75	0.2	0.4	0.2
2	ONE	COMPLEX	NOVEL	NOVEL	DURATION (MONTHS)	6	11		6	
					RESOURCE (FTE'S)	0.5	0.75	0.2	0.4	0.2
3	TWO	SIMPLE	STANDARD	NOVEL	DURATION (MONTHS)	4	8		3	
					RESOURCE (FTE'S)	0.3	0.6	0.2	0.5	0.2
4	TWO	COMPLEX	NOVEL	STANDARD	DURATION (MONTHS)	6	10		4	
					RESOURCE (FTE'S)	0.4	0.75	0.2	0.5	0.2
5	THREE	SIMPLE	NOVEL	STANDARD	DURATION (MONTHS)	5	7		5	
					RESOURCE (FTE'S)	0.5	0.75	0.3	0.5	0.2
6	THREE	COMPLEX	STANDARD	NOVEL	DURATION (MONTHS)	5	9		5	
					RESOURCE (FTE'S)	0.5	75	0.3	0.5	0.2
7	FOUR PLUS	SIMPLE	NOVEL	NOVEL	DURATION (MONTHS)	6	10		8	
					RESOURCE (FTE'S)	0.4	0.75	0.3	0.5	0.2
8	FOUR PLUS	COMPLEX	STANDARD	STANDARD	DURATION (MONTHS)	4	12		8	
					RESOURCE (FTE'S)	0.5	0.75	0.3	0.5	0.2

DESIGN RESOURCE REQUIRED FOR EACH INSTRUMENT WITH THE FOLLOWING CHARACTERISTICS

SCENARIO	INSTRUMENT DESIGN COMPLEXITY	INSTRUMENT DESIGN NOVELTY	INSTRUMENT MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	CHARTER -GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE7	GATE 7-GATE 8	PROJECT TYPE
1	COMPLEX	NOVEL	NOVEL	DURATION (MONTHS)	8	18		10		
				RESOURCE (FTE'S)	0.4	0.75	0.25	0.4	0.1	
2	SIMPLE	STANDARD	NOVEL	DURATION (MONTHS)	5	12		6		
				RESOURCE (FTE'S)	0.2	0.75	0.15	0.4	0.1	
3	COMPLEX	STANDARD	STANDARD	DURATION (MONTHS)	6	15		7		
				RESOURCE (FTE'S)	0.4	0.75	0.2	0.5	0.1	
4	SIMPLE	NOVEL	STANDARD	DURATION (MONTHS)	4	15		7		
				RESOURCE (FTE'S)	0.2	0.75	0.2	0.6	0.1	

TABLE 78 – DESIGN ENGINEERING RESPONSE 3

SCENARIO	NUMBER OF IMPLANT COMPONENTS	IMPLANT DESIGN COMPLEXITY	IMPLANT DESIGN NOVELTY	IMPLANT MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	CHARTER -GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE 7	GATE 7-GATE 8
1	ONE	SIMPLE	STANDARD	STANDARD	DURATION (MONTHS)	2	2	1	4	12
					RESOURCE (FTE'S)	0.2	1	0.2	0.2	0.1
2	ONE	COMPLEX	NOVEL	NOVEL	DURATION	4	4	1	6	12

					(MONTHS)					
					RESOURCE (FTE'S)	0.5	1	0.5	0.4	0.1
3	TWO	SIMPLE	STANDARD	NOVEL	DURATION (MONTHS)	2	3	1	5	12
					RESOURCE (FTE'S)	0.2	1	0.5	0.3	0.1
4	TWO	COMPLEX	NOVEL	STANDARD	DURATION (MONTHS)	4	6	1	8	12
					RESOURCE (FTE'S)	0.5	2	1	0.8	0.1
5	THREE	SIMPLE	NOVEL	STANDARD	DURATION (MONTHS)	4	4	1	8	12
					RESOURCE (FTE'S)	0.2	1	0.6	0.6	0.2
6	THREE	COMPLEX	STANDARD	NOVEL	DURATION (MONTHS)	4	6	1	8	12
					RESOURCE (FTE'S)	0.6	1.5	1	0.8	0.2
7	FOUR PLUS	SIMPLE	NOVEL	NOVEL	DURATION (MONTHS)	4	6	1	12	12
					RESOURCE (FTE'S)	0.2	1	1	0.6	0.4
8	FOUR PLUS	COMPLEX	STANDARD	STANDARD	DURATION (MONTHS)	4	6	1	12	12
					RESOURCE (FTE'S)	0.6	2	1	1	0.4

DESIGN RESOURCE REQUIRED FOR EACH INSTRUMENT WITH THE FOLLOWING CHARACTERISTICS

SCENARIO	INSTRUMENT DESIGN COMPLEXITY	INSTRUMENT DESIGN NOVELTY	INSTRUMENT MATERIAL TECHNOLOGY	PLEASE ESTIMATE....	CHARTER -GATE 2	GATE 2-GATE 3	GATE 3-GATE 6	GATE 6-GATE 7	GATE 7-GATE 8	PROJECT TYPE

1	COMPLEX	NOVEL	NOVEL	DURATION (MONTHS)	3	6	1	6	12	
				RESOURCE (FTE'S)	0.6	1	0.6	1	0.2	
2	SIMPLE	STANDARD	NOVEL	DURATION (MONTHS)	1	3	1	3	12	
				RESOURCE (FTE'S)	0.2	0.6	0.4	0.4	0.1	
3	COMPLEX	STANDARD	STANDARD	DURATION (MONTHS)	3	4	1	6	12	
				RESOURCE (FTE'S)	0.3	0.8	0.5	0.4	0.2	
4	SIMPLE	NOVEL	STANDARD	DURATION (MONTHS)	3	2	1	4	12	
				RESOURCE (FTE'S)	0.4	0.8	0.6	0.6	0.1	

APPENDIX 3B – SCOTTISH WATER RESPONSE

TABLE 79- SCOTTISH WATER RESPONSE

	SCENARIO	DURATION CAPEX 1- CAPEX 2	DURATION CAPEX 2- CAPEX 3	DURATION CAPEX 3- CAPEX 5	RESOUCE CAPEX 1- CAPEX 2	RESOURCE CAPEX 2- CAPEX 3	RESOURCE CAPEX 3- CAPEX 5
RESPONDENT 1	1	8	8	8	*80*	50	80
	2	6	8	8	50	100	150
	3	10	10	14	50	100	200
	4	10	12	16	80	120	250
	5	10	12	12	80	120	200
	6	12	14	16	120	160	250
	7	16	12	24	150	150	250
	8	24	30	24	300	380	400
RESPONDENT 2	1	4	5	13	24	33	120
	2	3	4	9	20	27	67
	3	3	4	9	21	28	72
	4	4	5	12	24	32	113
	5	3	4	9	20	27	67
	6	4	5	13	24	33	120
	7	3	4	9	20	28	64

	8	5	6	23	32	44	278

APPENDIX 4 – FULL ANALYSIS PROJECT MANAGEMENT EXAMPLE

4.1 PROJECT MANAGEMENT MODEL ANALYSIS COMBINATION MODEL: BOTH REPONDENTS RESULTS COMBINED AS REPLICATED CORNER POINTS

FRACTIONAL FACTORIAL DESIGN

FACTORS: 5 BASE DESIGN: 5, 8 RESOLUTION: III
REVIEWS: 16 REPLICATES: 2 FRACTION: 1/4
BLOCKS: 1 CENTER PTS (TOTAL): 0

* NOTE * SOME MAIN EFFECTS ARE CONFOUNDED WITH TWO-WAY INTERACTIONS.

DESIGN GENERATORS: D = AB, E = AC

ALIAS STRUCTURE

I + ABD + ACE + BCDE

A + BD + CE + ABCDE
B + AD + CDE + ABCE
C + AE + BDE + ABCD
D + AB + BCE + ACDE
E + AC + BCD + ABDE
BC + DE + ABE + ACD
BE + CD + ABC + ADE

KEY – ANALYSIS OUTCOMES
REQUIRES FINE TUNING – EXPERIMENT BY REMOVING TERMS
TOO MANY FACTORS REMOVED – REVERT TO PREVIOUS MODEL
BEST POSSIBLE FIT FOR DATA PROVIDED AND MODEL TYPE
R-SQ (ADJUSTED) VALUE –A MEASURE OF HOW WELL THE MODEL FITS THE DATA ADJUSTED FOR THE NUMBER OF TERMS TO PREVENT OVER-FITTING. THIS TERM IS USED FOR COMPARING ITERATIONS OF THE MODEL AND ASSESSING ADAPTATIONS UNTIL THE 'BEST' MODEL IS REACHED. A HIGHER R-SQ (ADJUSTED) VALUE = A BETTER FIT. THIS IS WHAT WE ARE LOOKING TO INFLATE THROUGH THE PROCESS OF REMOVING AND REINTRODUCING FACTORS.

RESOURCE GATE 0 - GATE 1

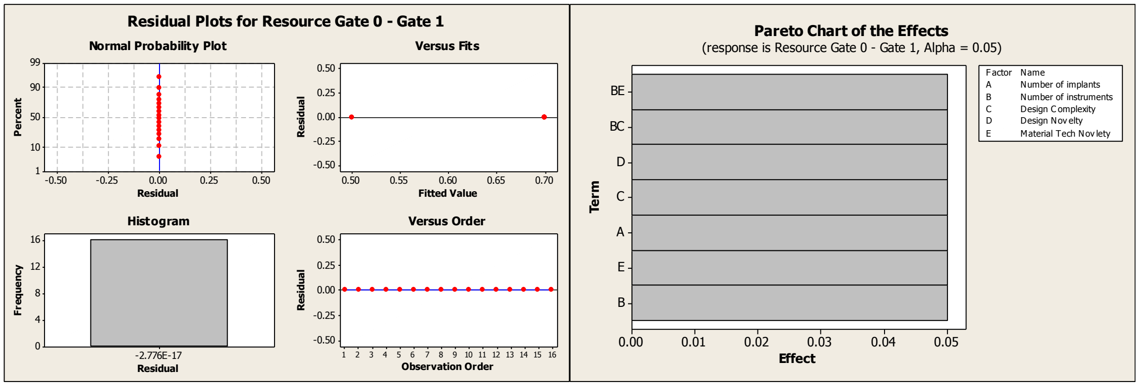


FIGURE 86 – PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 0 – GATE 1: RESIDUAL PLOTS, PARETO CHART.

TABLE 80 – PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 0 – GATE 1, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 0 – GATE 1: REVIEW 1.					
TERM	EFFECT	COEF	COEF	T	P
CONSTANT		0.67500	0	*	*
NUMBER OF IMPLANTS	0.05000	0.02500	0	*	*
NUMBER OF INSTRUMENTS	0.05000	0.02500	0	*	*
DESIGN COMPLEXITY	0.05000	0.02500	0	*	*
DESIGN NOVELTY	-0.05000	-0.02500	0	*	*
MATERIAL TECH NOVELTY	-0.05000	-0.02500	0	*	*
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-0.05000	-0.02500	0	*	*
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	0.05000	0.02500	0	*	*
S = 0	PRESS = 0.16				
R-SQ = 100.00%	R-SQ(PRED) = 0.00%	R-SQ(ADJ) = 100.00%			

ANALYSIS OF VARIANCE FOR RESOURCE GATE 0 - GATE 1 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.05000	0.05000	0.01000	*	*
2-WAY INTERACTIONS	2	0.02000	0.02000	0.01000	*	*
RESIDUAL ERROR	8	0.00000	0.00000	0.00000		
PURE ERROR	8	0.00000	0.00000	0.00000		
TOTAL	15	0.07000				
BEST MODEL WITH AVAILABLE DATA/FORMAT						

RESOURCE GATE 1 – CHARTER

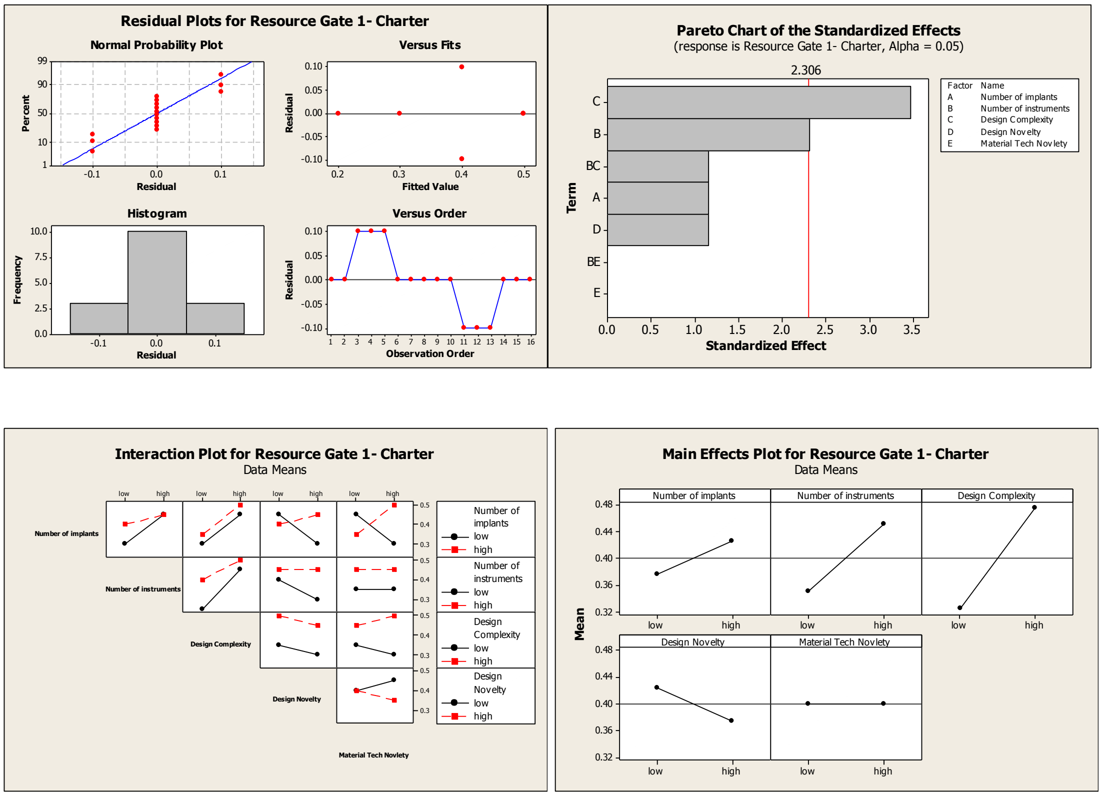


FIGURE 87 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 1 – CHARTER: RESIDUAL PLOTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 81 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 1 – CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 1 - CHARTER					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.40000	0.02165	18.48	0.000
NUMBER OF IMPLANTS	0.05000	0.02500	0.02165	1.15	0.282
NUMBER OF INSTRUMENTS	0.10000	0.05000	0.02165	2.31	0.050
DESIGN COMPLEXITY	0.15000	0.07500	0.02165	3.46	0.009
DESIGN NOVELTY	-0.05000	-0.02500	0.02165	-1.15	0.282
MATERIAL TECH NOVELTY	-0.00000	-0.00000	0.02165	-0.00	1.000
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-0.05000	-0.02500	0.02165	-1.15	0.282
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	-0.00000	-0.00000	0.02165	-0.00	1.000
S = 0.0866025 PRESS = 0.32					
R-SQ = 72.73% R-SQ(PRED) = 0.00% R-SQ(ADJ) = 48.86%					
ANALYSIS OF VARIANCE FOR RESOURCE GATE 1- CHARTER (CODED UNITS)					
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P

MAIN EFFECTS	5	0.150000	0.150000	0.030000	4.00	0.041
2-WAY INTERACTIONS	2	0.010000	0.010000	0.005000	0.67	0.540
RESIDUAL ERROR	8	0.060000	0.060000	0.007500		
PURE ERROR	8	0.060000	0.060000	0.007500		
TOTAL	15	0.220000				
FURTHER REVIEW REQUIRED: REMOVE ALL FACTORS EXCEPT NO. INSTUMENTS AND DES COMPLEXITY....						

TABLE 3 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 1 – CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

RESOURCE GATE 1- CHARTER: REVIEW 2 WITH NO. INSTRUMENTS AND DES COMPLEXITY REMOVED....					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.40000	0.02080	19.23	0.000
NUMBER OF INSTRUMENTS	0.10000	0.05000	0.02080	2.40	0.032
DESIGN COMPLEXITY	0.15000	0.07500	0.02080	3.61	0.003
S = 0.0832050	PRESS = 0.136331				
R-SQ = 59.09%	R-SQ(PRED) = 38.03%	R-SQ(ADJ) = 52.80%			
ANALYSIS OF VARIANCE FOR RESOURCE GATE 1- CHARTER (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	0.13000	0.13000	0.065000	9.39	0.003
RESIDUAL ERROR	13	0.09000	0.09000	0.006923		
LACK OF FIT	1	0.01000	0.01000	0.010000	1.50	0.244
PURE ERROR	12	0.08000	0.08000	0.006667		
TOTAL	15	0.22000				
ALL FACTORS ARE SIGNIFICANT. BEST MODEL AVAILABLE WITH DATA/ FORMAT						

RESOURCE CHARTER – GATE 2

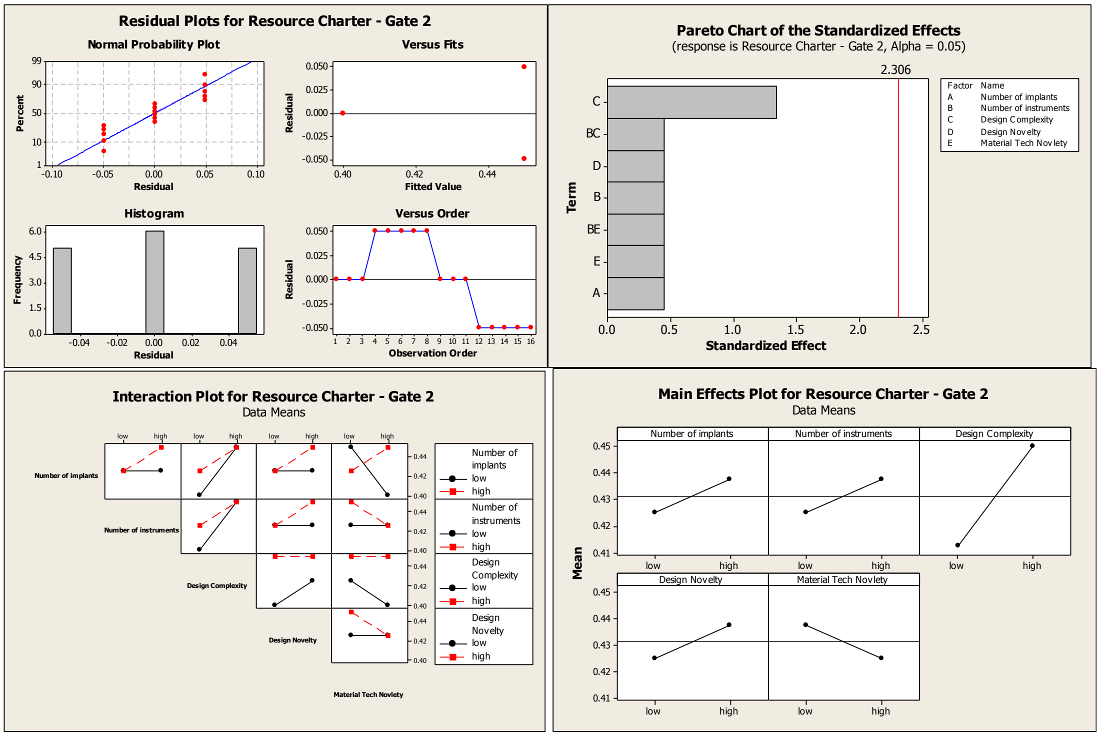


FIGURE 88 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE CHARTER – GATE 2: RESIDUAL PLOTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

FROM FIGURE 88 IT IS CLEAR THAT COMPLEXITY IS THE MOST SIGNIFICANT FACTOR.

TABLE 82 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE CHARTER–GATE 2, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE CHARTER – GATE 2: REVIEW 2 - REMOVE EVERYTHING EXCEPT COMPLEXITY						
ESTIMATED EFFECTS AND COEFFICIENTS FOR RESOURCE CHARTER - GATE 2 (CODED UNITS)						
TERM	EFFECT	COEF	SE COEF	T	P	
CONSTANT		0.43125	0.01133	38.07	0.000	
DESIGN COMPLEXITY	0.03750	0.01875	0.01133	1.66	0.120	
S = 0.0453163	PRESS = 0.0375510					
R-SQ = 16.36%	R-SQ(PRED) = 0.00%	R-SQ(ADJ) = 10.39%				
ANALYSIS OF VARIANCE FOR RESOURCE CHARTER - GATE 2 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	1	0.0056250	0.0056250	0.005625	2.74	0.120
RESIDUAL ERROR	14	0.0287500	0.0287500	0.002054		

PURE ERROR	14	0.0287500	0.0287500	0.002054
TOTAL	15	0.0343750		
BEST MODEL AVAILABLE WITH DATA/ FORMAT				

RESOURCE GATE 2- GATE 3

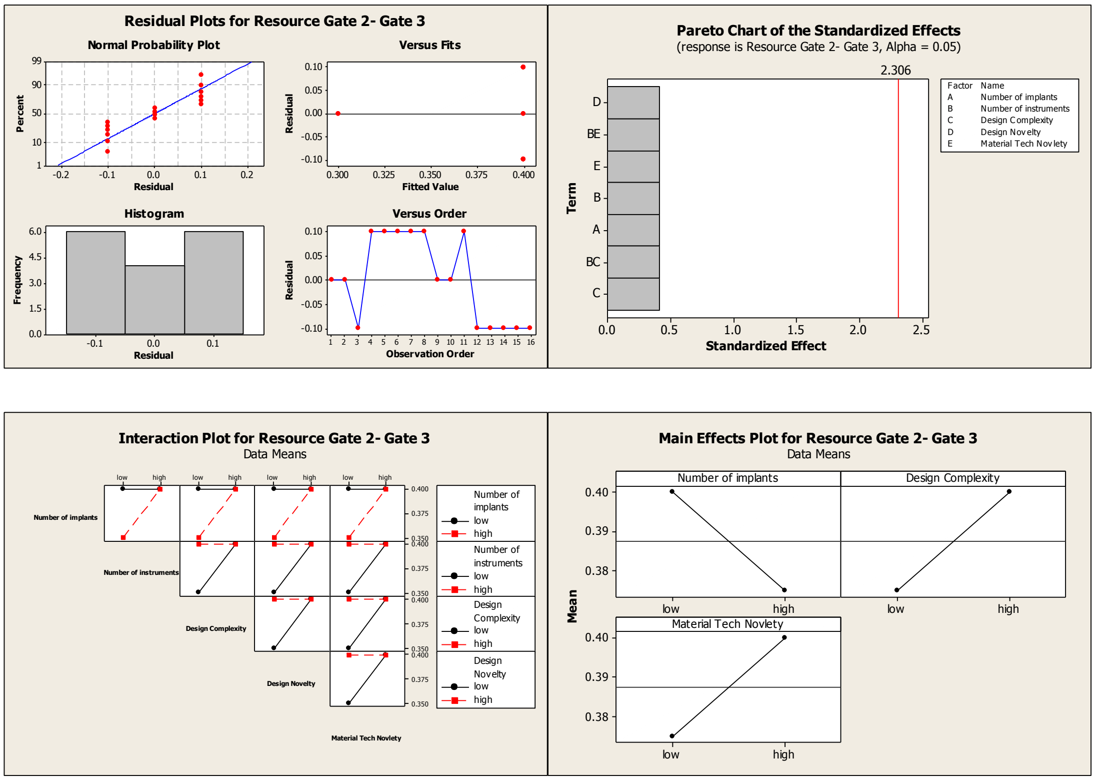


FIGURE 89 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 2 – GATE 3: RESIDUAL PLOTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 83 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 2–GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 2- GATE 3:REVIEW 1					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.38750	0.03062	12.66	0.000
NUMBER OF IMPLANTS	-0.02500	-0.01250	0.03062	-0.41	0.694
NUMBER OF INSTRUMENTS	0.02500	0.01250	0.03062	0.41	0.694
DESIGN COMPLEXITY	0.02500	0.01250	0.03062	0.41	0.694
DESIGN NOVELTY	0.02500	0.01250	0.03062	0.41	0.694
MATERIAL TECH NOVELTY	0.02500	0.01250	0.03062	0.41	0.694
NUMBER OF INSTRUMENTS*	-0.02500	-0.01250	0.03062	-0.41	0.694
DESIGN COMPLEXITY					
NUMBER OF INSTRUMENTS*	-0.02500	-0.01250	0.03062	-0.41	0.694
MATERIAL TECH NOVELTY					
S = 0.122474	PRESS = 0.52				
R-SQ = 12.73%	R-SQ(PRED) = 0.00%	R-SQ(ADJ) = 0.00%			

ANALYSIS OF VARIANCE FOR RESOURCE GATE 2- GATE 3 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.012500	0.012500	0.002500	0.17	0.968
2-WAY INTERACTIONS	2	0.005000	0.005000	0.002500	0.17	0.849
RESIDUAL ERROR	8	0.120000	0.120000	0.015000		
PURE ERROR	8	0.120000	0.120000	0.015000		
TOTAL	15	0.137500				
ALL FACTORS ARE SIGNIFICANT. BEST MODEL AVAILABLE WITH DATA/ FORMAT						

RESOURCE GATE 3 – GATE 6

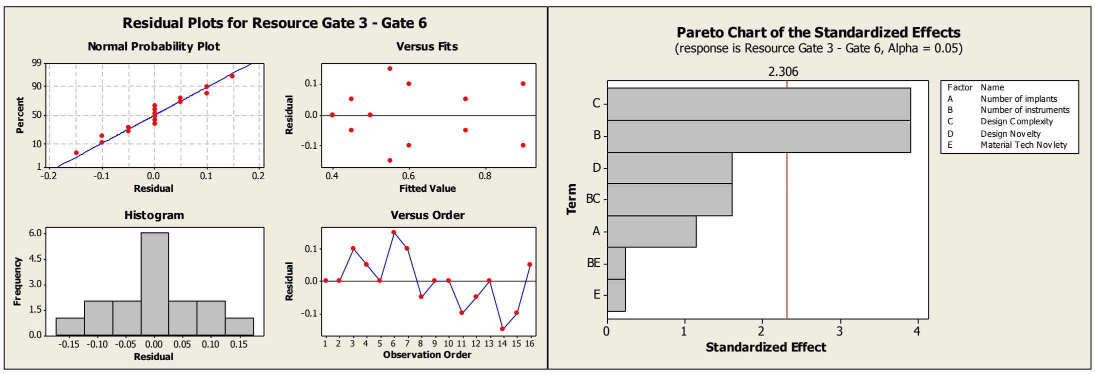


FIGURE 90 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 3 – GATE 6: RESIDUAL PLOTS, PARETO CHART.

TABLE 84 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 3–GATE 6, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 3- GATE 6: REVIEW 1					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.56875	0.02724	20.88	0.000
NUMBER OF IMPLANTS	-0.06250	-0.03125	0.02724	-1.15	0.284
NUMBER OF INSTRUMENTS	0.21250	0.10625	0.02724	3.90	0.005
DESIGN COMPLEXITY	0.21250	0.10625	0.02724	3.90	0.005
DESIGN NOVELTY	-0.08750	-0.04375	0.02724	-1.61	0.147
MATERIAL TECH NOVELTY	0.01250	0.00625	0.02724	0.23	0.824
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	0.08750	0.04375	0.02724	1.61	0.147
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	-0.01250	-0.00625	0.02724	-0.23	0.824
S = 0.108972 PRESS = 0.63					
R-SQ = 82.22% R-SQ(PRED) = 0.00% R-SQ(ADJ) = 66.67%					

ANALYSIS OF VARIANCE FOR RESOURCE GATE 3 - GATE 6 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.408125	0.408125	0.08162	6.87	0.009

2-WAY INTERACTIONS	2	0.031250	0.031250	0.01562	1.32	0.321
RESIDUAL ERROR	8	0.095000	0.095000	0.01188		
PURE ERROR	8	0.095000	0.095000	0.01188		
TOTAL	15	0.534375				
REMOVELESS SIGNIFICANT FACTORS....						
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

TABLE 85- PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 2–GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

RESOURCE GATE 3- GATE 6: REVIEW 2 WITH ONLY NUMBER OF INSTRUMENST AND DESIGN COMPELXITY					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.5688	0.02885	19.71	0.000
NUMBER OF INSTRUMENTS	0.2125	0.1062	0.02885	3.68	0.003
DESIGN COMPLEXITY	0.2125	0.1063	0.02885	3.68	0.003
S = 0.115401 PRESS = 0.262249					
R-SQ = 67.60% R-SQ(PRED) = 50.92% R-SQ(ADJ) = 62.62%					

ANALYSIS OF VARIANCE FOR RESOURCE GATE 3 - GATE 6 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	0.36125	0.36125	0.18062	13.56	0.001
RESIDUAL ERROR	13	0.17313	0.17313	0.01332		
LACK OF FIT	1	0.03063	0.03063	0.03063	2.58	0.134
PURE ERROR	12	0.14250	0.14250	0.01187		
TOTAL	15	0.53437				
oRIGIONAL REVIEW 1 MODEL HAD HIGHER R-SQ ADJUSTED VALUE.						

RESOURCE GATE 6 – GATE 7

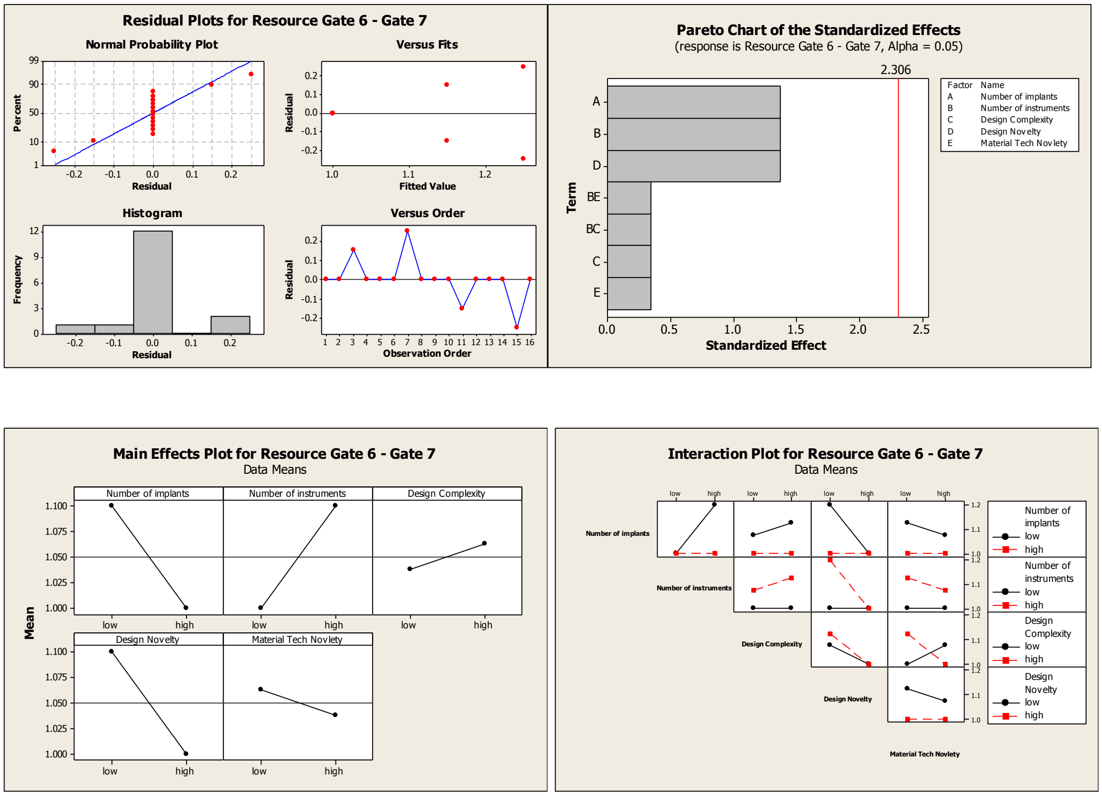


FIGURE 91 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 6 – GATE 7: RESIDUAL PLOTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

FROM FIGURE 91 IT IS CLEAR THAT NO. IMPLANTS, NO. INSTRUMENTS AND DESIGN NOVELTY ARE MUCH MORE SIGNIFICANT THAN THE OTHER FACTORS.

TABLE 86 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 6–GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 6 - GATE 7 REVIEW 2 (NO. IMPLANTS, NO. INST, NOVELTY)					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		1.05000	0.03062	34.29	0.000
NUMBER OF IMPLANTS	-0.10000	-0.05000	0.03062	-1.63	0.128
NUMBER OF INSTRUMENTS	0.10000	0.05000	0.03062	1.63	0.128
DESIGN NOVELTY	-0.10000	-0.05000	0.03062	-1.63	0.128
S = 0.122474 PRESS = 0.32					
R-SQ = 40.00% R-SQ(PRED) = 0.00% R-SQ(ADJ) = 25.00%					

ANALYSIS OF VARIANCE FOR RESOURCE GATE 6 - GATE 7 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	0.1200	0.1200	0.04000	2.67	0.095
RESIDUAL ERROR	12	0.1800	0.1800	0.01500		
PURE ERROR	12	0.1800	0.1800	0.01500		
TOTAL	15	0.3000				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

RESOURCE GATE 7 – GATE 8

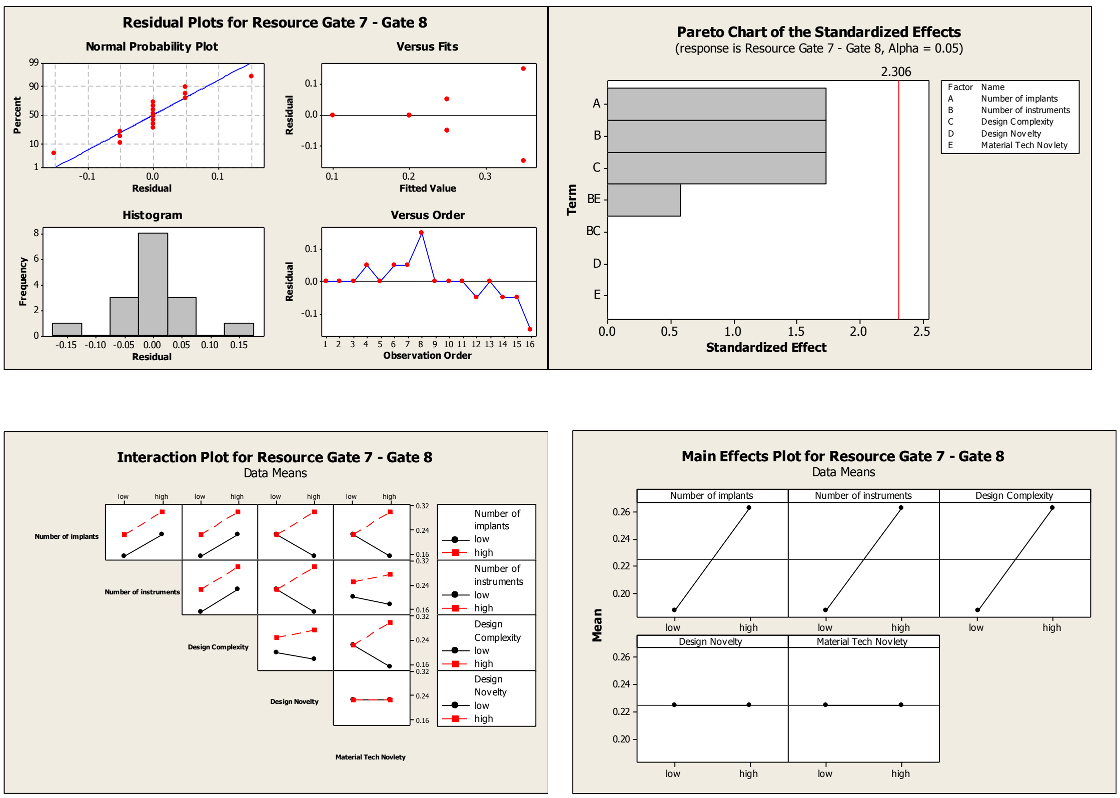


FIGURE 92 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 7 – GATE 8: RESIDUAL PLOTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 87 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 7–GATE 8, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 7 - GATE 8 REVIEW 1					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.225000	0.02165	10.39	0.000
NUMBER OF IMPLANTS	0.075000	0.037500	0.02165	1.73	0.122
NUMBER OF INSTRUMENTS	0.075000	0.037500	0.02165	1.73	0.122
DESIGN COMPLEXITY	0.075000	0.037500	0.02165	1.73	0.122
DESIGN NOVELTY	0.000000	0.000000	0.02165	0.00	1.000
MATERIAL TECH NOVELTY	0.000000	0.000000	0.02165	0.00	1.000

NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	0.000000	0.000000	0.02165	0.00	1.000
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	0.025000	0.012500	0.02165	0.58	0.580
S = 0.0866025 PRESS = 0.26					
R-SQ = 53.85% R-SQ(PRED) = 0.00% R-SQ(ADJ) = 13.46%					
ANALYSIS OF VARIANCE FOR RESOURCE GATE 7 - GATE 8 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.067500	0.067500	0.013500	1.80	0.219
2-WAY INTERACTIONS	2	0.002500	0.002500	0.001250	0.17	0.849
RESIDUAL ERROR	8	0.060000	0.060000	0.007500		
PURE ERROR	8	0.060000	0.060000	0.007500		
TOTAL	15	0.130000				
REMOVING ALL TERMS APART FROM NUMBER OF INSTRUMENTS, NUMBER OF IMPLANTS AND DESIGN COMPLEXITY….						

TABLE 88 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, RESOURCE GATE 6–GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

RESOURCE GATE 7 – GATE 8					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.22500	0.01804	12.47	0.000
NUMBER OF IMPLANTS	0.07500	0.03750	0.01804	2.08	0.060
NUMBER OF INSTRUMENTS	0.07500	0.03750	0.01804	2.08	0.060
DESIGN COMPLEXITY	0.07500	0.03750	0.01804	2.08	0.060
S = 0.0721688 PRESS = 0.111111					
R-SQ = 51.92% R-SQ(PRED) = 14.53% R-SQ(ADJ) = 39.90%					
ANALYSIS OF VARIANCE FOR RESOURCE GATE 7 - GATE 8 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	0.067500	0.067500	0.0225000	4.32	0.028
RESIDUAL ERROR	12	0.062500	0.062500	0.0052083		
LACK OF FIT	4	0.002500	0.002500	0.0006250	0.08	0.985
PURE ERROR	8	0.060000	0.060000	0.0075000		
TOTAL	15	0.130000				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

DURATION GATE 0 – GATE 1

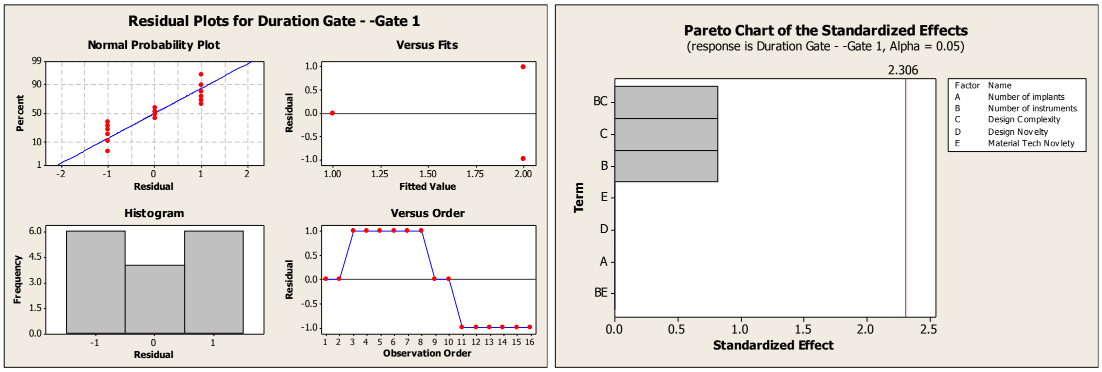


FIGURE 93 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 0 – GATE 1: RESIDUAL PLOTS, PARETO CHART

TABLE 89 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 0–GATE 1, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 0 – GATE 1 REVIEW 1						
TERM	EFFECT	COEF	SE COEF	T	P	
CONSTANT		1.7500	0.2500	7.00	0.000	
NUMBER OF INSTRUMENTS	0.5000	0.2500	0.2500	1.00	0.337	
DESIGN COMPLEXITY	0.5000	0.2500	0.2500	1.00	0.337	
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-0.5000	-0.2500	0.2500	-1.00	0.337	
S = 1	PRESS = 21.3333					
R-SQ = 20.00%	R-SQ(PRED) = 0.00%	R-SQ(ADJ) = 0.00%				
ANALYSIS OF VARIANCE FOR DURATION GATE - -GATE 1 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	2.000	2.000	1.000	1.00	0.397
2-WAY INTERACTIONS	1	1.000	1.000	1.000	1.00	0.337
RESIDUAL ERROR	12	12.000	12.000	1.000		
PURE ERROR	12	12.000	12.000	1.000		
TOTAL	15	15.000				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

DURATION GATE 1- CHARTER

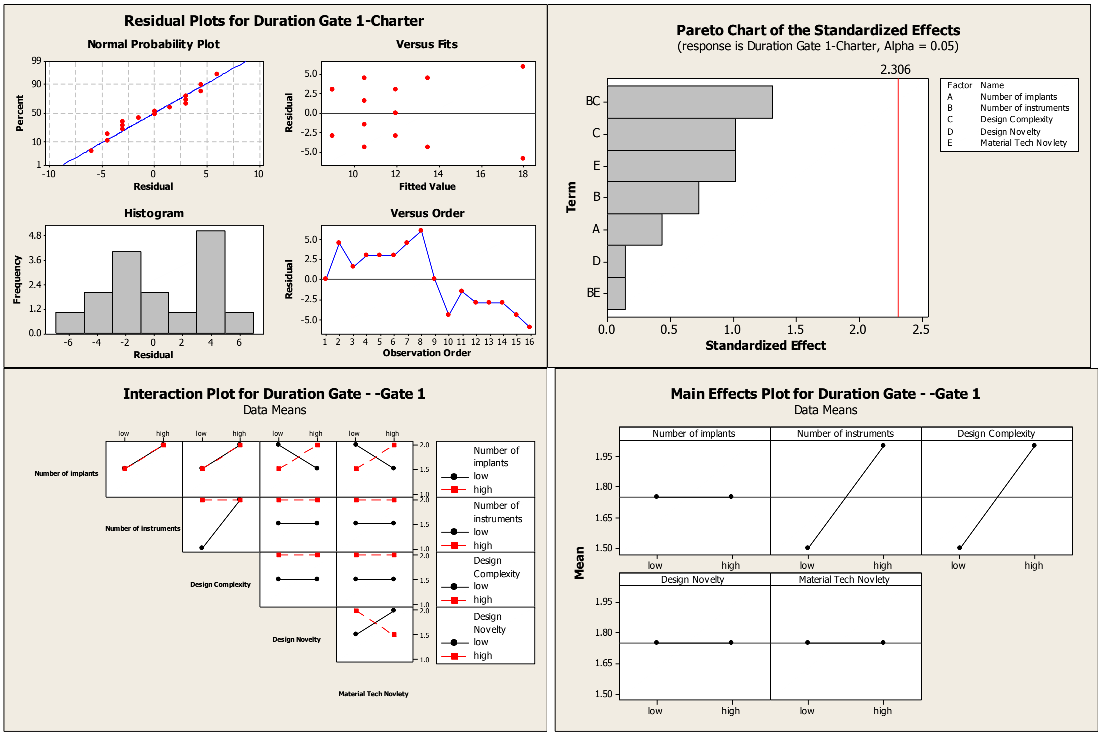


FIGURE 94 – PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 1- CHARTER: RESIDUAL PLOTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 90 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 1- CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 1 – CHARTER REVIEW 1					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		11.8125	1.285	9.19	0.000
NUMBER OF IMPLANTS	1.1250	0.5625	1.285	0.44	0.673
NUMBER OF INSTRUMENTS	1.8750	0.9375	1.285	0.73	0.487
DESIGN COMPLEXITY	2.6250	1.3125	1.285	1.02	0.337
DESIGN NOVELTY	0.3750	0.1875	1.285	0.15	0.888
MATERIAL TECH NOVELTY	2.6250	1.3125	1.285	1.02	0.337
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	3.3750	1.6875	1.285	1.31	0.226
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	0.3750	0.1875	1.285	0.15	0.888
S = 5.14174 PRESS = 1215					
R-SQ = 36.38% R-SQ(PRED) = 0.00% R-SQ(ADJ) = 0.00%					
ANALYSIS OF VARIANCE FOR DURATION GATE 1-CHARTER (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	74.813	74.813	14.96	0.57	0.725
2-WAY INTERACTIONS	2	46.125	46.125	23.06	0.87	0.454
RESIDUAL ERROR	8	211.500	211.500	26.44		
PURE ERROR	8	211.500	211.500	26.44		
TOTAL	15	332.438				
REMOVE EVERYTHING APART FROM NO. OF INSTRUMENTS, THE INSTRUMENT/ COMPLEXITY INTERACTION, DESIGN COMPLEXITY AND MATERIAL TECHNOLOGY.						

TABLE 91 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 1- CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION GATE 1- CHARTER REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		11.8125	1.112	10.62	0.000
NUMBER OF INSTRUMENTS	1.8750	0.9375	1.112	0.84	0.417
DESIGN COMPLEXITY	2.6250	1.3125	1.112	1.18	0.263
MATERIAL TECH NOVELTY	2.6250	1.3125	1.112	1.18	0.263
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	3.3750	1.6875	1.112	1.52	0.157
S = 4.44857 PRESS = 460.562					
R-SQ = 34.52% R-SQ(PRED) = 0.00% R-SQ(ADJ) = 10.71%					

ANALYSIS OF VARIANCE FOR DURATION GATE 1-CHARTER (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	69.187	69.187	23.062	1.17	0.367
2-WAY INTERACTIONS	1	45.563	45.563	45.563	2.30	0.157
RESIDUAL ERROR	11	217.688	217.688	19.790		
LACK OF FIT	3	6.188	6.188	2.063	0.08	0.970
PURE ERROR	8	211.500	211.500	26.438		
TOTAL	15	332.438				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

DURATION CHARTER – GATE 2

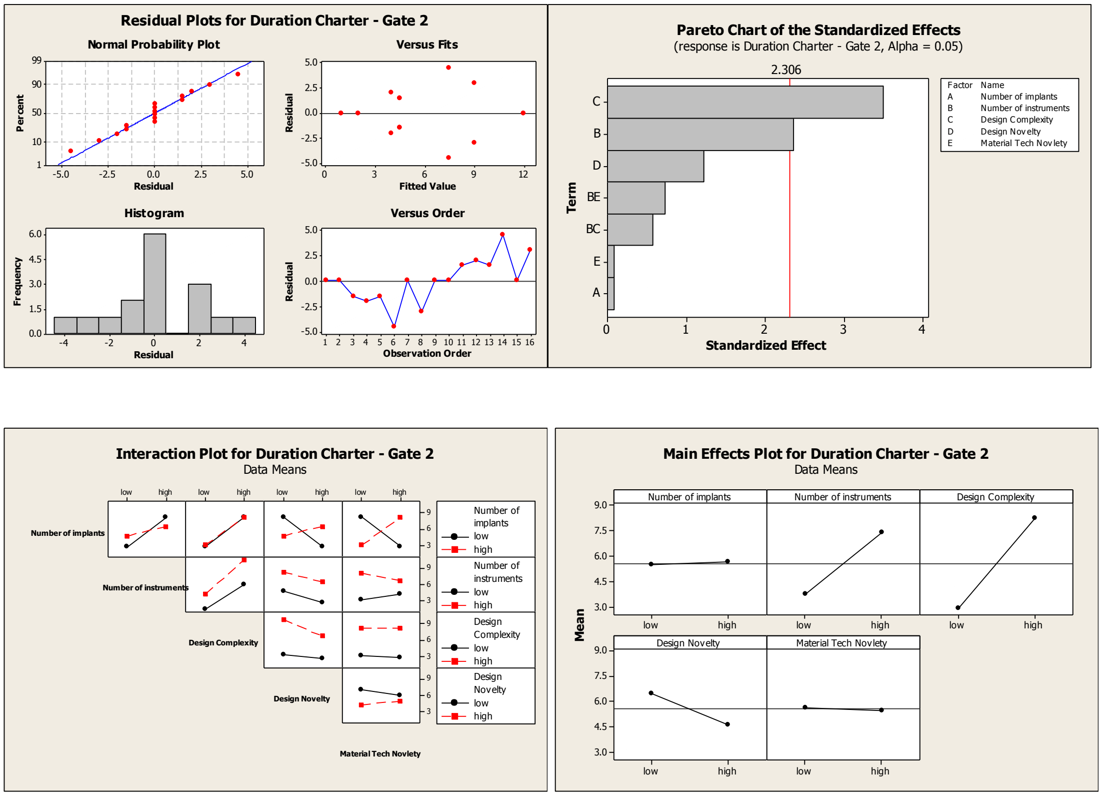


FIGURE 95 – PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION CHARTER – GATE 2: RESIDUAL PLOTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

FROM FIGURE 95 IT IS CLEAR THAT COMPLEXITY AND NO. OF INSTRUMENTS ARE THE MOST SIGNIFICANT CHARACTERISTICS.

TABLE 92 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION CHARTER- GATE 2, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

CHARTER - GATE 2 REVIEW 2 (NO. OF INSTRUMENTS AND COMPELXITY ONLY)					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		5.563	0.6857	8.11	0.000
NUMBER OF INSTRUMENTS	3.625	1.812	0.6857	2.64	0.020
DESIGN COMPLEXITY	5.375	2.688	0.6857	3.92	0.002
S = 2.74300 PRESS = 148.166					
R-SQ = 63.22% R-SQ(PRED) = 44.29% R-SQ(ADJ) = 57.56%					
ANALYSIS OF VARIANCE FOR DURATION CHARTER - GATE 2 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	168.125	168.125	84.063	11.17	0.002
RESIDUAL ERROR	13	97.812	97.812	7.524		
LACK OF FIT	1	3.062	3.062	3.062	0.39	0.545
PURE ERROR	12	94.750	94.750	7.896		
TOTAL	15	265.938				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

DURATION GATE 2 – GATE 3

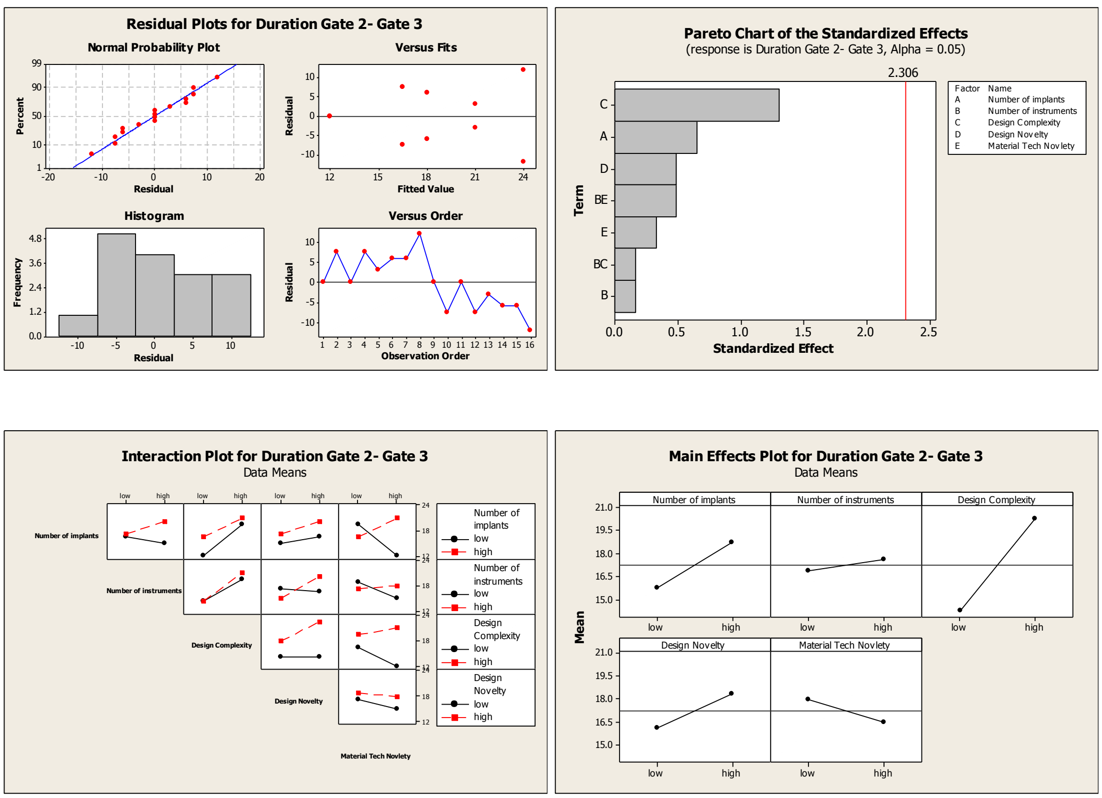


FIGURE 96 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 2- GATE 3: RESIDUAL PLOTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 93 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 2- GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 2- GATE 3 REVIEW 1					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		17.2500	2.296	7.51	0.000
NUMBER OF IMPLANTS	3.0000	1.5000	2.296	0.65	0.532
NUMBER OF INSTRUMENTS	0.7500	0.3750	2.296	0.16	0.874
DESIGN COMPLEXITY	6.0000	3.0000	2.296	1.31	0.228
DESIGN NOVELTY	2.2500	1.1250	2.296	0.49	0.637
MATERIAL TECH NOVELTY	-1.5000	-0.7500	2.296	-0.33	0.752
NUMBER OF INSTRUMENTS*	0.7500	0.3750	2.296	0.16	0.874

DESIGN COMPLEXITY					
NUMBER OF INSTRUMENTS*	2.2500	1.1250	2.296	0.49	0.637
MATERIAL TECH NOVELTY					
S = 9.18559	PRESS = 2880				
R-SQ = 25.74%	R-SQ(PRED) = 0.00%	R-SQ(ADJ) = 0.00%			
ANALYSIS OF VARIANCE FOR DURATION GATE 2- GATE 3 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	211.500	211.500	42.30	0.50	0.768
2-WAY INTERACTIONS	2	22.500	22.500	11.25	0.13	0.877
RESIDUAL ERROR	8	675.000	675.000	84.38		
PURE ERROR	8	675.000	675.000	84.38		
TOTAL	15	909.000				
REMOVE ALL FACTORS EXCEPT NO. IMPLANTS, DESIGN COMPLEXITY, DESIGN NOVELTY						

TABLE 94 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 2- GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION GATE 2 – GATE 3 REVIEW 2: ALL FACTORS EXCEPT NO. IMPLANTS, DESIGN COMPLEXITY, DESIGN NOVELTY					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		17.250	1.921	8.98	0.000
NUMBER OF IMPLANTS	3.000	1.500	1.921	0.78	0.450
DESIGN COMPLEXITY	6.000	3.000	1.921	1.56	0.144
DESIGN NOVELTY	2.250	1.125	1.921	0.59	0.569
S = 7.68521	PRESS = 1260				
R-SQ = 22.03%	R-SQ(PRED) = 0.00%	R-SQ(ADJ) = 2.54%			
ANALYSIS OF VARIANCE FOR DURATION GATE 2- GATE 3 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	200.25	200.25	66.750	1.13	0.376
RESIDUAL ERROR	12	708.75	708.75	59.062		
LACK OF FIT	4	33.75	33.75	8.437	0.10	0.979
PURE ERROR	8	675.00	675.00	84.375		
TOTAL	15	909.00				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

DURATION GATE 3- GATE 6

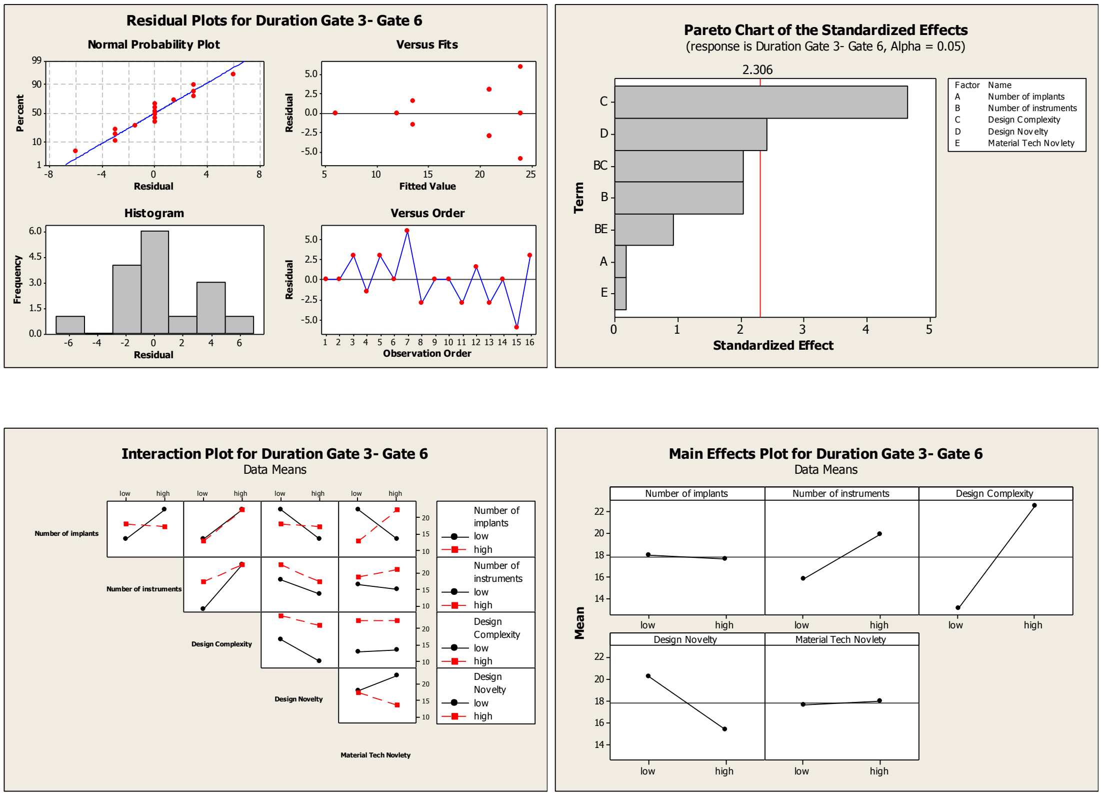


FIGURE 97 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 3- GATE 6: RESIDUAL PLOTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 95 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 2- GATE 6, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 3- GATE 6 REVIEW 1					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		17.813	1.010	17.64	0.000
NUMBER OF IMPLANTS	-0.375	-0.187	1.010	-0.19	0.857
NUMBER OF INSTRUMENTS	4.125	2.062	1.010	2.04	0.075
DESIGN COMPLEXITY	9.375	4.687	1.010	4.64	0.002
DESIGN NOVELTY	-4.875	-2.438	1.010	-2.41	0.042
MATERIAL TECH NOVELTY	0.375	0.187	1.010	0.19	0.857
NUMBER OF INSTRUMENTS*	-4.125	-2.063	1.010	-2.04	0.075
DESIGN COMPLEXITY					
NUMBER OF INSTRUMENTS*	1.875	0.938	1.010	0.93	0.380
MATERIAL TECH NOVELTY					
S = 4.03887 PRESS = 1179					
R-SQ = 82.08% R-SQ(PRED) = 0.00% R-SQ(ADJ) = 66.41%					

ANALYSIS OF VARIANCE FOR DURATION GATE 3- GATE 6 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	515.812	515.812	103.16	6.32	0.012
2-WAY INTERACTIONS	2	82.125	82.125	41.06	2.52	0.142
RESIDUAL ERROR	8	130.500	130.500	16.31		
PURE ERROR	8	130.500	130.500	16.31		
TOTAL	15	728.438				
REMOVE LEAST SIGNIFICANT FACTORS…..						

TABLE 96 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 2- GATE 6, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION GATE 3- GATE 6 REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		17.813	0.9098	19.58	0.000
NUMBER OF INSTRUMENTS	4.125	2.062	0.9098	2.27	0.045
DESIGN COMPLEXITY	9.375	4.688	0.9098	5.15	0.000
DESIGN NOVELTY	-4.875	-2.438	0.9098	-2.68	0.021
NUMBER OF INSTRUMENTS*	-4.125	-2.063	0.9098	-2.27	0.045
DESIGN COMPLEXITY					
S = 3.63927 PRESS = 308.231					
R-SQ = 80.00% R-SQ(PRED) = 57.69% R-SQ(ADJ) = 72.73%					
ANALYSIS OF VARIANCE FOR DURATION GATE 3- GATE 6 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	514.69	514.69	171.563	12.95	0.001
2-WAY INTERACTIONS	1	68.06	68.06	68.063	5.14	0.045
RESIDUAL ERROR	11	145.69	145.69	13.244		
LACK OF FIT	3	15.19	15.19	5.063	0.31	0.818
PURE ERROR	8	130.50	130.50	16.313		
TOTAL	15	728.44				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

DURATION GATE 6 – GATE 7

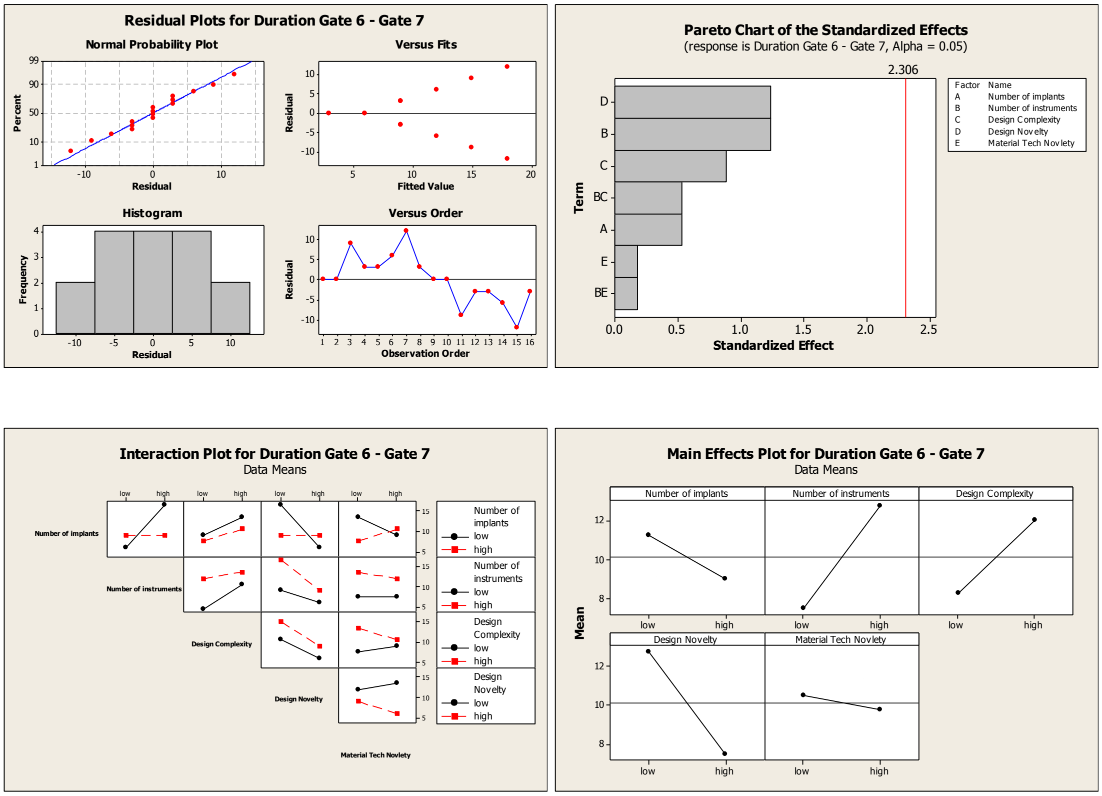


FIGURE 98 - FIGURE 99 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 6-GATE 7: RESIDUAL PLOTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 97- PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 6- GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 6 - GATE 7 REVIEW 1					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		10.125	2.121	4.77	0.001
NUMBER OF IMPLANTS	-2.250	-1.125	2.121	-0.53	0.610
NUMBER OF INSTRUMENTS	5.250	2.625	2.121	1.24	0.251
DESIGN COMPLEXITY	3.750	1.875	2.121	0.88	0.403
DESIGN NOVELTY	-5.250	-2.625	2.121	-1.24	0.251
MATERIAL TECH NOVELTY	-0.750	-0.375	2.121	-0.18	0.864
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-2.250	-1.125	2.121	-0.53	0.610
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	-0.750	-0.375	2.121	-0.18	0.864
S = 8.48528 PRESS = 2484					

R-SQ = 35.84%	R-SQ(PRED) = 0.00%	R-SQ(ADJ) = 0.00%				
ANALYSIS OF VARIANCE FOR DURATION GATE 6 - GATE 7 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	299.250	299.250	59.85	0.83	0.562
2-WAY INTERACTIONS	2	22.500	22.500	11.25	0.16	0.858
RESIDUAL ERROR	8	576.000	576.000	72.00		
PURE ERROR	8	576.000	576.000	72.00		
TOTAL	15	897.750				
REMOVE ALL FACTORS EXCEPT NO. INSTRUMNETS, DESIGN COMPLEXITY, DESIGN NOVELTY, NO. INSTRUMENTS * DESIGN COMPLEXITY...						

TABLE 98 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 6- GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION GATE 6 - GATE 7 REVIEW 2: ALL FACTORS REMOVED EXCEPT NO. INST, DESIGN COMPLEXITY, DESIGN NOVELTY AND NO. INSTUMENTS * DESIGN COMPLEXITY					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		10.125	1.848	5.48	0.000
NUMBER OF INSTRUMENTS	5.250	2.625	1.848	1.42	0.183
DESIGN COMPLEXITY	3.750	1.875	1.848	1.01	0.332
DESIGN NOVELTY	-5.250	-2.625	1.848	-1.42	0.183
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-2.250	-1.125	1.848	-0.61	0.555
S = 7.39010	PRESS = 1271.01				
R-SQ = 33.08%	R-SQ(PRED) = 0.00%	R-SQ(ADJ) = 8.75%			

ANALYSIS OF VARIANCE FOR DURATION GATE 6 - GATE 7 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	276.75	276.75	92.250	1.69	0.227
2-WAY INTERACTIONS	1	20.25	20.25	20.250	0.37	0.555
RESIDUAL ERROR	11	600.75	600.75	54.614		
LACK OF FIT	3	24.75	24.75	8.250	0.11	0.949
PURE ERROR	8	576.00	576.00	72.000		
TOTAL	15	897.75				
REMOVE NO. INSTUMENTS * DESIGN COMPLEXITY						

TABLE 99 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 6- GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 3.

DURATION GATE 6 - GATE 7 REVIEW 3					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		10.125	1.798	5.63	0.000
NUMBER OF INSTRUMENTS	5.250	2.625	1.798	1.46	0.170
DESIGN COMPLEXITY	3.750	1.875	1.798	1.04	0.318
DESIGN NOVELTY	-5.250	-2.625	1.798	-1.46	0.170
S = 7.19375	PRESS = 1104				
R-SQ = 30.83%	R-SQ(PRED) = 0.00%	R-SQ(ADJ) = 13.53%			
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT					

DURATION GATE 7 – GATE 8

TABLE 100 - PROJECT MANAGEMENT, COMBINED RESULTS MODEL, DURATION GATE 7- GATE 8, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 7 - GATE 8 USING DATA	
TERM	COEF
CONSTANT	12.0000
CONSISTENTLY = 12 MONTHS	

2.2.2 PROJECT MANAGEMENT MODEL ANALYSIS BASED UPON RESPODNENT #1 RESULTS

FRACTIONAL FACTORIAL DESIGN

FACTORS: 5 BASE DESIGN: 5, 8 RESOLUTION: III
REVIEWS: 8 REPLICATES: 1 FRACTION: 1/4
BLOCKS: 1 CENTER PTS (TOTAL): 0

* NOTE * SOME MAIN EFFECTS ARE CONFOUNDED WITH TWO-WAY INTERACTIONS.

DESIGN GENERATORS: D = AB, E = AC

ALIAS STRUCTURE

I + ABD + ACE + BCDE

A + BD + CE + ABCDE
B + AD + CDE + ABCE
C + AE + BDE + ABCD
D + AB + BCE + ACDE
E + AC + BCD + ABDE
BC + DE + ABE + ACD
BE + CD + ABC + ADE

RESOURCE GATE 0 – GATE 1

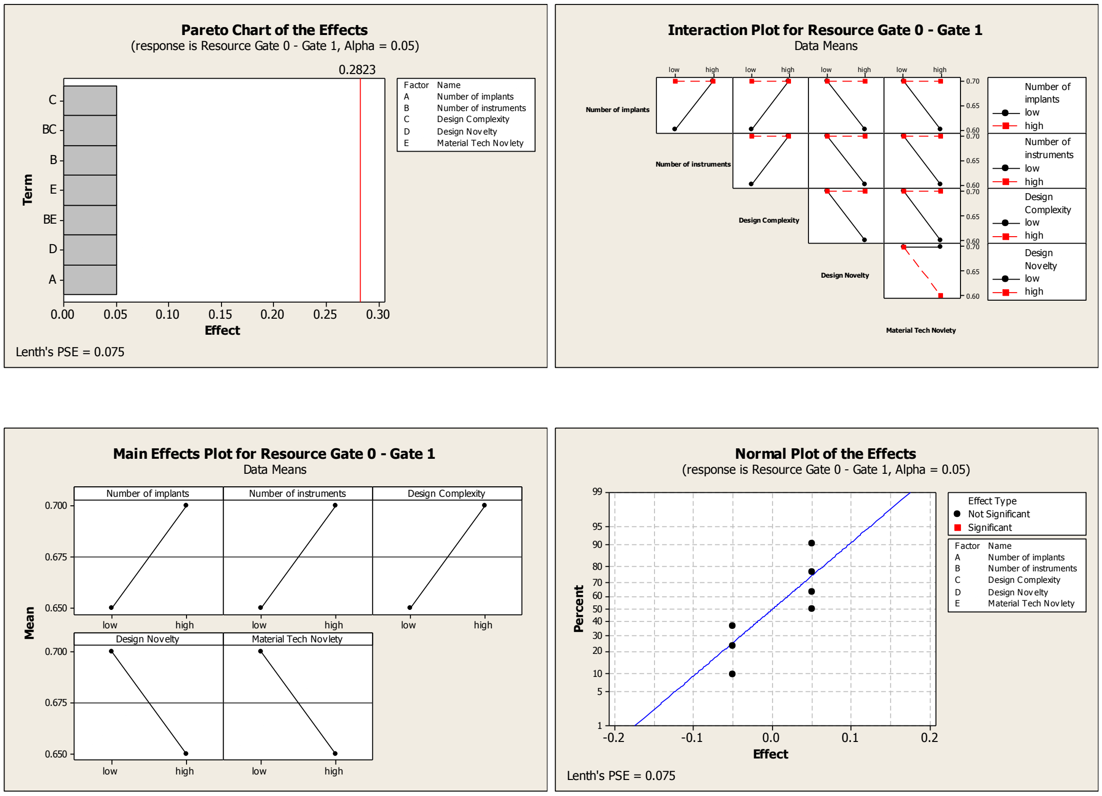


FIGURE 100 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 0 – GATE 1: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 101 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 0-GATE 1, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 0 - GATE 1 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		0.67500
NUMBER OF IMPLANTS	0.05000	0.02500
NUMBER OF INSTRUMENTS	0.05000	0.02500
DESIGN COMPLEXITY	0.05000	0.02500
DESIGN NOVELTY	-0.05000	-0.02500
MATERIAL TECH NOVELTY	-0.05000	-0.02500
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-0.05000	-0.02500
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	0.05000	0.02500
S = * PRESS = *		

ANALYSIS OF VARIANCE FOR RESOURCE GATE 0 - GATE 1 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.02500	0.02500	0.005000	*	*
2-WAY INTERACTIONS	2	0.01000	0.01000	0.005000	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	0.03500				
ALL FACTORS ARE SIGNIFICANT - THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

RESOURCE GATE 1- CHARTER

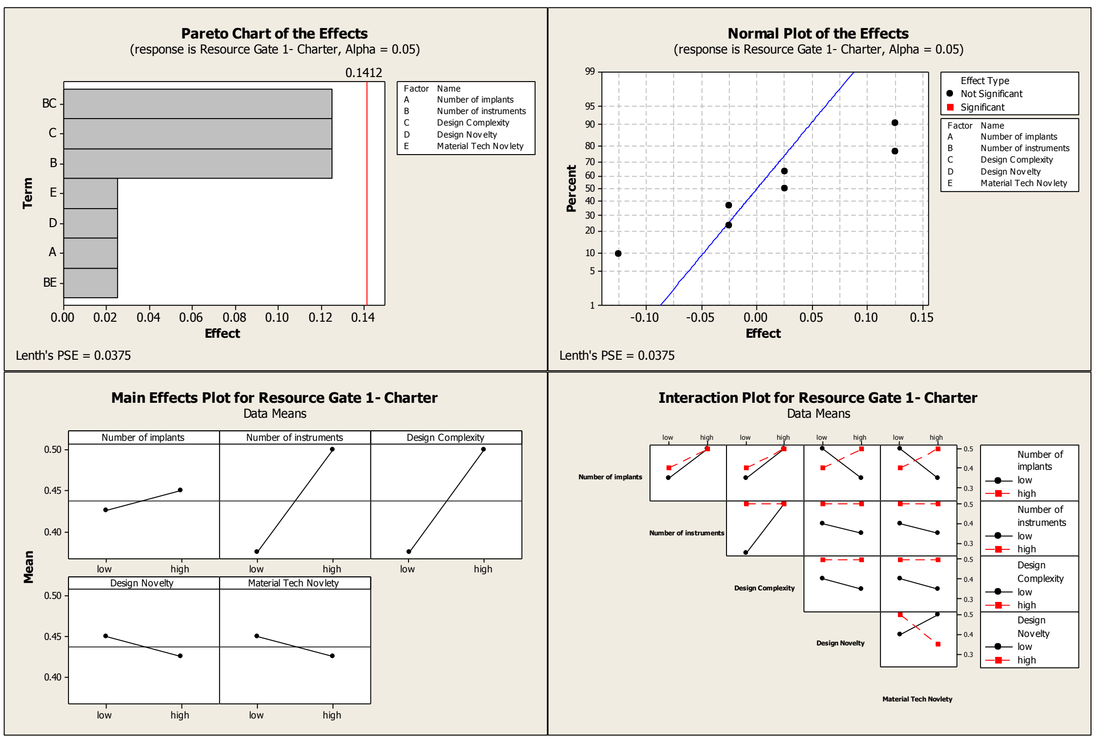


FIGURE 101 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 1 – CHARTER: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 102 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 1 - CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 1- CHARTER		
TERM	EFFECT	COEF
CONSTANT		0.43750

NUMBER OF IMPLANTS	0.02500	0.01250
NUMBER OF INSTRUMENTS	0.12500	0.06250
DESIGN COMPLEXITY	0.12500	0.06250
DESIGN NOVELTY	-0.02500	-0.01250
MATERIAL TECH NOVELTY	-0.02500	-0.01250
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-0.12500	-0.06250
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	0.02500	0.01250

S = * PRESS = *

ANALYSIS OF VARIANCE FOR RESOURCE GATE 1- CHARTER (CODED UNITS)

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.06625	0.06625	0.01325	*	*
2-WAY INTERACTIONS	2	0.03250	0.03250	0.01625	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	0.09875				

REMOVING ALL FACTORS EXCEPT NO. INSTRUMENTS, DESIGN COMPLEXITY AND NO. INSTRUMENTS * DESIGN COMPLEXITY….

TABLE 103 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 1 - CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

RESOURCE GATE 1- CHARTER REVIEW 2

TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.43750	0.01250	35.00	0.000
NUMBER OF INSTRUMENTS	0.12500	0.06250	0.01250	5.00	0.007
DESIGN COMPLEXITY	0.12500	0.06250	0.01250	5.00	0.007
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-0.12500	-0.06250	0.01250	-5.00	0.007

S = 0.0353553 PRESS = 0.02

R-SQ = 94.94% R-SQ(PRED) = 79.75% R-SQ(ADJ) = 91.14%

ANALYSIS OF VARIANCE FOR RESOURCE GATE 1- CHARTER (CODED UNITS)

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	0.062500	0.062500	0.031250	25.00	0.005
2-WAY INTERACTIONS	1	0.031250	0.031250	0.031250	25.00	0.007
RESIDUAL ERROR	4	0.005000	0.005000	0.001250		
PURE ERROR	4	0.005000	0.005000	0.001250		
TOTAL	7	0.098750				

THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT

RESOURCE CHARTER – GATE 2

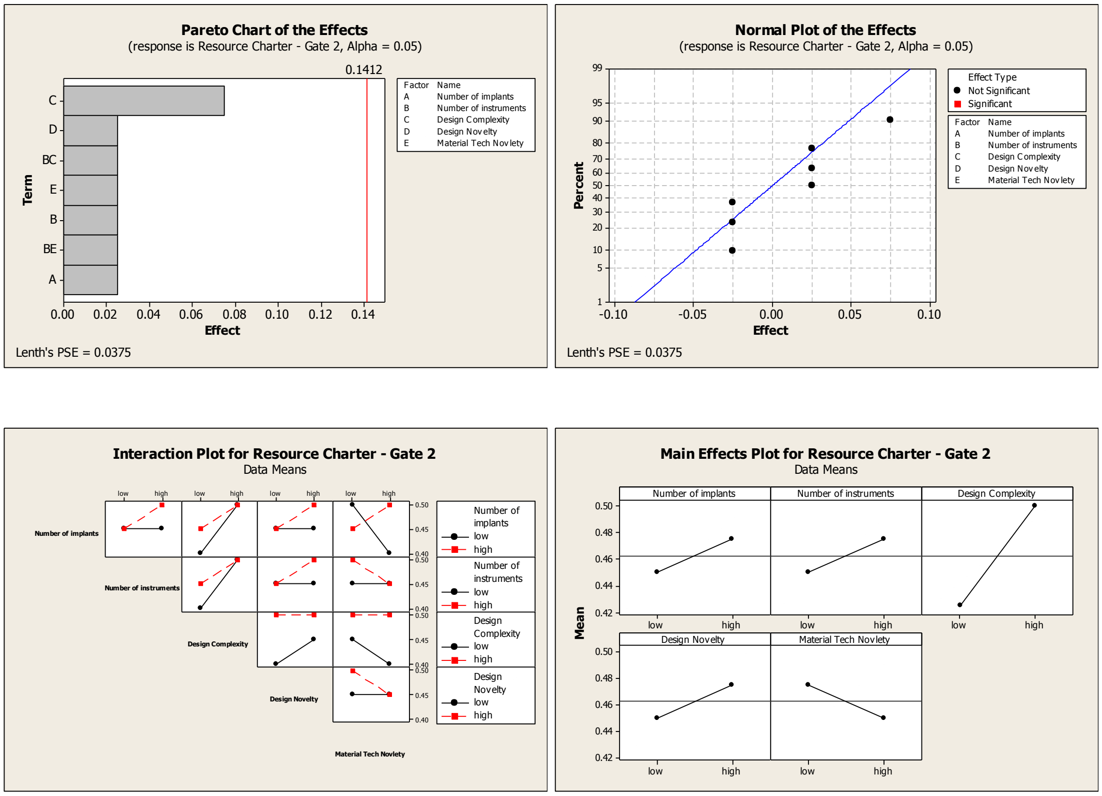


FIGURE 102 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE CHARTER – GATE 2: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 104 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE CHARTER – GATE 2, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE CHARTER - GATE 2 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		0.46250
NUMBER OF IMPLANTS	0.02500	0.01250
NUMBER OF INSTRUMENTS	0.02500	0.01250
DESIGN COMPLEXITY	0.07500	0.03750
DESIGN NOVELTY	0.02500	0.01250
MATERIAL TECH NOVELTY	-0.02500	-0.01250
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-0.02500	-0.01250
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	-0.02500	-0.01250
S = * PRESS = *		

ANALYSIS OF VARIANCE FOR RESOURCE CHARTER - GATE 2 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.016250	0.016250	0.003250	*	*
2-WAY INTERACTIONS	2	0.002500	0.002500	0.001250	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	0.018750				
REMOVE ALL TERMS EXCEPT DESIGN COMPLEXITY….						

TABLE 105 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE CHARTER – GATE 2, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

RESOURCE CHARTER – GATE 2 REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.46250	0.01250	37.00	0.000
DESIGN COMPLEXITY	0.07500	0.03750	0.01250	3.00	0.024
S = 0.0353553	PRESS = 0.0133333				
R-SQ = 60.00%	R-SQ(PRED) = 28.89%	R-SQ(ADJ) = 53.33%			

ANALYSIS OF VARIANCE FOR RESOURCE CHARTER - GATE 2 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	1	0.011250	0.011250	0.011250	9.00	0.024
RESIDUAL ERROR	6	0.007500	0.007500	0.001250		
PURE ERROR	6	0.007500	0.007500	0.001250		
TOTAL	7	0.018750				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

RESOURCE GATE 2 – GATE 3

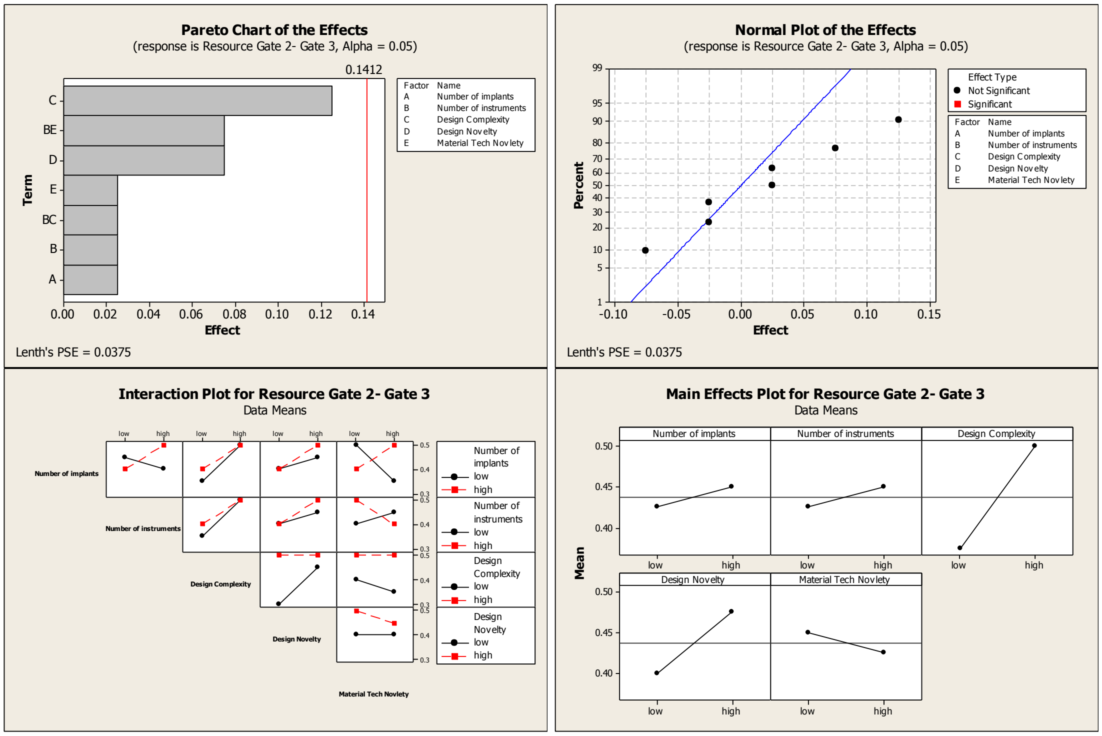


FIGURE 103 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 2 – GATE 3: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 106 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 2 – GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 2- GATE 3 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		0.43750
NUMBER OF IMPLANTS	0.02500	0.01250
NUMBER OF INSTRUMENTS	0.02500	0.01250
DESIGN COMPLEXITY	0.12500	0.06250
DESIGN NOVELTY	0.07500	0.03750
MATERIAL TECH NOVELTY	-0.02500	-0.01250
NUMBER OF INSTRUMENTS*	-0.02500	-0.01250
DESIGN COMPLEXITY		
NUMBER OF INSTRUMENTS*	-0.07500	-0.03750
MATERIAL TECH NOVELTY		
S = * PRESS = *		
ANALYSIS OF VARIANCE FOR RESOURCE GATE 2- GATE 3 (CODED UNITS)		

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.04625	0.04625	0.009250	*	*
2-WAY INTERACTIONS	2	0.01250	0.01250	0.006250	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	0.05875				
REMOVE LEAST SIGNIFICANT FACTORS – INCLUDE NO. INST, DESIGN COMPLEXITY, DESIGN NOVELTY, MAT TECH NOVELTY AND NO. INST * MAT TECH NOVELTY.						

TABLE 107- PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 2 – GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

RESOURCE GATE 2- GATE 3 REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.43750	0.01250	35.00	0.001
NUMBER OF INSTRUMENTS	0.02500	0.01250	0.01250	1.00	0.423
DESIGN COMPLEXITY	0.12500	0.06250	0.01250	5.00	0.038
DESIGN NOVELTY	0.07500	0.03750	0.01250	3.00	0.095
MATERIAL TECH NOVELTY	-0.02500	-0.01250	0.01250	-1.00	0.423
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	-0.07500	-0.03750	0.01250	-3.00	0.095
S = 0.0353553 PRESS = 0.04					
R-SQ = 95.74% R-SQ(PRED) = 31.91% R-SQ(ADJ) = 85.11%					
ANALYSIS OF VARIANCE FOR RESOURCE GATE 2- GATE 3 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	4	0.045000	0.045000	0.011250	9.00	0.102
2-WAY INTERACTIONS	1	0.011250	0.011250	0.011250	9.00	0.095
RESIDUAL ERROR	2	0.002500	0.002500	0.001250		
TOTAL	7	0.058750				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

RESOURCE GATE 3- GATE 6

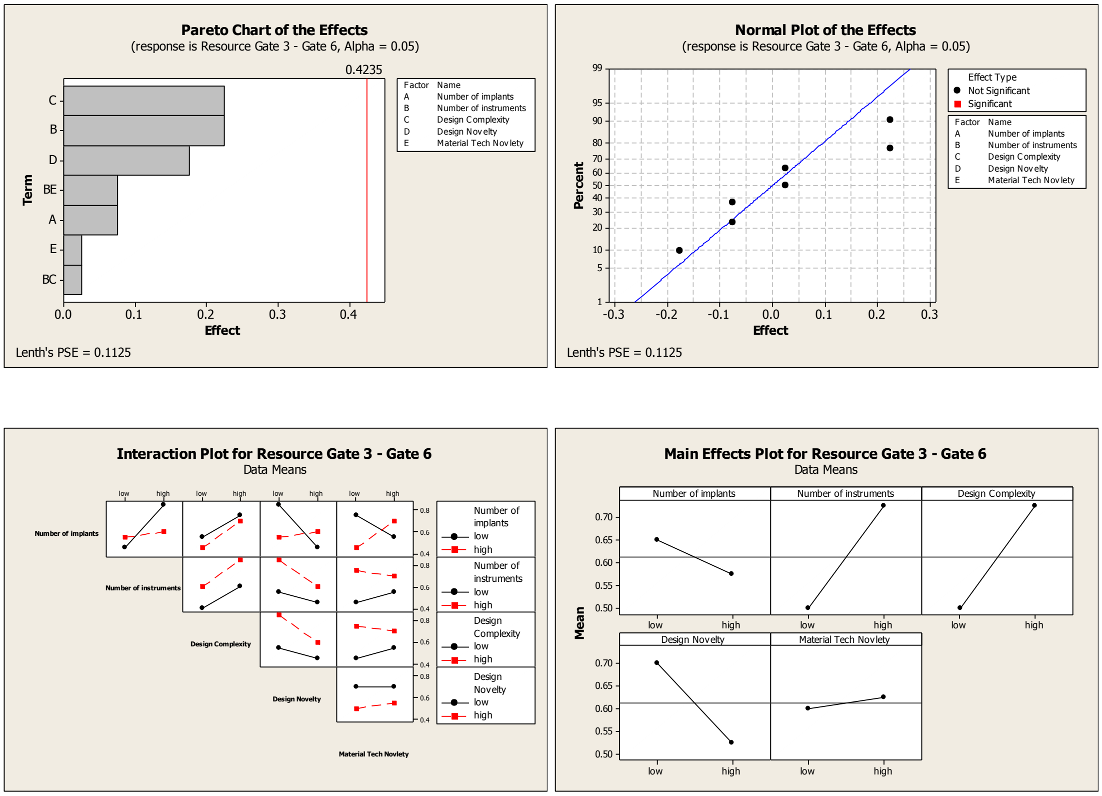


FIGURE 104 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 3 – GATE 6: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 108 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 3– GATE 6, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 3 – GATE 6 REVIEW 2 (NO. INSTRUMENTS, DESIGN COMPLEXITY, DESIGN NOVELTY)						
TERM		EFFECT	COEF	SE COEF	T	P
CONSTANT			0.61250	0.02795	21.91	0.000
NUMBER OF INSTRUMENTS		0.22500	0.11250	0.02795	4.02	0.016
DESIGN COMPLEXITY		0.22500	0.11250	0.02795	4.02	0.016
DESIGN NOVELTY		-0.17500	-0.08750	0.02795	-3.13	0.035
S = 0.0790569	PRESS = 0.1					
R-SQ = 91.34%	R-SQ(PRED) = 65.37%		R-SQ(ADJ) = 84.85%			
ANALYSIS OF VARIANCE FOR RESOURCE GATE 3 - GATE 6 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P

MAIN EFFECTS	3	0.26375	0.26375	0.087917	14.07	0.014
RESIDUAL ERROR	4	0.02500	0.02500	0.006250		
TOTAL	7	0.28875				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

RESOURCE GATE 6 – GATE 7

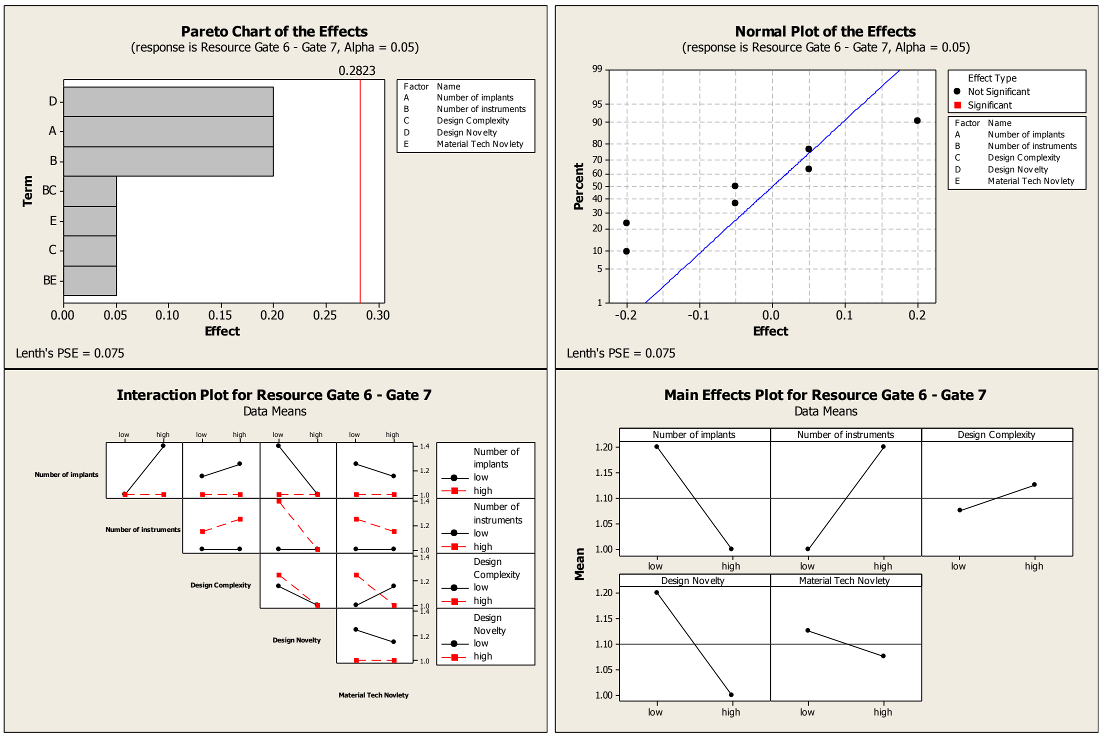


FIGURE 105 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 6 – GATE 7: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 109 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 6– GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 6 - GATE 7 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		1.1000
NUMBER OF IMPLANTS	-0.2000	-0.1000
NUMBER OF INSTRUMENTS	0.2000	0.1000
DESIGN COMPLEXITY	0.0500	0.0250
DESIGN NOVELTY	-0.2000	-0.1000
MATERIAL TECH NOVELTY	-0.0500	-0.0250
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	0.0500	0.0250
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	-0.0500	-0.0250
S = * PRESS = *		

ANALYSIS OF VARIANCE FOR RESOURCE GATE 6 - GATE 7 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.25000	0.25000	0.050000	*	*
2-WAY INTERACTIONS	2	0.01000	0.01000	0.005000	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	0.26000				
REMOVE ALL FACTORS EXCEPT DESIGN NOVELTY, NO. OF INSTRUMENTS AND NO. OF IMPLANTS						

TABLE 110 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 6– GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

RESOURCE GATE 6 – 7 REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		1.1000	0.02500	44.00	0.000
NUMBER OF IMPLANTS	-0.2000	-0.1000	0.02500	-4.00	0.016
NUMBER OF INSTRUMENTS	0.2000	0.1000	0.02500	4.00	0.016
DESIGN NOVELTY	-0.2000	-0.1000	0.02500	-4.00	0.016
S = 0.0707107 PRESS = 0.08					
R-SQ = 92.31% R-SQ(PRED) = 69.23% R-SQ(ADJ) = 86.54%					
ANALYSIS OF VARIANCE FOR RESOURCE GATE 6 - GATE 7 (CODED UNITS)					
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	0.24000	0.24000	0.080000	16.00	0.011
RESIDUAL ERROR	4	0.02000	0.02000	0.005000		
PURE ERROR	4	0.02000	0.02000	0.005000		
TOTAL	7	0.26000				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

RESOURCE GATE 7 – GATE 8

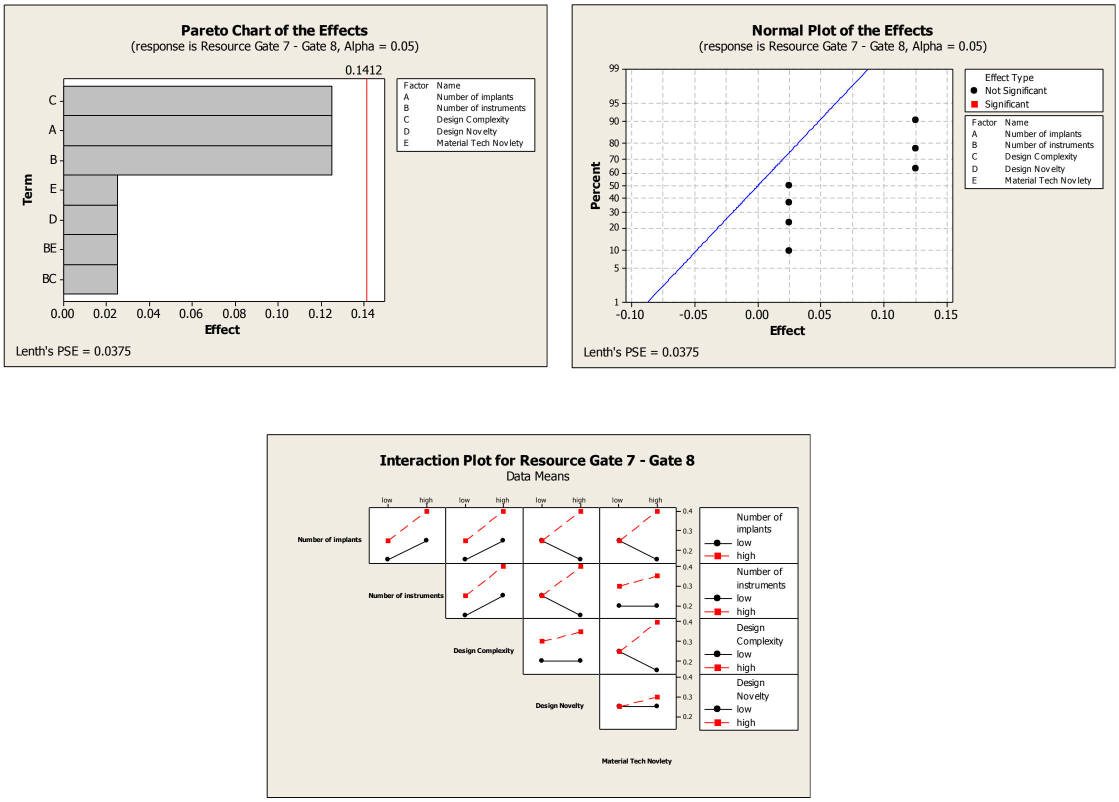


FIGURE 106 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 7 – GATE 8: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS.

TABLE 111 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, RESOURCE GATE 7– GATE 8, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 7 - GATE 8 REVIEW 1					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.26250	0.01250	21.00	0.000
NUMBER OF IMPLANTS	0.12500	0.06250	0.01250	5.00	0.007
NUMBER OF INSTRUMENTS	0.12500	0.06250	0.01250	5.00	0.007
DESIGN COMPLEXITY	0.12500	0.06250	0.01250	5.00	0.007
S = 0.0353553 PRESS = 0.02					
R-SQ = 94.94% R-SQ(PRED) = 79.75% R-SQ(ADJ) = 91.14%					
ANALYSIS OF VARIANCE FOR RESOURCE GATE 7 - GATE 8 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	0.093750	0.093750	0.031250	25.00	0.005
RESIDUAL ERROR	4	0.005000	0.005000	0.001250		
TOTAL	7	0.098750				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

DURATION GATE 0 – GATE 1

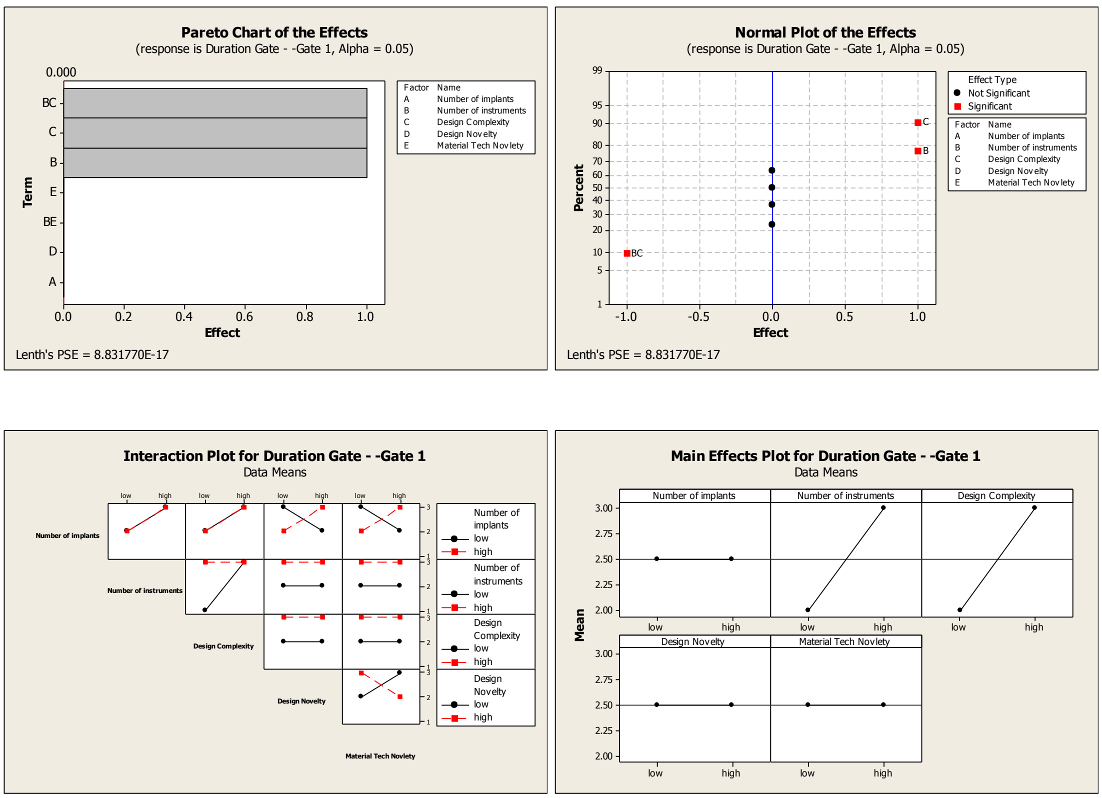


FIGURE 107 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 0 – GATE 1: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 112 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 0– GATE 1, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE - GATE 1 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		2.5000
NUMBER OF IMPLANTS	-0.0000	-0.0000
NUMBER OF INSTRUMENTS	1.0000	0.5000
DESIGN COMPLEXITY	1.0000	0.5000
DESIGN NOVELTY	0.0000	0.0000

MATERIAL TECH NOVELTY	0.0000	0.0000
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-1.0000	-0.5000
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	0.0000	0.0000

S = * PRESS = *

ANALYSIS OF VARIANCE FOR DURATION GATE - -GATE 1 (CODED UNITS)

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	4.000	4.000	0.8000	*	*
2-WAY INTERACTIONS	2	2.000	2.000	1.0000	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	6.000				

REMOVE ALL FACTORS EXCEPT NO. OF INSTRUMENTS, COMPLEXITY AND NO. OF INSTUMENTS * COMPLEXITY

TABLE 113 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 0– GATE 1, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION GATE - -GATE 1 REVIEW 2

TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		2.5000	0	*	*
NUMBER OF INSTRUMENTS	1.0000	0.5000	0	*	*
DESIGN COMPLEXITY	1.0000	0.5000	0	*	*
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-1.0000	-0.5000	0	*	*

S = 0 PRESS = 0

R-SQ = 100.00% R-SQ(PRED) = 100.00% R-SQ(ADJ) = 100.00%

ANALYSIS OF VARIANCE FOR DURATION GATE - -GATE 1 (CODED UNITS)

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	4.000	4.000	2.000	*	*
2-WAY INTERACTIONS	1	2.000	2.000	2.000	*	*
RESIDUAL ERROR	4	0.000	0.000	0.000		
PURE ERROR	4	0.000	0.000	0.000		
TOTAL	7	6.000				

THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT

DURATION GATE 1- CHARTER

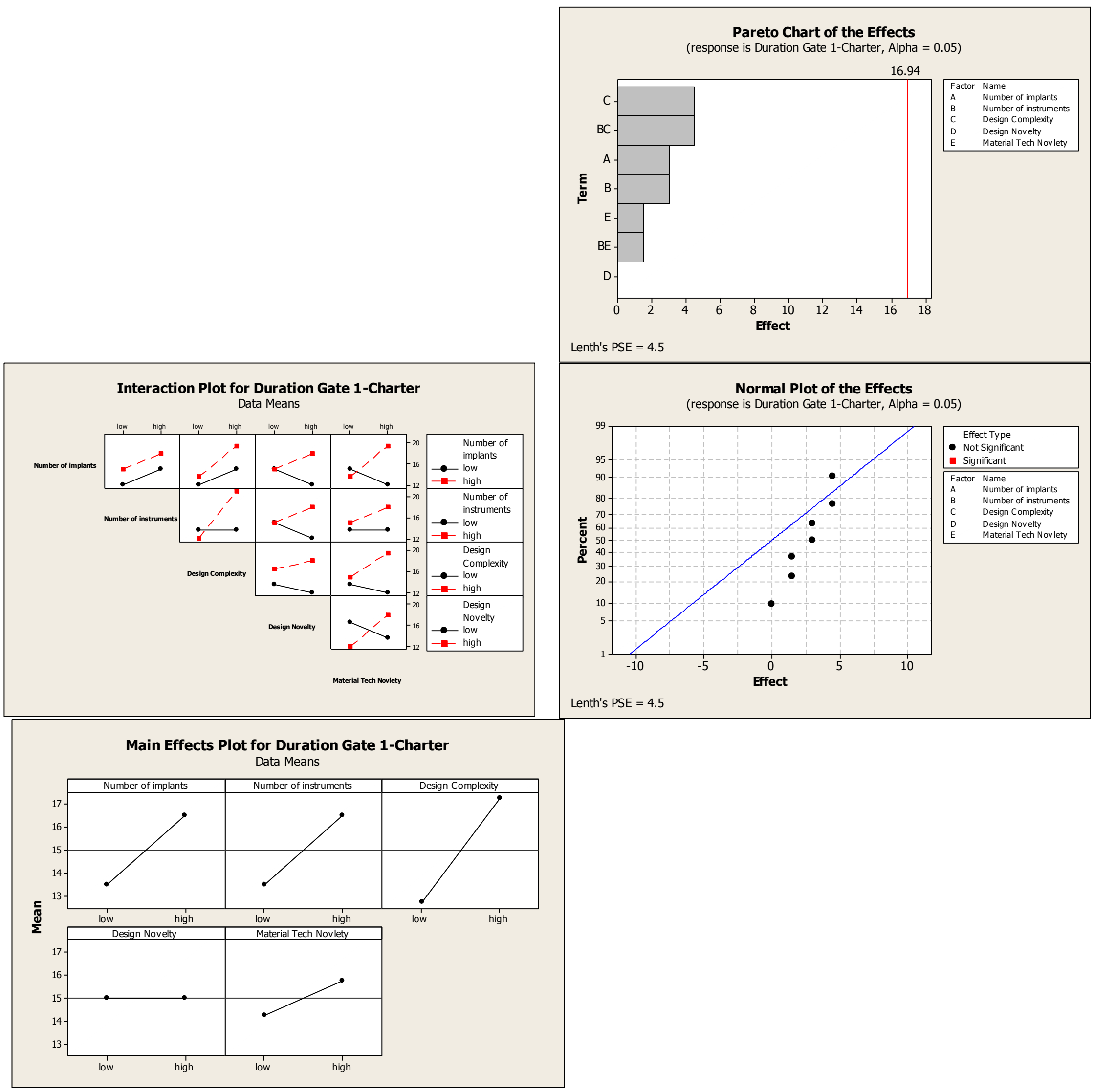


FIGURE 108 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 1 - CHARTER: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 114 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 1 - CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 1- CHARTER REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		15.0000
NUMBER OF IMPLANTS	3.0000	1.5000
NUMBER OF INSTRUMENTS	3.0000	1.5000
DESIGN COMPLEXITY	4.5000	2.2500
DESIGN NOVELTY	-0.0000	-0.0000
MATERIAL TECH NOVELTY	1.5000	0.7500
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	4.5000	2.2500
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	1.5000	0.7500
S = * PRESS = *		
ANALYSIS OF VARIANCE FOR DURATION GATE 1-CHARTER (CODED UNITS)		

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	81.00	81.00	16.20	*	*
2-WAY INTERACTIONS	2	45.00	45.00	22.50	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	126.00				
REMOVE ALL FACTORS EXCEPT NO. IMPLANTS, NO. INSTRUMENTS. DESIGN COMPLEXITY AND NO. INSTRUMENTS * DESIGN COMPLEXITY						

TABLE 115 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 1 - CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION GATE 1-CHARTER REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		15.000	0.6124	24.49	0.000
NUMBER OF IMPLANTS	3.000	1.500	0.6124	2.45	0.092
NUMBER OF INSTRUMENTS	3.000	1.500	0.6124	2.45	0.092
DESIGN COMPLEXITY	4.500	2.250	0.6124	3.67	0.035
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	4.500	2.250	0.6124	3.67	0.035
S = 1.73205 PRESS = 64					
R-SQ = 92.86% R-SQ(PRED) = 49.21% R-SQ(ADJ) = 83.33%					
ANALYSIS OF VARIANCE FOR DURATION GATE 1-CHARTER (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	76.500	76.500	25.500	8.50	0.056
2-WAY INTERACTIONS	1	40.500	40.500	40.500	13.50	0.035
RESIDUAL ERROR	3	9.000	9.000	3.000		
TOTAL	7	126.000				

THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT

DURATION CHARTER – GATE 2

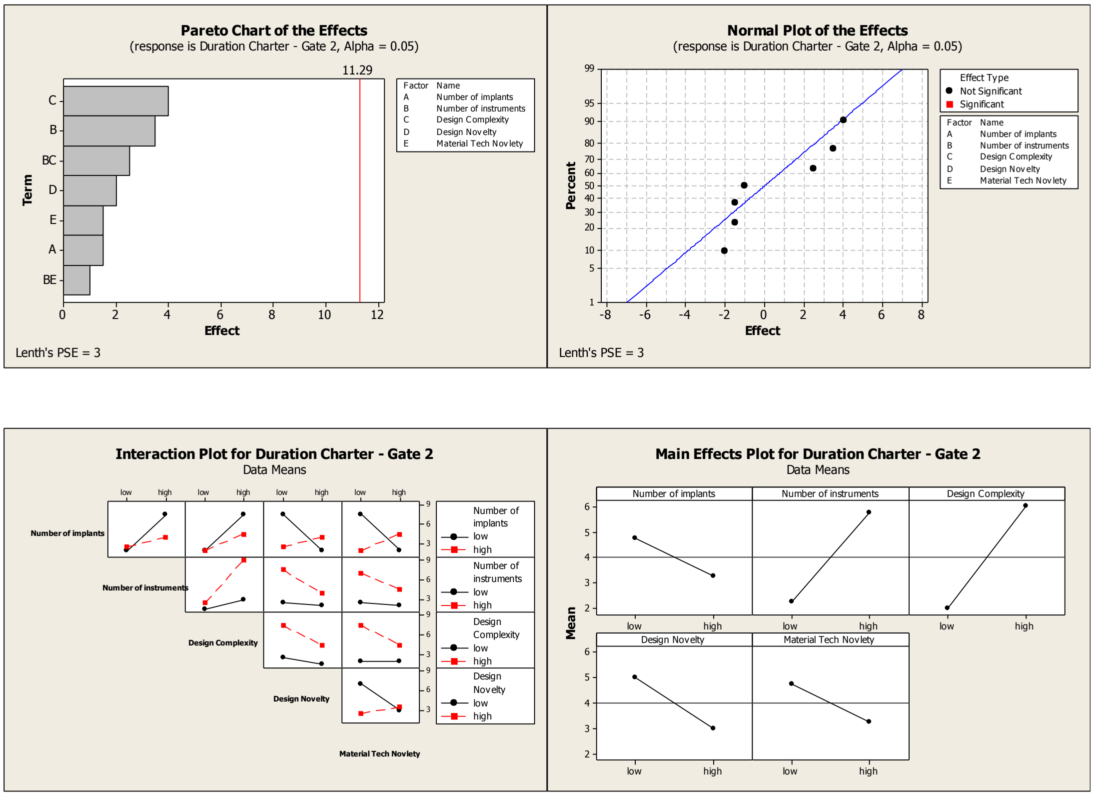


FIGURE 109 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION CHARTER – GATE 2: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 116 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION CHARTER – GATE 2, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION CHARTER - GATE 2 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		4.000
NUMBER OF IMPLANTS	-1.500	-0.750
NUMBER OF INSTRUMENTS	3.500	1.750
DESIGN COMPLEXITY	4.000	2.000
DESIGN NOVELTY	-2.000	-1.000
MATERIAL TECH NOVELTY	-1.500	-0.750
NUMBER OF INSTRUMENTS*	2.500	1.250
DESIGN COMPLEXITY		
NUMBER OF INSTRUMENTS*	-1.000	-0.500
MATERIAL TECH NOVELTY		
S = * PRESS = *		
ANALYSIS OF VARIANCE FOR DURATION CHARTER - GATE 2 (CODED UNITS)		

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	73.50	73.50	14.700	*	*
2-WAY INTERACTIONS	2	14.50	14.50	7.250	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	88.00				
REMOVE ALL FACTORS EXCEPT NO. OF INSTRUMENTS, DESIGN COMPLEXITY AND NO. OF INSTRUMENTS * DESIGN COMPLEXITY						

TABLE 117 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION CHARTER – GATE 2, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION CHARTER - GATE 2 REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		4.000	0.7706	5.19	0.007
NUMBER OF INSTRUMENTS	3.500	1.750	0.7706	2.27	0.086
DESIGN COMPLEXITY	4.000	2.000	0.7706	2.60	0.060
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	2.500	1.250	0.7706	1.62	0.180
S = 2.17945	PRESS = 76				
R-SQ = 78.41%	R-SQ(PRED) = 13.64%	R-SQ(ADJ) = 62.22%			
ANALYSIS OF VARIANCE FOR DURATION CHARTER - GATE 2 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	56.50	56.50	28.250	5.95	0.063
2-WAY INTERACTIONS	1	12.50	12.50	12.500	2.63	0.180
RESIDUAL ERROR	4	19.00	19.00	4.750		
PURE ERROR	4	19.00	19.00	4.750		
TOTAL	7	88.00				
RE – INTRODUCE DESIGN NOVELTY…..						

TABLE 118 PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION CHARTER – GATE 2, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 3.

DURATION CHARTER – GATE 2 REVIEW 3					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		4.000	0.6770	5.91	0.010
NUMBER OF INSTRUMENTS	3.500	1.750	0.6770	2.58	0.081
DESIGN COMPLEXITY	4.000	2.000	0.6770	2.95	0.060
DESIGN NOVELTY	-2.000	-1.000	0.6770	-1.48	0.236
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	2.500	1.250	0.6770	1.85	0.162
S = 1.91485	PRESS = 78.2222				
R-SQ = 87.50%	R-SQ(PRED) = 11.11%	R-SQ(ADJ) = 70.83%			

ANALYSIS OF VARIANCE FOR DURATION CHARTER - GATE 2 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	64.50	64.50	21.500	5.86	0.090
2-WAY INTERACTIONS	1	12.50	12.50	12.500	3.41	0.162
RESIDUAL ERROR	3	11.00	11.00	3.667		
TOTAL	7	88.00				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

DURATION GATE 2- GATE 3

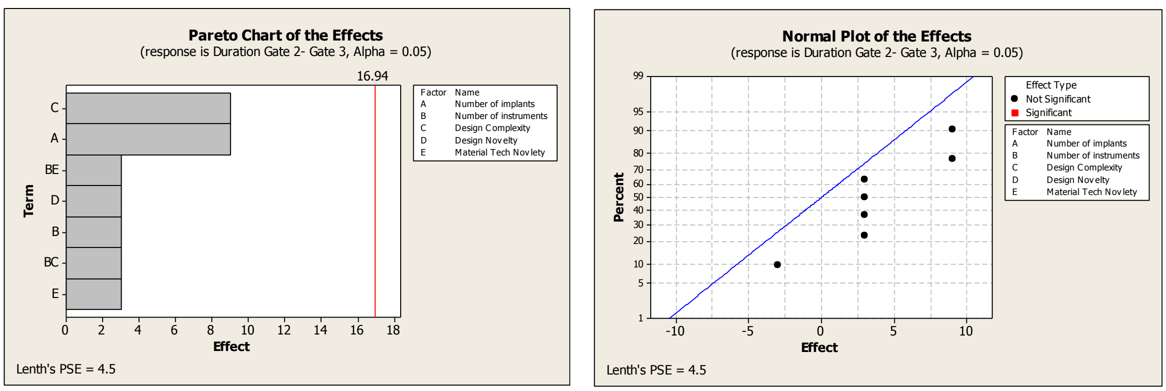


FIGURE 110 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 2 – GATE 3: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 119 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 2 – GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 2- GATE 3 REVIEW 1						
TERM		EFFECT	COEF			
CONSTANT			22.500			
NUMBER OF IMPLANTS		9.000	4.500			
NUMBER OF INSTRUMENTS		3.000	1.500			
DESIGN COMPLEXITY		9.000	4.500			
DESIGN NOVELTY		3.000	1.500			
MATERIAL TECH NOVELTY		-3.000	-1.500			
NUMBER OF INSTRUMENTS*		3.000	1.500			
DESIGN COMPLEXITY						
NUMBER OF INSTRUMENTS*		3.000	1.500			
MATERIAL TECH NOVELTY						
S = * PRESS = *						
ANALYSIS OF VARIANCE FOR DURATION GATE 2- GATE 3 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	378.00	378.00	75.60	*	*
2-WAY INTERACTIONS	2	36.00	36.00	18.00	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	414.00				

REMOVE ALL FACTORS EXCEPT NO. OF IMPLANTS AND DESIGN COMPLEXITY

TABLE 120 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 2 – GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION GATE 2- GATE 3 REVIEW 2 – NO. IMPLANTS AND DESIGN COMPLEXITY ONLY					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		22.500	1.500	15.00	0.000
NUMBER OF IMPLANTS	9.000	4.500	1.500	3.00	0.030
DESIGN COMPLEXITY	9.000	4.500	1.500	3.00	0.030
S = 4.24264	PRESS = 230.4				
R-SQ = 78.26%	R-SQ(PRED) = 44.35%	R-SQ(ADJ) = 69.57%			
ANALYSIS OF VARIANCE FOR DURATION GATE 2- GATE 3 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	324.00	324.00	162.00	9.00	0.022
RESIDUAL ERROR	5	90.00	90.00	18.00		
LACK OF FIT	1	18.00	18.00	18.00	1.00	0.374
PURE ERROR	4	72.00	72.00	18.00		
TOTAL	7	414.00				

THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT

DURATION GATE 3 - GATE 6

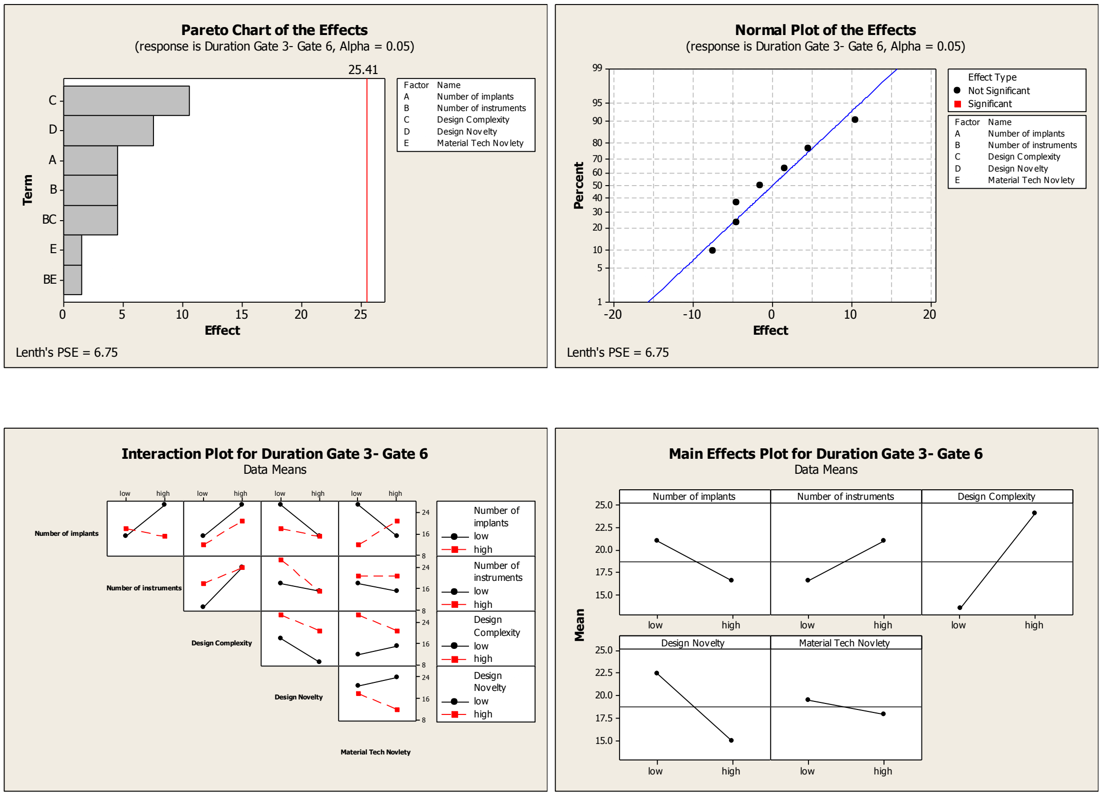


FIGURE 111 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 3 – GATE 6: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 121 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 3 – GATE 6, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 3- GATE 6 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		18.750
NUMBER OF IMPLANTS	-4.500	-2.250
NUMBER OF INSTRUMENTS	4.500	2.250
DESIGN COMPLEXITY	10.500	5.250
DESIGN NOVELTY	-7.500	-3.750
MATERIAL TECH NOVELTY	-1.500	-0.750
NUMBER OF INSTRUMENTS*	-4.500	-2.250
DESIGN COMPLEXITY		
NUMBER OF INSTRUMENTS*	1.500	0.750
MATERIAL TECH NOVELTY		
S = * PRESS = *		
ANALYSIS OF VARIANCE FOR DURATION GATE 3- GATE 6 (CODED UNITS)		

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	418.50	418.50	83.70	*	*
2-WAY INTERACTIONS	2	45.00	45.00	22.50	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	463.50				
REMOVE ALL FACTORS EXCEPT DESIGN COMPLEXITY AND DESIGN NOVELTY						

TABLE 122 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 3 – GATE 6, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

ESTIMATED EFFECTS AND COEFFICIENTS FOR DURATION GATE 3- GATE 6 (CODED UNITS)					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		18.750	1.806	10.38	0.000
DESIGN COMPLEXITY	10.500	5.250	1.806	2.91	0.034
DESIGN NOVELTY	-7.500	-3.750	1.806	-2.08	0.093
S = 5.10882 PRESS = 334.08					
R-SQ = 71.84% R-SQ(PRED) = 27.92% R-SQ(ADJ) = 60.58%					
ANALYSIS OF VARIANCE FOR DURATION GATE 3- GATE 6 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	333.000	333.000	166.500	6.38	0.042
RESIDUAL ERROR	5	130.500	130.500	26.100		
LACK OF FIT	1	4.500	4.500	4.500	0.14	0.725
PURE ERROR	4	126.000	126.000	31.500		
TOTAL	7	463.500				
RE - INTRODUCE NO. IMPLANTS, NO. OF INSTRUMENTS AND NO. OF INSTRUMENTS * COMPLEXITY						

TABLE 123 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 3 – GATE 6, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 3.

DURATION GATE 3- GATE 6 REVIEW 3					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		18.750	0.7500	25.00	0.002
NUMBER OF IMPLANTS	-4.500	-2.250	0.7500	-3.00	0.095
NUMBER OF INSTRUMENTS	4.500	2.250	0.7500	3.00	0.095
DESIGN COMPLEXITY	10.500	5.250	0.7500	7.00	0.020
DESIGN NOVELTY	-7.500	-3.750	0.7500	-5.00	0.038
NUMBER OF INSTRUMENTS*	-4.500	-2.250	0.7500	-3.00	0.095
DESIGN COMPLEXITY					
S = 2.12132 PRESS = 144					
R-SQ = 98.06% R-SQ(PRED) = 68.93% R-SQ(ADJ) = 93.20%					
ANALYSIS OF VARIANCE FOR DURATION GATE 3- GATE 6 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	4	414.000	414.000	103.500	23.00	0.042
2-WAY INTERACTIONS	1	40.500	40.500	40.500	9.00	0.095
RESIDUAL ERROR	2	9.000	9.000	4.500		
TOTAL	7	463.500				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

DURATION GATE 6 – GATE 7

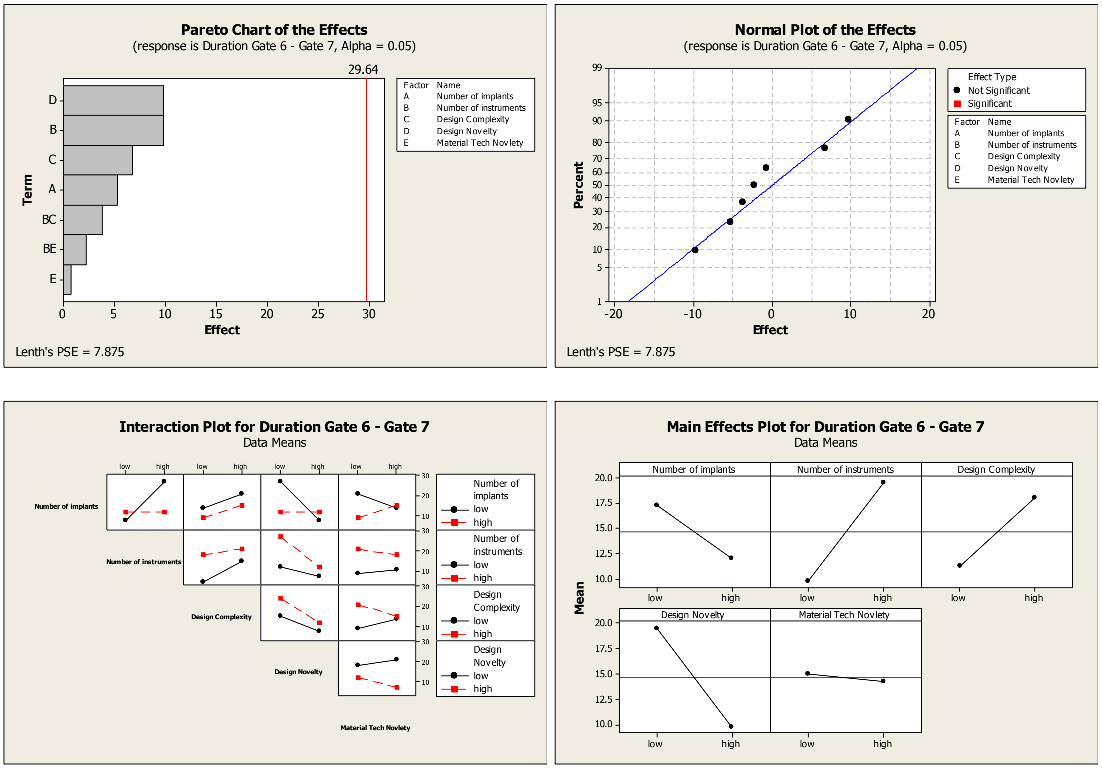


FIGURE 112- PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 6 – GATE 7: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 124 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 6 – GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 6 - GATE 7 REVIEW 1						
TERM	EFFECT	COEF				
CONSTANT		14.625				
NUMBER OF IMPLANTS	-5.250	-2.625				
NUMBER OF INSTRUMENTS	9.750	4.875				
DESIGN COMPLEXITY	6.750	3.375				
DESIGN NOVELTY	-9.750	-4.875				
MATERIAL TECH NOVELTY	-0.750	-0.375				
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-3.750	-1.875				
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	-2.250	-1.125				
S = * PRESS = *						
ANALYSIS OF VARIANCE FOR DURATION GATE 6 - GATE 7 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	527.62	527.62	105.52	*	*

2-WAY INTERACTIONS	2	38.25	38.25	19.12	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	565.87				
REMOVE LEAST SIGNIFICANT FACTORS – LEAVING NO. OF INSTRUMENTS AND DESIGN NOVELTY						

TABLE 125 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 6 – GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION GATE 6 - GATE 7 REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		14.625	2.154	6.79	0.001
NUMBER OF INSTRUMENTS	9.750	4.875	2.154	2.26	0.073
DESIGN NOVELTY	-9.750	-4.875	2.154	-2.26	0.073
S = 6.09303	PRESS = 475.2				
R-SQ = 67.20%	R-SQ(PRED) = 16.02%	R-SQ(ADJ) = 54.08%			
ANALYSIS OF VARIANCE FOR DURATION GATE 6 - GATE 7 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	380.25	380.25	190.12	5.12	0.062
RESIDUAL ERROR	5	185.62	185.62	37.12		
LACK OF FIT	1	55.12	55.12	55.12	1.69	0.263
PURE ERROR	4	130.50	130.50	32.63		
TOTAL	7	565.87				
REINTRODUCE NO. OF IMPLANTS AND DESIGN COMPLEXITY						

TABLE 126 - PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 6 – GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 3.

DURATION GATE 6 - GATE 7 REVIEW 3					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		14.625	1.281	11.42	0.001
NUMBER OF IMPLANTS	-5.250	-2.625	1.281	-2.05	0.133
NUMBER OF INSTRUMENTS	9.750	4.875	1.281	3.81	0.032
DESIGN COMPLEXITY	6.750	3.375	1.281	2.63	0.078
DESIGN NOVELTY	-9.750	-4.875	1.281	-3.81	0.032
S = 3.62284	PRESS = 280				
R-SQ = 93.04%	R-SQ(PRED) = 50.52%	R-SQ(ADJ) = 83.76%			
ANALYSIS OF VARIANCE FOR DURATION GATE 6 - GATE 7 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	4	526.50	526.50	131.62	10.03	0.044
RESIDUAL ERROR	3	39.37	39.37	13.12		
TOTAL	7	565.87				

THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT

DURATION GATE 7 – GATE 8

TABLE 127- PROJECT MANAGEMENT, RESPONDENT #1 MODEL, DURATION GATE 7– GATE 8, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 7 - GATE 8		
TERM	EFFECT	COEF
CONSTANT		12.0000
NUMBER OF IMPLANTS	0.0000	0.0000
NUMBER OF INSTRUMENTS	0.0000	0.0000
DESIGN COMPLEXITY	0.0000	0.0000
DESIGN NOVELTY	0.0000	0.0000
MATERIAL TECH NOVELTY	0.0000	0.0000
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	0.0000	0.0000
NUMBER OF INSTRUMENTS* MATERIAL TECH NOVELTY	0.0000	0.0000
DURATION GATE 6- GATE 7 IS CONSISTENTLY 12		

PROJECT MANAGEMENT MODEL ANALYSIS BASED UPON RESPONDENT #2 RESULTS

FRACTIONAL FACTORIAL DESIGN

FACTORS: 5 BASE DESIGN: 5, 8 RESOLUTION: III
REVIEWS: 8 REPLICATES: 1 FRACTION: 1/4
BLOCKS: 1 CENTER PTS (TOTAL): 0

* NOTE * SOME MAIN EFFECTS ARE CONFOUNDED WITH TWO-WAY INTERACTIONS.

DESIGN GENERATORS: D = AB, E = AC

ALIAS STRUCTURE

I + ABD + ACE + BCDE

A + BD + CE + ABCDE
B + AD + CDE + ABCE
C + AE + BDE + ABCD
D + AB + BCE + ACDE
E + AC + BCD + ABDE
BC + DE + ABE + ACD
BE + CD + ABC + ADE

RESOURCE GATE 0 – GATE 1

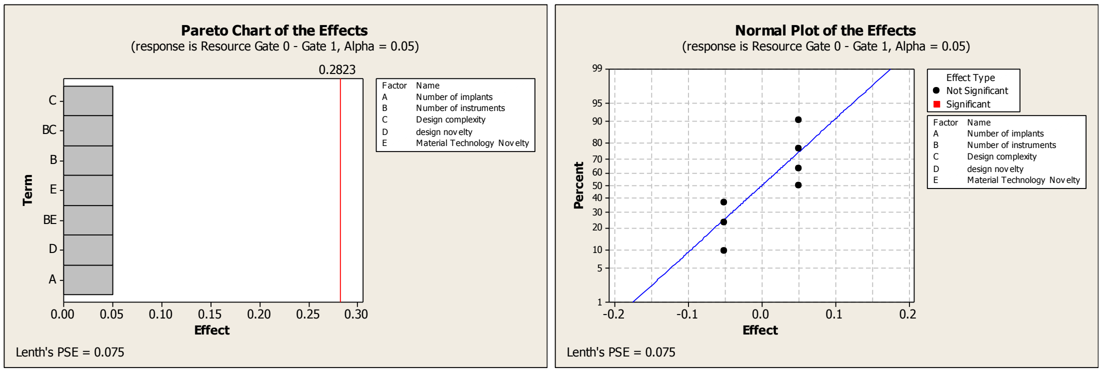


FIGURE 113 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 0 – GATE 1: NORMAL PLOT OF EFFECTS, PARETO CHART.

TABLE 128 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 0 – GATE 1, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 0 - GATE 1 REVIEW 1						
TERM		EFFECT	COEF			
CONSTANT			0.67500			
NUMBER OF IMPLANTS		0.05000	0.02500			
NUMBER OF INSTRUMENTS		0.05000	0.02500			
DESIGN COMPLEXITY		0.05000	0.02500			
DESIGN NOVELTY		-0.05000	-0.02500			
MATERIAL TECHNOLOGY NOVELTY		-0.05000	-0.02500			
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY		-0.05000	-0.02500			
NUMBER OF INSTRUMENTS* MATERIAL TECHNOLOGY NOVELTY		0.05000	0.02500			
S = * PRESS = *						
ANALYSIS OF VARIANCE FOR RESOURCE GATE 0 - GATE 1 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.02500	0.02500	0.005000	*	*
2-WAY INTERACTIONS	2	0.01000	0.01000	0.005000	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	0.03500				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

RESOURCE GATE 1- CHARTER

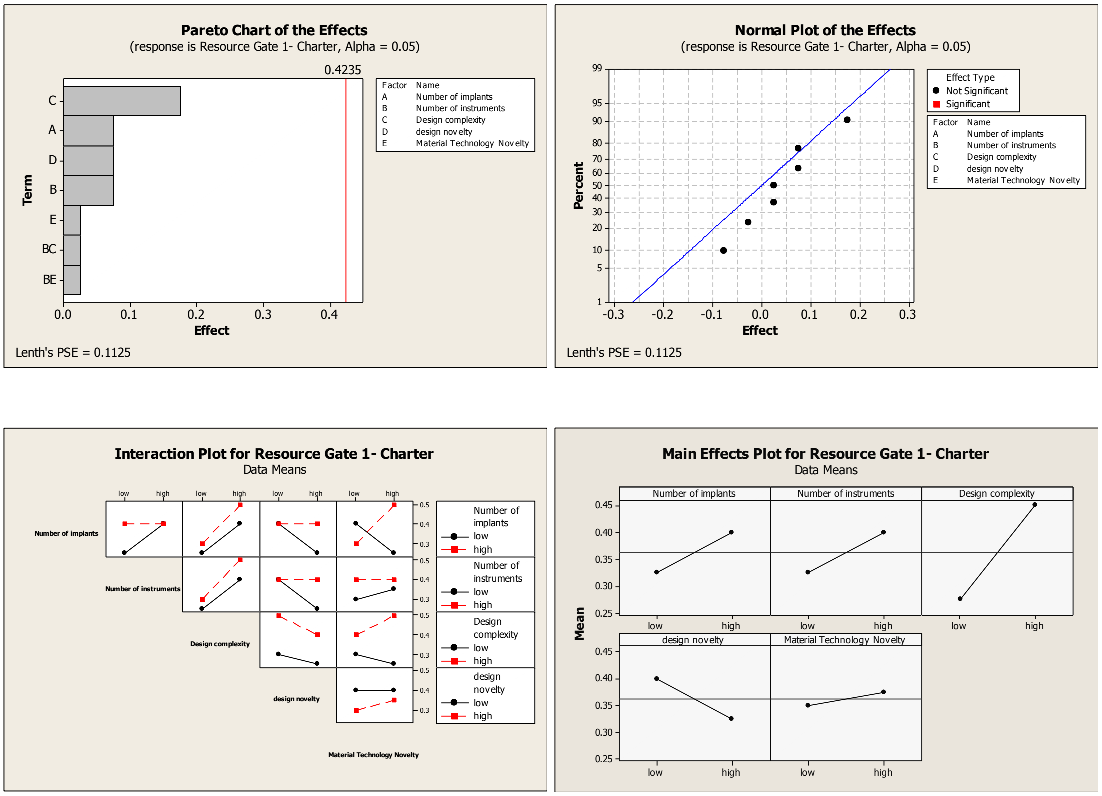


FIGURE 114 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 1- CHARTER: NORMAL PLOT OF EFFECTS, PARETO CHART, INTERACTION PLOTS AND MAIN EFFECTS PLOTS.

TABLE 129 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 1 – CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 1- CHARTER REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		0.36250
NUMBER OF IMPLANTS	0.07500	0.03750
NUMBER OF INSTRUMENTS	0.07500	0.03750
DESIGN COMPLEXITY	0.17500	0.08750
DESIGN NOVELTY	-0.07500	-0.03750
MATERIAL TECHNOLOGY NOVELTY	0.02500	0.01250
NUMBER OF INSTRUMENTS*	0.02500	0.01250
DESIGN COMPLEXITY		
NUMBER OF INSTRUMENTS*	-0.02500	-0.01250
MATERIAL TECHNOLOGY NOVELTY		
S = * PRESS = *		

ANALYSIS OF VARIANCE FOR RESOURCE GATE 1- CHARTER (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.096250	0.096250	0.019250	*	*
2-WAY INTERACTIONS	2	0.002500	0.002500	0.001250	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	0.098750				
REMOVE ALL FACTORS EXCEPT NO. IMPLANTS, NO. INSTRUMENTS, DESIGN COMPLEXITY AND DESIGN NOVELTY						

TABLE 130 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 1 – CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

RESOURCE GATE 1- CHARTER REVIEW 2						
TERM	EFFECT	COEF	SE COEF	T	P	
CONSTANT		0.36250	0.01250	29.00	0.000	
NUMBER OF IMPLANTS	0.07500	0.03750	0.01250	3.00	0.058	
NUMBER OF INSTRUMENTS	0.07500	0.03750	0.01250	3.00	0.058	
DESIGN COMPLEXITY	0.17500	0.08750	0.01250	7.00	0.006	
DESIGN NOVELTY	-0.07500	-0.03750	0.01250	-3.00	0.058	
S = 0.0353553 PRESS = 0.0266667						
R-SQ = 96.20% R-SQ(PRED) = 73.00% R-SQ(ADJ) = 91.14%						
ANALYSIS OF VARIANCE FOR RESOURCE GATE 1- CHARTER (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	4	0.095000	0.095000	0.023750	19.00	0.018
RESIDUAL ERROR	3	0.003750	0.003750	0.001250		
TOTAL	7	0.098750				
REMOVE ALL FACTORS EXCEPT DESIGN COMPLEXITY						
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

TABLE 131 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 1 – CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 3.

RESOURCE GATE 1- CHARTER REVIEW 3					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.36250	0.02795	12.97	0.000
DESIGN COMPLEXITY	0.17500	0.08750	0.02795	3.13	0.020
S = 0.0790569 PRESS = 0.0666667					
R-SQ = 62.03% R-SQ(PRED) = 32.49% R-SQ(ADJ) = 55.70%					
LOWER R-SQ ADJUSTED VALUE....REVERT TO PREVIOUS MODEL.					

RESOURCE CHARTER – GATE 2

TABLE 132 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE CHARTER – GATE 2, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE CHARTER - GATE 2 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		0.400000
NUMBER OF IMPLANTS	-0.000000	-0.000000
NUMBER OF INSTRUMENTS	-0.000000	-0.000000
DESIGN COMPLEXITY	-0.000000	-0.000000
DESIGN NOVELTY	-0.000000	-0.000000
MATERIAL TECHNOLOGY NOVELTY	-0.000000	-0.000000
NUMBER OF INSTRUMENTS*	-0.000000	-0.000000
DESIGN COMPLEXITY		
NUMBER OF INSTRUMENTS*	-0.000000	-0.000000
MATERIAL TECHNOLOGY NOVELTY		
RESOURCE CHARTER – GATE 2 IS CONSISTENTLY 0.4		

RESOURCE GATE 2 – GATE 3

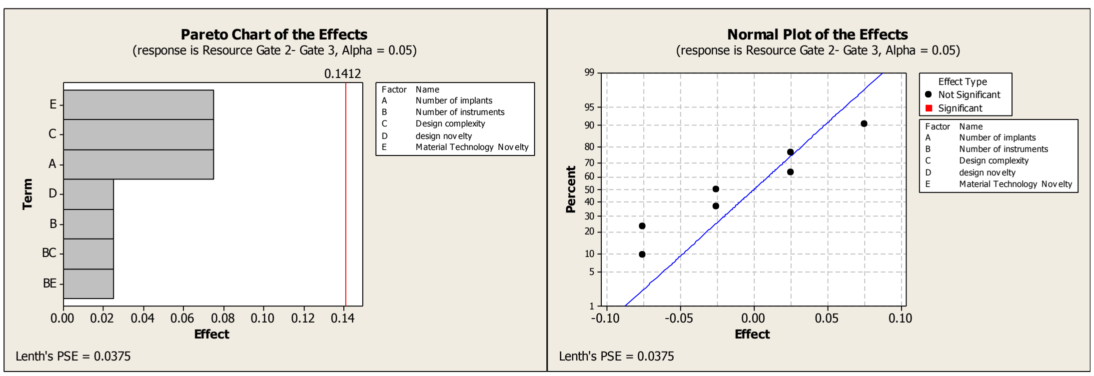


FIGURE 115 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 2 – GATE 3: NORMAL PLOT OF EFFECTS, PARETO CHART.

TABLE 133 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 2 – GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 2- GATE 3		
TERM	EFFECT	COEF
CONSTANT		0.33750
NUMBER OF IMPLANTS	-0.07500	-0.03750
NUMBER OF INSTRUMENTS	0.02500	0.01250
DESIGN COMPLEXITY	-0.07500	-0.03750
DESIGN NOVELTY	-0.02500	-0.01250
MATERIAL TECHNOLOGY NOVELTY	0.07500	0.03750

NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-0.02500	-0.01250				
NUMBER OF INSTRUMENTS* MATERIAL TECHNOLOGY NOVELTY	0.02500	0.01250				
S = * PRESS = *						
ANALYSIS OF VARIANCE FOR RESOURCE GATE 2- GATE 3 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.036250	0.036250	0.007250	*	*
2-WAY INTERACTIONS	2	0.002500	0.002500	0.001250	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	0.038750				
REMOVE ALL FACTORS EXCEPT NO. IMPLANTS, DESIGN COMPLEXITY AND MATERIAL TECHNOLOGY NOVELTY						

TABLE 134 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 2 – GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

RESOURCE GATE 2- GATE 3 REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.33750	0.01250	27.00	0.000
NUMBER OF IMPLANTS	-0.07500	-0.03750	0.01250	-3.00	0.040
DESIGN COMPLEXITY	-0.07500	-0.03750	0.01250	-3.00	0.040
MATERIAL TECHNOLOGY NOVELTY	0.07500	0.03750	0.01250	3.00	0.040

S = 0.0353553 PRESS = 0.02					
R-SQ = 87.10% R-SQ(PRED) = 48.39% R-SQ(ADJ) = 77.42%					
ANALYSIS OF VARIANCE FOR RESOURCE GATE 2- GATE 3 (CODED UNITS)					
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	0.033750	0.033750	0.011250	9.00	0.030
RESIDUAL ERROR	4	0.005000	0.005000	0.001250		
PURE ERROR	4	0.005000	0.005000	0.001250		
TOTAL	7	0.038750				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

RESOURCE GATE 3 – GATE 6

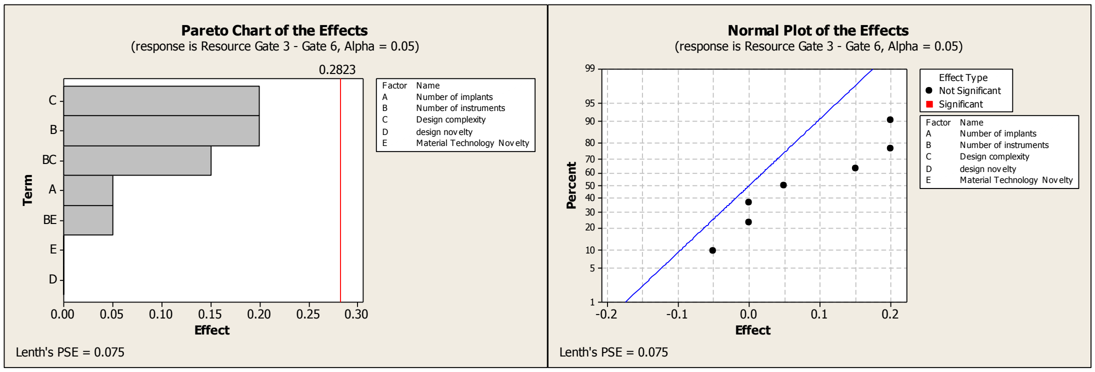


FIGURE 116 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 3- GATE 6: NORMAL PLOT OF EFFECTS, PARETO CHART.

TABLE 135 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 3 – GATE 6, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 3 - GATE 6 REVIEW 1						
TERM		EFFECT	COEF			
CONSTANT			0.52500			
NUMBER OF IMPLANTS		-0.05000	-0.02500			
NUMBER OF INSTRUMENTS		0.20000	0.10000			
DESIGN COMPLEXITY		0.20000	0.10000			
DESIGN NOVELTY		-0.00000	-0.00000			
MATERIAL TECHNOLOGY NOVELTY		-0.00000	-0.00000			
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY		0.15000	0.07500			
NUMBER OF INSTRUMENTS* MATERIAL TECHNOLOGY NOVELTY		0.05000	0.02500			
S = * PRESS = *						
ANALYSIS OF VARIANCE FOR RESOURCE GATE 3 - GATE 6 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	0.16500	0.16500	0.03300	*	*
2-WAY INTERACTIONS	2	0.05000	0.05000	0.02500	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	0.21500				
REMOVE ALL FACTORS EXCEPT NO. OF INSTRUMENTS, DESIGN COMPLEXITY AND NO. OF INSTRUMENTS* DESIGN COMPLEXITY						

TABLE 136- PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 3 – GATE 6, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

RESOURCE GATE 3 - GATE 6 REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		0.52500	0.01768	29.70	0.000
NUMBER OF INSTRUMENTS	0.20000	0.10000	0.01768	5.66	0.005
DESIGN COMPLEXITY	0.20000	0.10000	0.01768	5.66	0.005
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	0.15000	0.07500	0.01768	4.24	0.013
S = 0.05 PRESS = 0.04					
R-SQ = 95.35% R-SQ(PRED) = 81.40% R-SQ(ADJ) = 91.86%					

ANALYSIS OF VARIANCE FOR RESOURCE GATE 3 - GATE 6 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	0.160000	0.160000	0.080000	32.00	0.003
2-WAY INTERACTIONS	1	0.045000	0.045000	0.045000	18.00	0.013
RESIDUAL ERROR	4	0.010000	0.010000	0.002500		
PURE ERROR	4	0.010000	0.010000	0.002500		
TOTAL	7	0.215000				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

RESOURCE GATE 6 – GATE 7

TABLE 137 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 6 – GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 6 - GATE 7 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		1.00000
NUMBER OF IMPLANTS	0.00000	0.00000
NUMBER OF INSTRUMENTS	0.00000	0.00000
DESIGN COMPLEXITY	0.00000	0.00000
DESIGN NOVELTY	0.00000	0.00000
MATERIAL TECHNOLOGY NOVELTY	0.00000	0.00000
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	0.00000	0.00000
RESOURCE GATE 6 – GATE 7 IS CONSISTENTLY 1		

RESOURCE GATE 7 – GATE 8

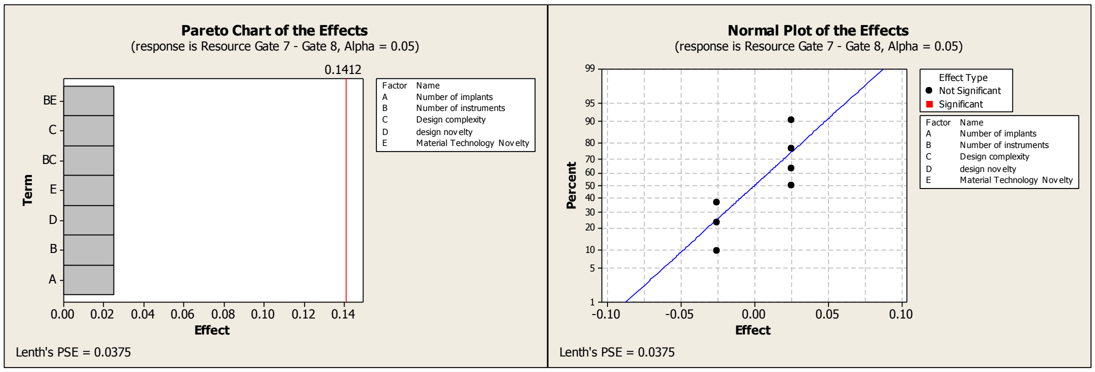


FIGURE 117- PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 7 – GATE 8: NORMAL PLOT OF EFFECTS, PARETO CHART.

TABLE 138 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, RESOURCE GATE 7 – GATE 8, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

RESOURCE GATE 7 – GATE 8					
TERM		EFFECT	COEF		
CONSTANT			0.18750		
NUMBER OF IMPLANTS		0.02500	0.01250		
NUMBER OF INSTRUMENTS		0.02500	0.01250		
DESIGN COMPLEXITY		0.02500	0.01250		
DESIGN NOVELTY		-0.02500	-0.01250		
MATERIAL TECHNOLOGY NOVELTY		-0.02500	-0.01250		
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY		-0.02500	-0.01250		
NUMBER OF INSTRUMENTS* MATERIAL TECHNOLOGY NOVELTY		0.02500	0.01250		
S = * PRESS = *					
ANALYSIS OF VARIANCE FOR RESOURCE GATE 7 - GATE 8 (CODED UNITS)					
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F P
MAIN EFFECTS	5	0.006250	0.006250	0.001250	* *
2-WAY INTERACTIONS	2	0.002500	0.002500	0.001250	* *
RESIDUAL ERROR	0	*	*	*	
TOTAL	7	0.008750			
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT					

DURATION GATE 0 -GATE 1

TABLE 139 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 0 – GATE 1, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 0 – GATE 1	
TERM	COEF
CONSTANT	1.00000
NUMBER OF IMPLANTS	0.000000000

NUMBER OF INSTRUMENTS	0.000000000
DESIGN COMPLEXITY	0.000000000
DESIGN NOVELTY	0.000000000
MATERIAL TECHNOLOGY NOVELTY	0.000000000
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	0.000000000
NUMBER OF INSTRUMENTS* MATERIAL TECHNOLOGY NOVELTY	0.000000000
RESOURCE GATE 6 – GATE 7 IS CONSISTENTLY 1	

DURATION GATE 1- CHARTER

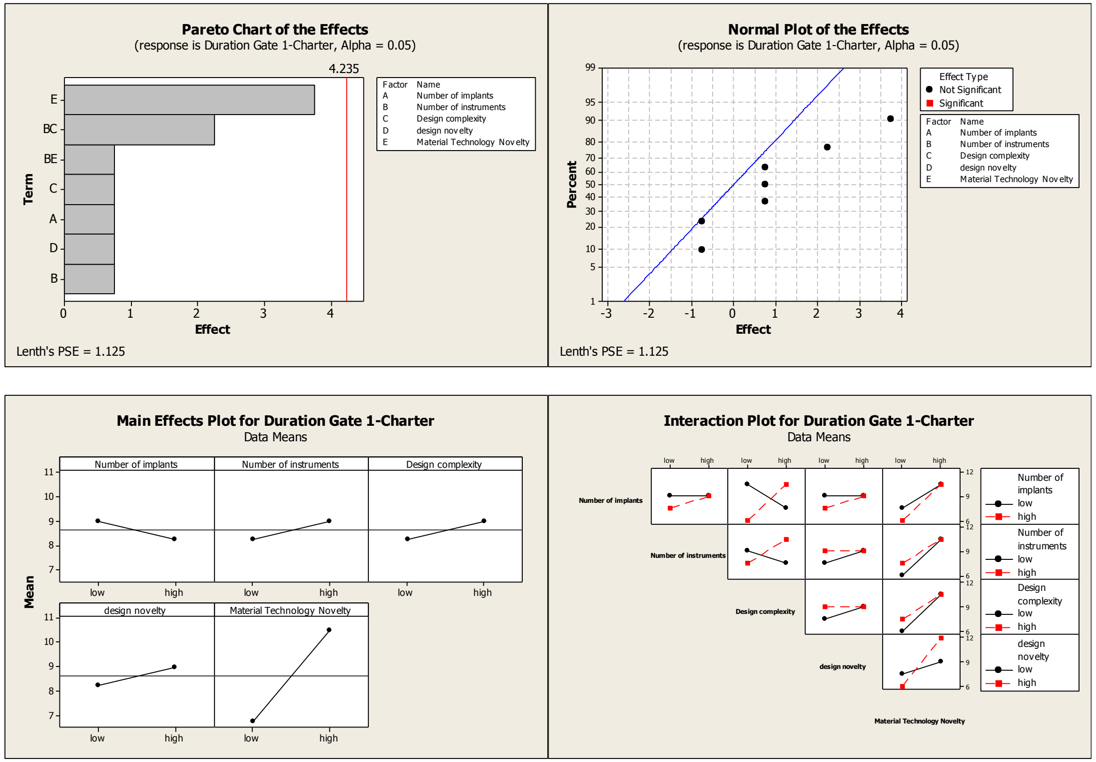


FIGURE 118 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 1 - CHARTER: NORMAL PLOT OF EFFECTS, PARETO CHART.

TABLE 140 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 1 – CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 1-CHARTER REVIEW 1

TERM	EFFECT	COEF
CONSTANT		8.6250
NUMBER OF IMPLANTS	-0.7500	-0.3750
NUMBER OF INSTRUMENTS	0.7500	0.3750
DESIGN COMPLEXITY	0.7500	0.3750
DESIGN NOVELTY	0.7500	0.3750
MATERIAL TECHNOLOGY NOVELTY	3.7500	1.8750
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	2.2500	1.1250
NUMBER OF INSTRUMENTS* MATERIAL TECHNOLOGY NOVELTY	-0.7500	-0.3750

S = * PRESS = *

ANALYSIS OF VARIANCE FOR DURATION GATE 1-CHARTER (CODED UNITS)

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	32.63	32.63	6.525	*	*
2-WAY INTERACTIONS	2	11.25	11.25	5.625	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	43.88				

REMOVE ALL FACTORS EXCEPT NO. INSTRUMENTS, DESIGN COMPLEXITY, MATERIAL TECHNOLOGY NOVELTY, NO. OF INSTRUMENTS* DESIGN COMPLEXITY….

TABLE 141 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 1 – CHARTER, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION GATE 1-CHARTER REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P

CONSTANT		8.6250	0.3750	23.00	0.000
NUMBER OF INSTRUMENTS	0.7500	0.3750	0.3750	1.00	0.391
DESIGN COMPLEXITY	0.7500	0.3750	0.3750	1.00	0.391
MATERIAL TECHNOLOGY NOVELTY	3.7500	1.8750	0.3750	5.00	0.015
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	2.2500	1.1250	0.3750	3.00	0.058

S = 1.06066 PRESS = 24

R-SQ = 92.31% R-SQ(PRED) = 45.30% R-SQ(ADJ) = 82.05%

ANALYSIS OF VARIANCE FOR DURATION GATE 1-CHARTER (CODED UNITS)

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	30.375	30.375	10.125	9.00	0.052
2-WAY INTERACTIONS	1	10.125	10.125	10.125	9.00	0.058
RESIDUAL ERROR	3	3.375	3.375	1.125		
TOTAL	7	43.875				

THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT

DURATION CHARTER – GATE 2

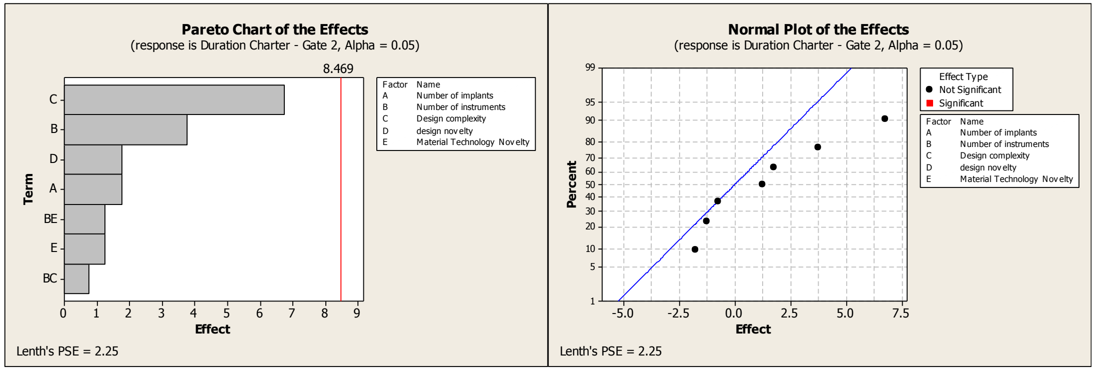


FIGURE 119 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION CHARTER – GATE 2: NORMAL PLOT OF EFFECTS, PARETO CHART.

TABLE 142 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION CHARTER – GATE 2, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION CHARTER - GATE 2 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		7.1250
NUMBER OF IMPLANTS	1.7500	0.8750
NUMBER OF INSTRUMENTS	3.7500	1.8750
DESIGN COMPLEXITY	6.7500	3.3750
DESIGN NOVELTY	-1.7500	-0.8750
MATERIAL TECHNOLOGY NOVELTY	1.2500	0.6250
NUMBER OF INSTRUMENTS*	-0.7500	-0.3750
DESIGN COMPLEXITY		
NUMBER OF INSTRUMENTS*	-1.2500	-0.6250
MATERIAL TECHNOLOGY NOVELTY		
S = * PRESS = *		

ANALYSIS OF VARIANCE FOR DURATION CHARTER - GATE 2 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	134.625	134.625	26.925	*	*
2-WAY INTERACTIONS	2	4.250	4.250	2.125	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	138.875				
REMOVE ALL FACTORS EXCEPT NO. IMPLANT, NO. OF INSTRUMENTS, DESIGN COMPLEXITY, DESIGN NOVELTY						

TABLE 143 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION CHARTER – GATE 2, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION CHARTER - GATE 2 REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		7.1250	0.5543	12.85	0.001
NUMBER OF IMPLANTS	1.7500	0.8750	0.5543	1.58	0.213
NUMBER OF INSTRUMENTS	3.7500	1.8750	0.5543	3.38	0.043
DESIGN COMPLEXITY	6.7500	3.3750	0.5543	6.09	0.009
DESIGN NOVELTY	-1.7500	-0.8750	0.5543	-1.58	0.213
S = 1.56791 PRESS = 52.4444					
R-SQ = 94.69% R-SQ(PRED) = 62.24% R-SQ(ADJ) = 87.61%					
ANALYSIS OF VARIANCE FOR DURATION CHARTER - GATE 2 (CODED UNITS)					

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	4	131.500	131.500	32.875	13.37	0.030
RESIDUAL ERROR	3	7.375	7.375	2.458		
TOTAL	7	138.875				

REMOVE ALL FACTORS EXCEPT DESIGN COMPLEXITY
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT

TABLE 144 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION CHARTER – GATE 2, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 3.

DURATION CHARTER - GATE 2 REVIEW 3					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		7.125	0.7004	10.17	0.000
NUMBER OF INSTRUMENTS	3.750	1.875	0.7004	2.68	0.044
DESIGN COMPLEXITY	6.750	3.375	0.7004	4.82	0.005
S = 1.98116	PRESS = 50.24X				
R-SQ = 85.87%	R-SQ(PRED) = 63.82%	R-SQ(ADJ) = 80.22%			
ANALYSIS OF VARIANCE FOR DURATION CHARTER - GATE 2 (CODED UNITS)					
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	119.250	119.250	59.625	15.19	0.008
RESIDUAL ERROR	5	19.625	19.625	3.925		
LACK OF FIT	1	1.125	1.125	1.125	0.24	0.648
PURE ERROR	4	18.500	18.500	4.625		
TOTAL	7	138.875				
LOWER R-SQ ADJUSTED VALUE….REVERT TO PREVIOUS MODEL.					

DURATION GATE 2- GATE 3

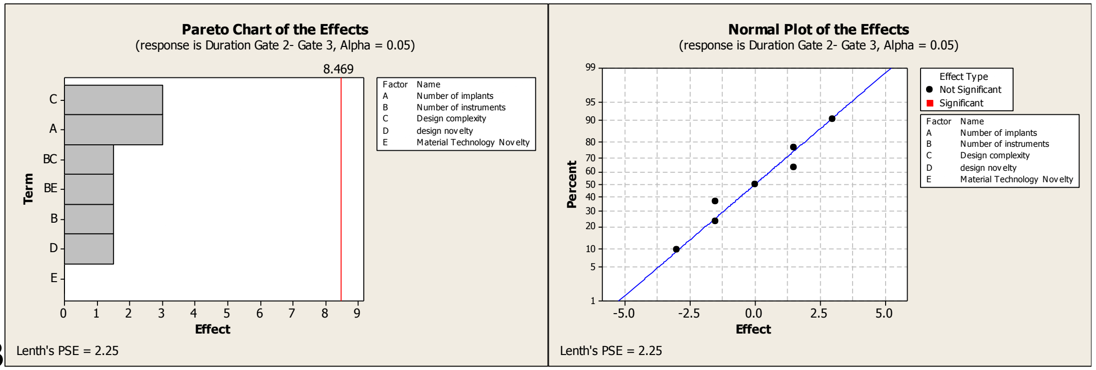


FIGURE 120 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 2 – GATE 3: NORMAL PLOT OF EFFECTS, PARETO CHART.

TABLE 145 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 2 – GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 2- GATE 3 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		12.000
NUMBER OF IMPLANTS	-3.000	-1.500
NUMBER OF INSTRUMENTS	-1.500	-0.750
DESIGN COMPLEXITY	3.000	1.500
DESIGN NOVELTY	1.500	0.750
MATERIAL TECHNOLOGY NOVELTY	-0.000	-0.000
NUMBER OF INSTRUMENTS*	-1.500	-0.750
DESIGN COMPLEXITY		
NUMBER OF INSTRUMENTS*	1.500	0.750
MATERIAL TECHNOLOGY NOVELTY		
S = * PRESS = *		

ANALYSIS OF VARIANCE FOR DURATION GATE 2- GATE 3 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	45.000	45.000	9.000	*	*
2-WAY INTERACTIONS	2	9.000	9.000	4.500	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	54.000				
REMOVE ALL FACTORS EXCEPT NO. OF IMPLANTS AND DESIGN COMPLEXITY						

TABLE 146 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 2 – GATE 3, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION GATE 2- GATE 3 REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		12.000	0.6708	17.89	0.000
NUMBER OF IMPLANTS	-3.000	-1.500	0.6708	-2.24	0.076
DESIGN COMPLEXITY	3.000	1.500	0.6708	2.24	0.076
S = 1.89737	PRESS = 46.08				
R-SQ = 66.67%	R-SQ(PRED) = 14.67%	R-SQ(ADJ) = 53.33%			

ANALYSIS OF VARIANCE FOR DURATION GATE 2- GATE 3 (CODED UNITS)						
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	2	36.00	36.00	18.000	5.00	0.064
RESIDUAL ERROR	5	18.00	18.00	3.600		
LACK OF FIT	1	0.00	0.00	0.000	0.00	1.000
PURE ERROR	4	18.00	18.00	4.500		
TOTAL	7	54.00				

THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT

DURATION GATE 3- GATE 6

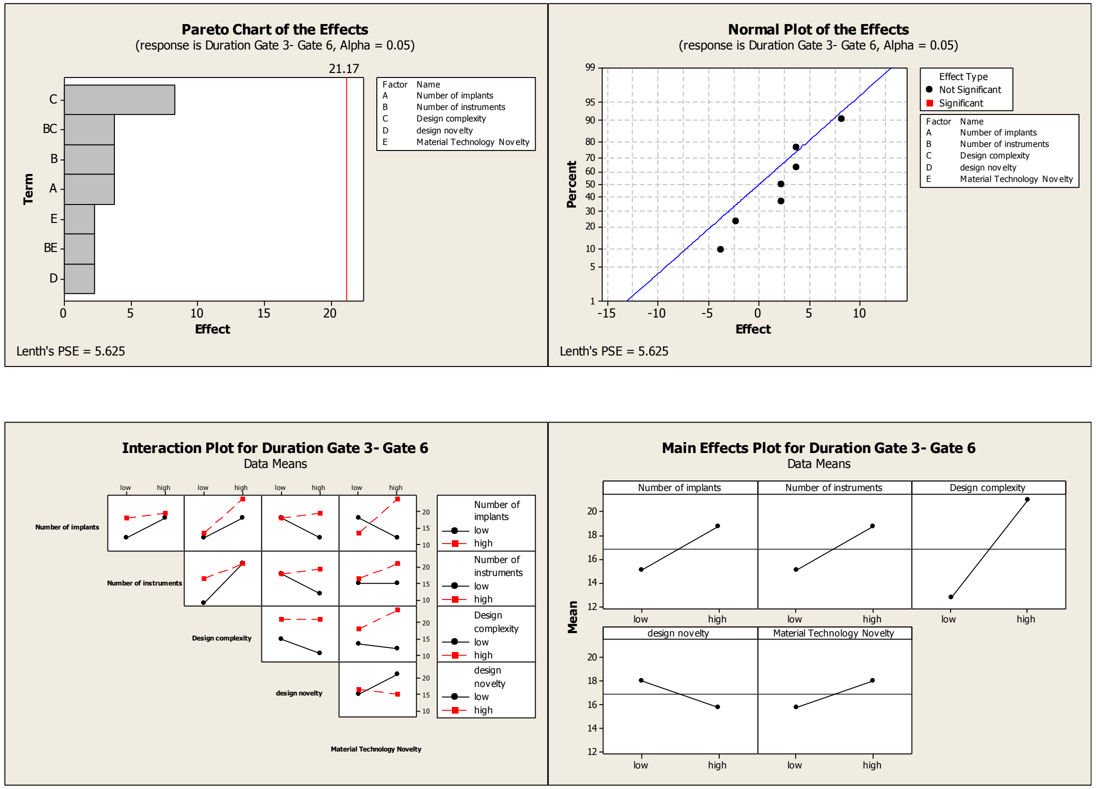


FIGURE 121 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 3 – GATE 6: NORMAL PLOT OF EFFECTS, PARETO CHART.

TABLE 147 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 3– GATE 6, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 3- GATE 6 REVIEW 1		
TERM	EFFECT	COEF
CONSTANT		16.875
NUMBER OF IMPLANTS	3.750	1.875
NUMBER OF INSTRUMENTS	3.750	1.875
DESIGN COMPLEXITY	8.250	4.125
DESIGN NOVELTY	-2.250	-1.125
MATERIAL TECHNOLOGY NOVELTY	2.250	1.125
NUMBER OF INSTRUMENTS*	-3.750	-1.875
DESIGN COMPLEXITY		
NUMBER OF INSTRUMENTS*	2.250	1.125
MATERIAL TECHNOLOGY NOVELTY		
S = * PRESS = *		
ANALYSIS OF VARIANCE FOR DURATION GATE 3- GATE 6 (CODED UNITS)		

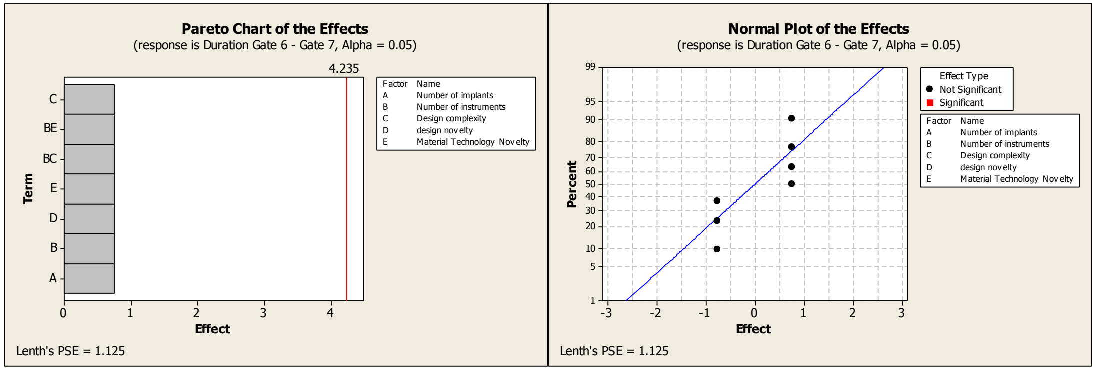
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	212.62	212.62	42.52	*	*
2-WAY INTERACTIONS	2	38.25	38.25	19.13	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	250.88				
REMOVE ALL FACTORS EXCEPT NO. OF IMPLANTS, NO. OF INSTRUMENTS, DESIGN COMPLEXITY AND NO. INSTRUMENTS * DESIGN COMPLEXITY						

TABLE 148 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 3– GATE 6, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 2.

DURATION GATE 3- GATE 6 REVIEW 2					
TERM	EFFECT	COEF	SE COEF	T	P
CONSTANT		16.875	1.125	15.00	0.001
NUMBER OF IMPLANTS	3.750	1.875	1.125	1.67	0.194

NUMBER OF INSTRUMENTS	3.750	1.875	1.125	1.67	0.194
DESIGN COMPLEXITY	8.250	4.125	1.125	3.67	0.035
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	-3.750	-1.875	1.125	-1.67	0.194
S = 3.18198 PRESS = 216					
R-SQ = 87.89% R-SQ(PRED) = 13.90% R-SQ(ADJ) = 71.75%					
ANALYSIS OF VARIANCE FOR DURATION GATE 3- GATE 6 (CODED UNITS)					
SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	3	192.37	192.38	64.13	6.33	0.082
2-WAY INTERACTIONS	1	28.13	28.13	28.13	2.78	0.194
RESIDUAL ERROR	3	30.37	30.37	10.12		
TOTAL	7	250.87				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

DURATION GATE 6 – GATE 7



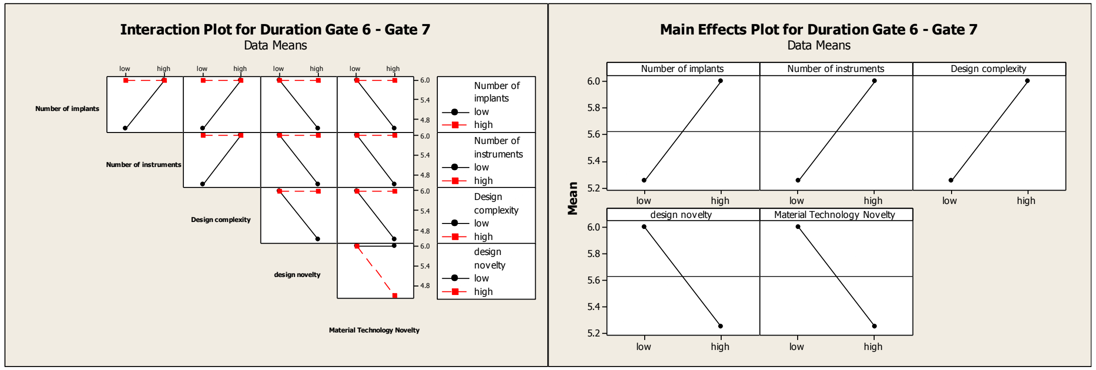


FIGURE 122 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 6 – GATE 7: NORMAL PLOT OF EFFECTS, PARETO CHART.

TABLE 149 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 6– GATE 7, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 6 - GATE 7 REVIEW 1		
TERM	EFFECT	COEF
TERM	EFFECT	COEF
CONSTANT		5.6250
NUMBER OF IMPLANTS	0.7500	0.3750
NUMBER OF INSTRUMENTS	0.7500	0.3750
DESIGN COMPLEXITY	0.7500	0.3750
DESIGN NOVELTY	-0.7500	-0.3750
MATERIAL TECHNOLOGY NOVELTY	-0.7500	-0.3750
NUMBER OF INSTRUMENTS*	-0.7500	-0.3750
DESIGN COMPLEXITY		
NUMBER OF INSTRUMENTS*	0.7500	0.3750
MATERIAL TECHNOLOGY NOVELTY		

S = * PRESS = *
ANALYSIS OF VARIANCE FOR DURATION GATE 6 - GATE 7 (CODED UNITS)

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P
MAIN EFFECTS	5	5.625	5.625	1.125	*	*
2-WAY INTERACTIONS	2	2.250	2.250	1.125	*	*
RESIDUAL ERROR	0	*	*	*		
TOTAL	7	7.875				
THIS MODEL PROVIDES THE BEST FIT WITH THE AVAILABLE DATA/ IN THIS FORMAT						

DURATION GATE 7 – GATE 8

TABLE 150 - PROJECT MANAGEMENT, RESPONDENT #2 MODEL, DURATION GATE 7– GATE 8, EFFECTS OF EACH FACTOR, COEFFICIENTS, P-VALUES AND ANOVA: RUN 1.

DURATION GATE 7 - GATE 8 REVIEW 1	
TERM	COEF
CONSTANT	12.0000
NUMBER OF IMPLANTS	0.000000000
NUMBER OF INSTRUMENTS	0.000000000
DESIGN COMPLEXITY	0.000000000
DESIGN NOVELTY	0.000000000
MATERIAL TECHNOLOGY NOVELTY	0.000000000
NUMBER OF INSTRUMENTS* DESIGN COMPLEXITY	0.000000000
NUMBER OF INSTRUMENTS* MATERIAL TECHNOLOGY NOVELTY	0.000000000
DURATION GATE 7 – 8 IS CONSISTENTLY 12	

APPENDIX 5 A– MODEL COEFFICIENTS

TABLE 1 - ESTIMATED COEFFICIENTS FOR PROJECT MANAGEMENT MODELS

			FRONT END - GATE 1	GATE 1- CHARTER	CHARTER -GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7- GATE 8
PROJECT MANAGEMENT	DURATION	**CONSTANT**	2.5	8.625	7.125	17.25	16.875	5.625	12
		THE NUMBER OF IMPLANTS				1.5	1.875	0.375	
		THE NUMBER OF INSTRUMENTS	0.5	0.375	1.875		1.875	0.375	
		DESIGN COMPLEXITY	0.5	0.375	3.375	3	4.125	0.375	
		DESIGN NOVELTY				1.125		-0.375	
		MATERIAL TECHNOLOGY NOVELTY		1.875				-0.375	
		NO. INSTRUMENTS * COMPLEXITY	-0.5	1.125			-1.875		
		NO. INSTRUMENTS * MAN TECH NOV		-0.375					
	RESOURCE	**CONSTANT**	0.7	0.3625	0.4625	0.3875	0.525	1.1	0.2625
		THE NUMBER OF IMPLANTS		0.0375		-0.0125		-0.1	0.0625
		THE NUMBER OF INSTRUMENTS		0.0375		0.0125	0.1	0.1	0.0625
		DESIGN COMPLEXITY		0.0875	0.0375	0.0125	0.1		0.0625
		DESIGN NOVELTY		-0.0375		0.0125		-0.1	
		MATERIAL TECHNOLOGY NOVELTY				0.0125			
		NO. INSTRUMENTS * COMPLEXITY					0.075		

TABLE 151 - ESTIMATED COEFFICIENTS FOR BIO-ENGINEERING MODELS

			FRONT END - GATE 1	GATE 1- CHARTER	CHARTER -GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7- GATE 8
BIO- ENGINEERING	DURATION	**CONSTANT**	9	6.375	11.25	24	19.88	12	12
		THE NUMBER OF IMPLANTS	3	1.875		7.5			
		THE NUMBER OF INSTRUMENTS	3	1.125	-0.75	4.5			
		DESIGN COMPLEXITY			2.25				
		DESIGN NOVELTY	3	2.625			16.2		
		MATERIAL TECHNOLOGY NOVELTY			0.75				
		NO. INSTRUMENTS * MAN TECH NOV			-2.25				
	RESOURCE	**CONSTANT**	1.75	1.75	2.25	2.25	0.8	2.25	0.1
		THE NUMBER OF IMPLANTS	0.25	0.25	0.75	0.75	-0.3	1	
		THE NUMBER OF INSTRUMENTS	0.75	0.75	1.25	1.25	0.45	1	
		DESIGN NOVELTY	0.25	0.25	0.75	0.75	-0.45	0.75	

TABLE 152 - ESTIMATED COEFFICIENTS FOR REGULATORY MODELS

REGULATORY	DURATIO N	**CONSTANT**						13.263	
		DESIGN NOVELTY						9.794	
	RESOUR CE	**CONSTANT**	0.05	0.025	0.025	0.1	0.1	0.3625	0.25
		THE NUMBER OF IMPLANTS						0.0875	0.05
		MANUFACTURING PROCESS NOVELTY						-0.0875	-0.05

TABLE 4 - ESTIMATED COEFFICIENTS FOR QUALITY MODELS

			FRONT END - GATE 1	GATE 1- CHARTER	CHARTER -GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7-GATE 8
DESIGN QUALITY	DURATION	**CONSTANT**	1	1	4.125	18	21.75	11.625	12
		THE NUMBER OF IMPLANTS			0.375	1.5		1.875	
		THE NUMBER OF INSTRUMENTS			1.125	1.5	3.75	1.875	
		DESIGN COMPLEXITY			0.375	4.5	3.75	3.375	
		DESIGN NOVELTY			0.375				
		MATERIAL TECHNOLOGY NOVELTY			-0.375		3.75		
		NO. INSTRUMENTS * COMPLEXITY			0.375			-1.875	
		NO. INSTRUMENTS * MAN TECH NOV			-0.375	-1.5			
	RESOURCE	**CONSTANT**	0.1	0.1	0.25	0.875	1.4375	1.5	0.2625
		THE NUMBER OF IMPLANTS				0.25	0.375	0.25	0.0625
		THE NUMBER OF INSTRUMENTS				0.25	0.5625	0.25	0.0625
		DESIGN COMPLEXITY				0.1875	0.375	0.125	0.0625
		DESIGN NOVELTY				0.125	0.125		
		MATERIAL TECHNOLOGY NOVELTY						-0.125	
		NO. INSTRUMENTS * COMPLEXITY				0.1875	0.125	0.125	
		NO. INSTRUMENTS * MAN TECH NOV						-0.125	

TABLE 5 – COEFFICENTS TEST GROUP MODEL

			FRONT END - GATE 1	GATE 1- CHARTER	CHARTER - GATE 2	GATE 2- GATE 3	GATE 3- GATE 6	GATE 6- GATE7	GATE 7- GATE 8
TEST	DURATION	**CONSTANT**	4.5	0	0	6.375	3.75	4.25	12
		INSTRUMENT NOVELTY	4.5			3.375	0.75	2.25	
		INSTRUMENT COMPLEXITY				1.875	0.75	1.25	
		MAN PROCESS NOVELTY	2.25			1.875		1.25	
		NOVELTY * MAN PRO NOV	2.25			1.875	0.75	1.25	
		CONSTANT	24.75			13.5	29	8	12
		IMPLANT NOVELTY	7.35						
		IMPLANT COMPLEXITY				3.5	6	5.5	
		MAN PROCESS NOVELTY	10.25			8	17		
		NOVELTY * MAN PRO NOV	-7.25						
	RESOURCE	**CONSTANT**	0.675			0.8125	1.8125	0.9437	0.06
		INSTRUMENT NOVELTY	0.675			0.7125	1.7125	0.1937	
		INSTRUMENT COMPLEXITY	0.325			0.55	1.2375	0.1812	
		MAN PROCESS NOVELTY				0.3	0.7375	0.1313	
		NOVELTY * MAN PRO NOV	0.325			0.55	1.2375	0.1313	
		CONSTANT	0.6375			0.4	2.3	0.59375	0.06
		IMPLANT NOVELTY	0.1375						
		IMPLANT COMPLEXITY				0.1			
		MAN PROCESS NOVELTY	0.3625			0.225	1.162	0.09375	
		NOVELTY * MAN PRO NOV	-0.1375						

Table 153 - COEFFICENTS DESIGN ENGINEERING MODELS

			Front End - Gate 1	Gate 1- Charter	Charter - Gate 2	Gate 2- Gate 3	Gate 3- Gate 6	Gate 6- Gate7	Gate 7-Gate 8
		Constant			4.3333	7.0625	0	5.7917	12
Design	Duration	**No. implants**			0.333	1.2292	0	1.2083	0
		Implant Design complexity			0.25	0.7292	0	0.5	0
		Implant Design novlety			0.9167	0.5833	0	0.5833	0
		Mat tech nov (implant)			0	0	0	0.4167	0
					4.1667	10.5	0	6.083	12
		Instrument design complexity			-0.8333	-1.667	0	-1.083	0
		Instrument design nov			0	-0.5	0	0.75	0
		Inst material tech			0.5	1.333	0	0	0
	Resource	Constant			0.39129	0.91667	0.3792	0.5	0.21667
		No. implants			0.02463	0.08333	0.1542	0.1	0.05
		Implant Design complexity			0.09129	0.11042	0	0.05417	0
		Implant Design novlety			0.01629	0	0	0	0
		Mat tech nov (implant)			0	0	0	0	0
		Constant			0.30833	0.7667	0.30833	0.54583	0.11667
		Instrument design complexity			-0.075	-0.03333	-0.03333	-0.0625	-0.01667
		Instrument design nov			0	0	0.00833	0.1125	0
		Inst material tech			0.04167	0.03333	0.05	0	0

APPENDIX 5 B – SCOTTISH WATER MODEL COEFFICENTS

Respondent	Variable	Duration capex 1- capex 2	Duration capex 2- capex 3	Duration capex 3- capex 5	Resouce capex 1- capex 2	Resource capex 2- capex 3	Resource capex 3- capex 5
Respondent 1	no. milestones		2.75			42.5	40
	meterage	3	2.75	4.25	31.25	40	52.5
	Project value	3.5	3.75	2.75	48.75	55	52.5
	reputational standing						
	Project value						
	Compexity						
	Procurment timescales				31.25		
	Constant	12	13.25	15.25	113.75	147.5	222.5
Respondent 2	no. milestones	0.275	0.275	2.064	1.85	2.544	31.98
	meterage						
	Project value						
	reputational standing	0.275	0.275	2.064	1.85	2.544	31.98
	Project value						
	Compexity	0.325	0.325	2.391	2.186	3.006	34.78
	Procurment timescales						
	Constant	3.425	3.425	12.055	23.041	31.681	112.66

APPENDIX 6 A – MODEL BUILDING GUIDANCE

A Systems Approach to Resource Planning:
Coupling Human and Business Systems Performance

University of Strathclyde Glasgow

Guide to creating Minitab model

Abigail Hird

The Systems Engineering Doctorate Centre

DePuy companies of Johnson & Johnson

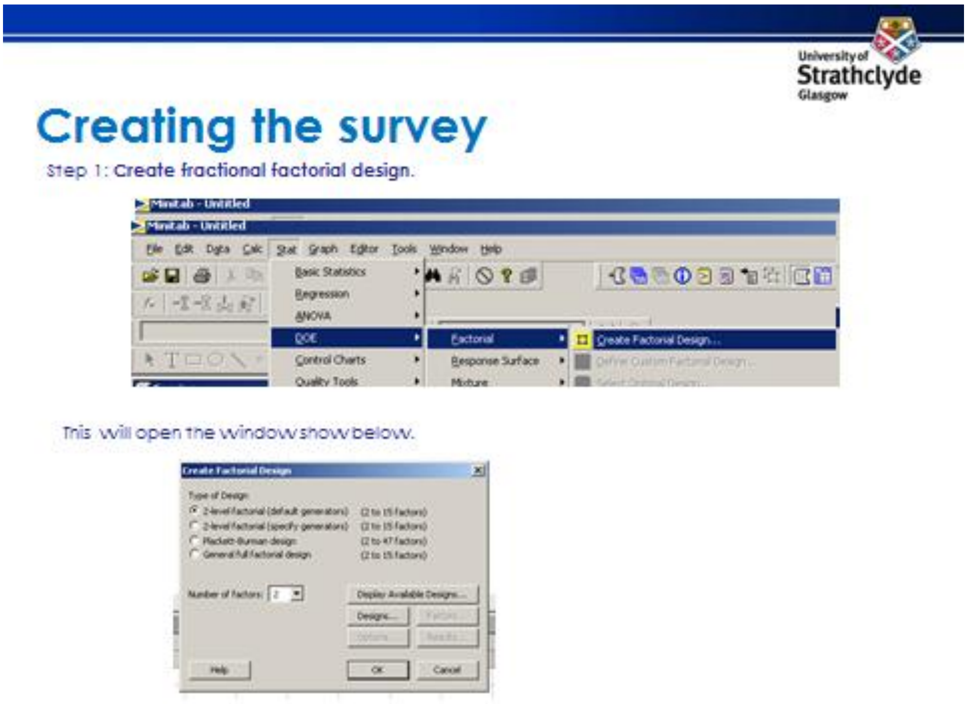
EPSRC

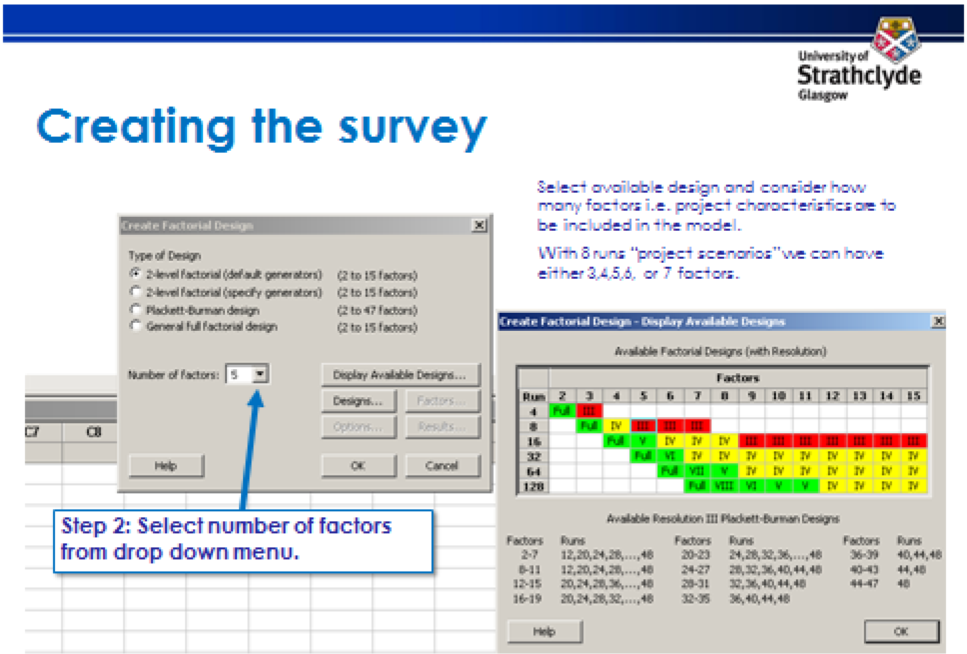
University of Strathclyde Glasgow

Overview

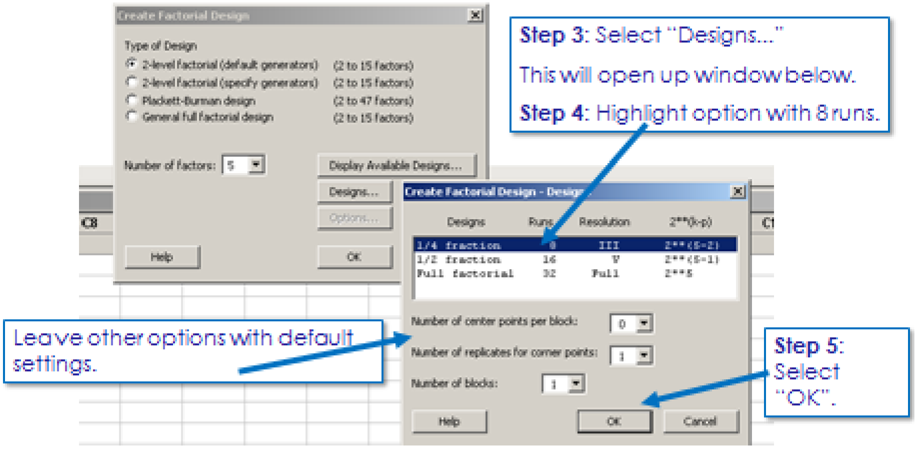
Example from creation of the project management model.
Description of fractional factorial design (2 level models).

- Creating the survey
- Analysing the results.
- Transferring the results to excel.

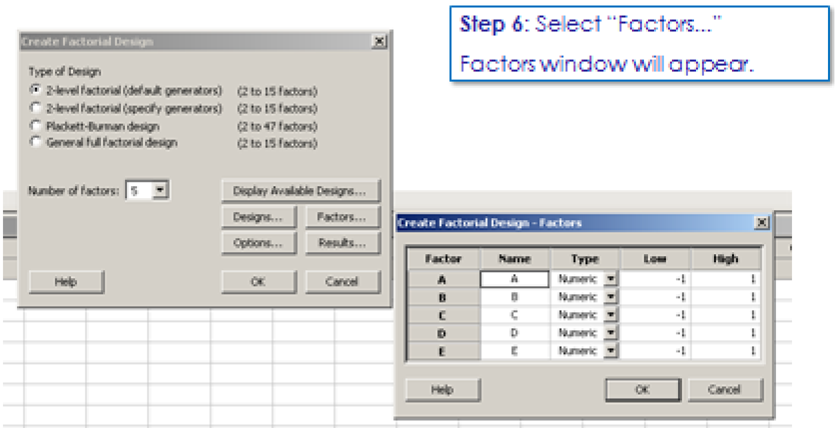

University of Strathclyde Glasgow
Creating the survey
Step 1: Create fractional factorial design.
This will open the window show below.


University of Strathclyde Glasgow
Creating the survey
Select available design and consider how many factors i.e. project characteristics are to be included in the model.
With 8 runs "project scenarios" we can have either 3,4,5,6, or 7 factors.
Create Factorial Design
Type of Design
2-level factorial (default generators) (2 to 15 factors)
2-level factorial (specify generators) (2 to 15 factors)
Plackett-Burman design (2 to 47 factors)
General full factorial design (2 to 15 factors)
Number of factors:
Display Available Designs...
Create Factorial Design - Display Available Designs
Available Factorial Designs (with Resolution)
Available Resolution III Plackett-Burman Designs
Step 2: Select number of factors from drop down menu.

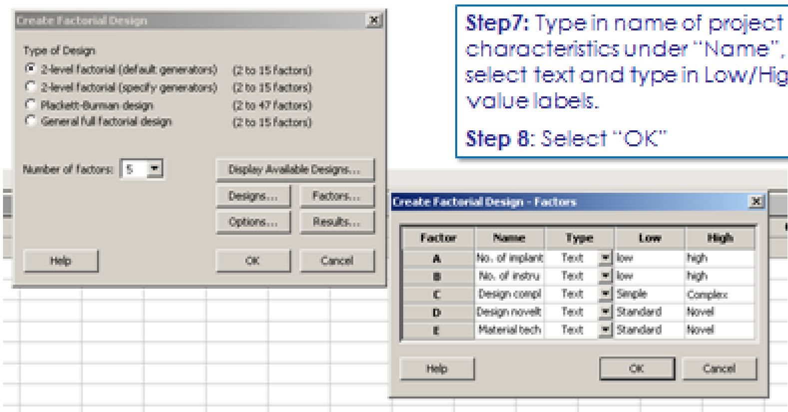
Creating the survey



Creating the survey



Creating the survey



Step7: Type in name of project characteristics under "Name", select text and type in Low/High value labels.

Step 8: Select "OK"

Creating the survey

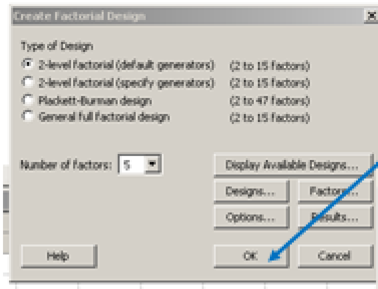
Step9: Select "Options.."

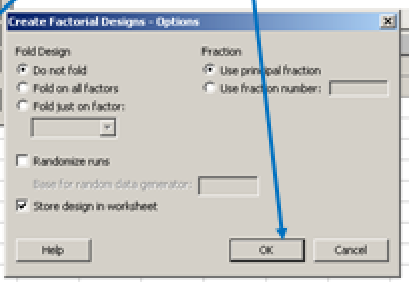
Step 10*: Deselect Randomize runs.

Step 11: Accept defaults for other factors.

Step 12: Select "OK"

Step 13: Select "OK"





* Deselecting "randomize runs" means that we can consistently regenerate the same survey format and copy results straight in. Not randomizing runs means we always have to refer back to the same Minitab file and makes it awkward to analyse multiple model versions

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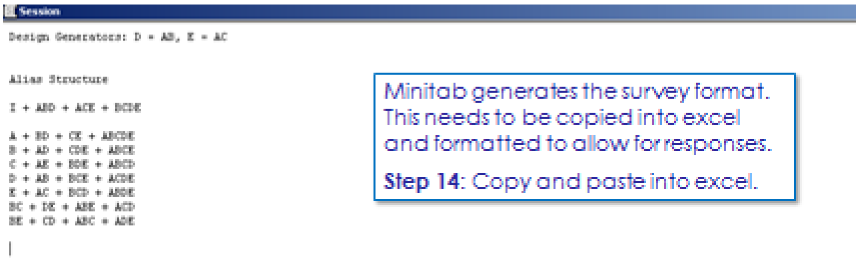
Creating the survey



Minitab generates the survey format. This needs to be copied into excel and formatted to allow for responses.

Step 14: Copy and paste into excel.

Worksheet 1 ***

↓	C1	C2	C3	C4	C5-T	C6-T	C7-T	C8-T	C9-T
	StdOrder	RunOrder	CenterPt	Blocks	No. of implant type	No. of instruments	Design complexity	Design novelty	Material technology
1	1	1	1	1	low	low	Simple	Novel	Novel
2	2	2	1	1	high	low	Simple	Standard	Standard
3	3	3	1	1	low	high	Simple	Standard	Novel
4	4	4	1	1	high	high	Simple	Novel	Standard
5	5	5	1	1	low	low	Complex	Novel	Standard
6	6	6	1	1	high	low	Complex	Standard	Novel
7	7	7	1	1	low	high	Complex	Standard	Standard
8	8	8	1	1	high	high	Complex	Novel	Novel
9									

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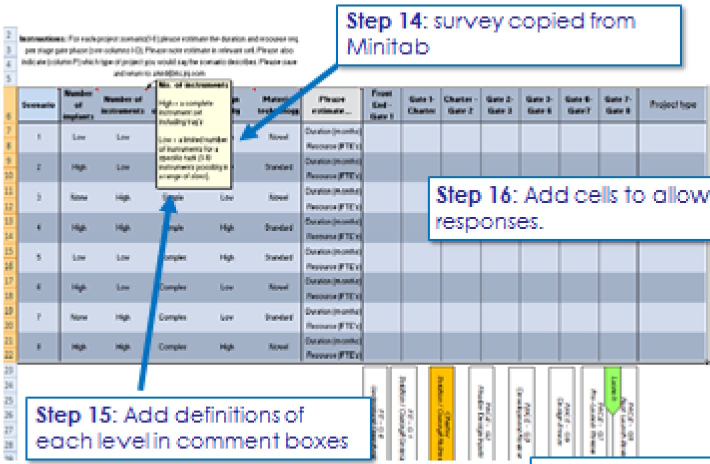
Creating the survey

Step 14: survey copied from Minitab



Step 16: Add cells to allow for responses.

Step 15: Add definitions of each level in comment boxes

Step 17: For clarity, some guidance of time-frames can be added.

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Glasgow

Creating the survey

Send to functional leaders and await responses....

Scenario	Number of implants	Number of instruments	Design complexity	Design novelty	Material technology	Please estimate...	Front End - Gate 1	Gate 1 - Charter	Charter - Gate 2	Gate 2 - Gate 3	Gate 3 - Gate 4	Gate 4 - Gate7	Gate 7 - Gate 8	Project type
1	Low	Low	Simple	High	Novel	Duration (months)	1	12	1	12	4	3	12	
						Resource (FTEs)	1.1	0.2	0.4	0.4	0.4	1	0.1	
2	High	Low	Simple	Low	Standard	Duration (months)	1	18	2	24	12	6	12	
						Resource (FTEs)	0.7	0.3	0.4	0.5	0.4	1	0.2	
3	None	High	Simple	Low	Novel	Duration (months)	3	12	3	12	24	24	12	
						Resource (FTEs)	0.7	0.5	0.4	0.3	0.7	1.5	0.2	
4	High	High	Simple	High	Standard	Duration (months)	3	12	2	24	12	12	12	
						Resource (FTEs)	0.7	0.5	0.5	0.5	0.5	1	0.5	
5	Low	Low	Complex	High	Standard	Duration (months)	3	12	3	24	24	12	12	
						Resource (FTEs)	0.7	0.3	0.5	0.5	0.3	1	0.2	
6	High	Low	Complex	Low	Novel	Duration (months)	3	18	3	24	24	18	12	
						Resource (FTEs)	0.7	0.5	0.5	0.5	0.7	1	0.3	
7	None	High	Complex	Low	Standard	Duration (months)	3	18	12	24	30	30	12	
						Resource (FTEs)	0.7	0.5	0.5	0.5	1	1.5	0.3	
8	High	High	Complex	High	Novel	Duration (months)	3	24	6	36	18	12	12	
						Resource (FTEs)	0.7	0.5	0.5	0.8	0.7	1	0.8	

Next step: entering the results into Mini-tab.

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Analysing the survey results

Before we can analyse the results we need to enter them into Minitab.

	C7-T	C8-T	C9-T	C10	C11	
nents	Design complexity	Design novelty	Material technology	Duration Front End - Gate 1	Duration Gate 1- Charter	Duration
	Simple	Novel	Novel			
	Simple	Standard	Standard			
	Simple	Standard	Novel			
	Simple	Novel	Standard			
	Complex	Novel	Standard			

Step 18: Type response headings into column headings in Minitab. Do this for both Duration and Resource per stage gate.

-

Analysing the survey results

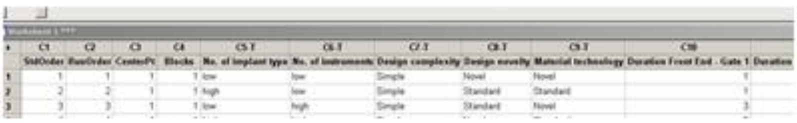
C9-T	C10	C11	C12
Material technology	Duration Front End - Gate 1	Duration Gate 1- Charter	Duration Charter -Gate 2
Novel	1	12	1
Standard	1	15	2
Novel	3	12	3
Standard	3	12	2
Standard	3	12	3
Novel	3	15	3
Standard	3	18	12
Novel	3	24	6

Step 19: Copy and Paste the responses from excel into Minitab under the corresponding columns.

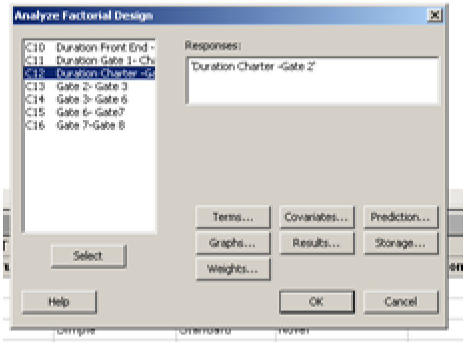
Analysing the survey results

For demonstration purposes, we will create a model for columns C12 "Duration Charter – Gate 2"

Step 20: Select "Analyze Factorial Design"



Analysing the survey results

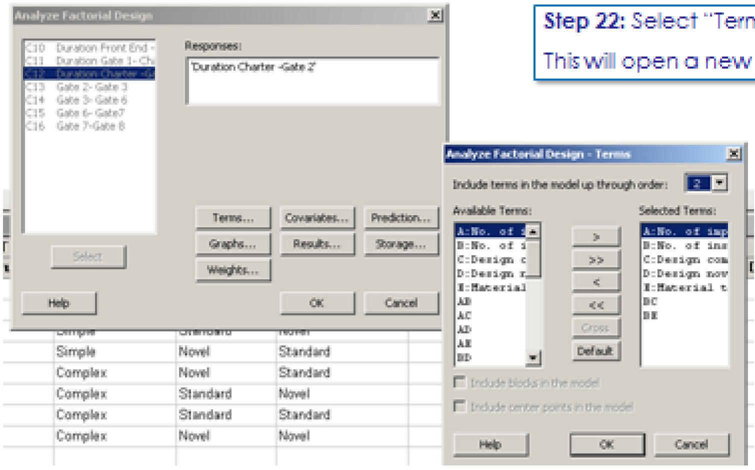


Step 21: Select which model is to be created by highlighting and clicking on "Select". This will move it to the response box.

Analysing the survey results

Step 22: Select "Terms..."

This will open a new window.



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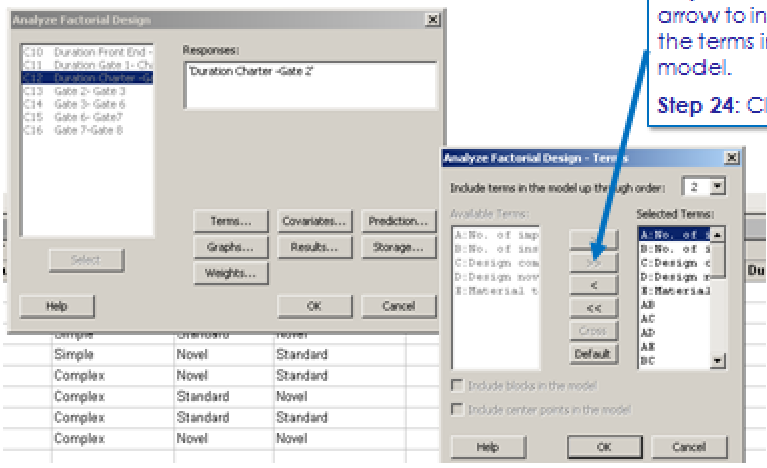
Analysing the survey results

Step 23: select double arrow to include all the terms in the model.

Step 24: Click "OK".



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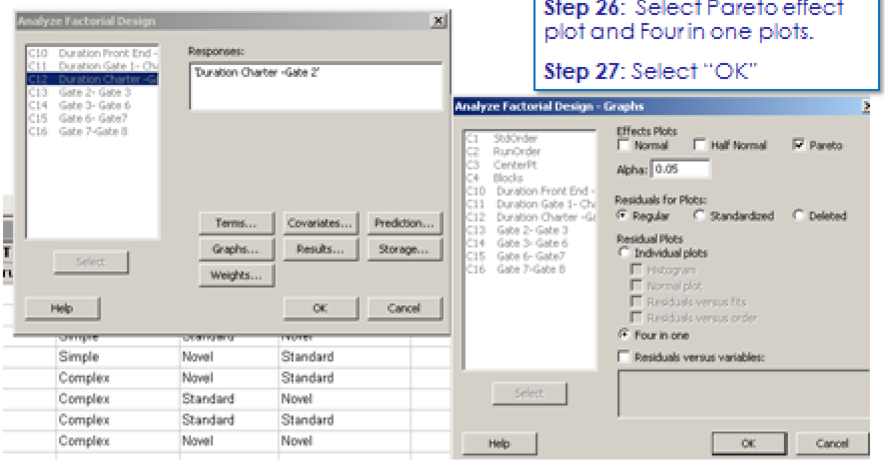
Analysing the survey results

Step 25: Select "Graphs.."

Step 26: Select Pareto effect plot and Four in one plots.

Step 27: Select "OK"



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Analysing the survey results

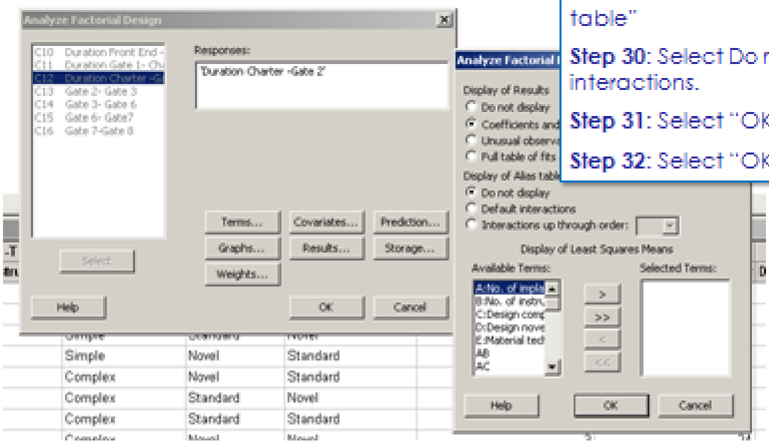
Step 28: Select "Results.."

Step 29: Select "Display coefficients and ANOVA table"

Step 30: Select Do not display interactions.

Step 31: Select "OK"

Step 32: Select "OK"



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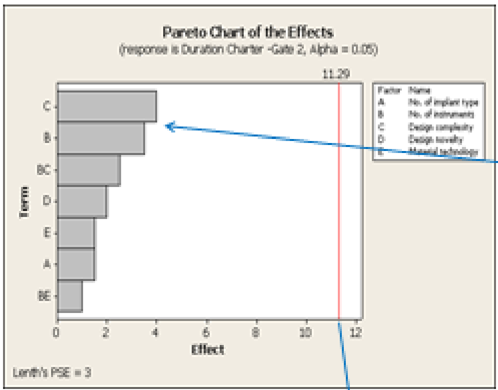
Analysing the survey results

Reading the results..



Design complexity is the most significant factor, followed by no. of instruments and the interaction between the two.

Point at which there is 95% chance that the factor is significant.

Analysing the survey results

Reading the results..

Factorial Fit: Duration Cha versus No. of impla, No. of instr, ...

Estimated Effects and Coefficients for Duration Charter -Gate 2 (coded units)

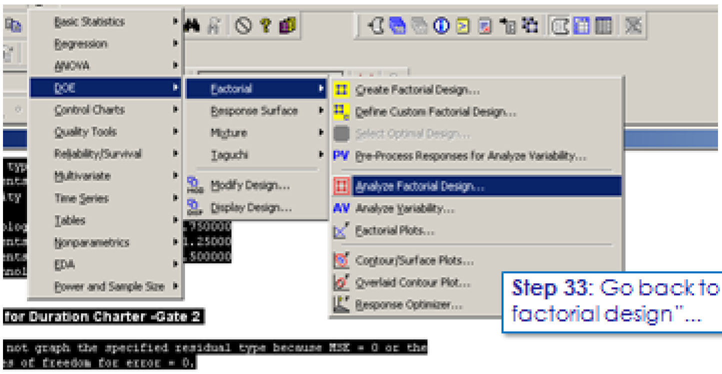
Term	Effect	Coef
Constant		4.000
No. of implant type	-1.500	-0.750
No. of instruments	3.500	1.750
Design complexity	4.000	2.000
Design novelty	-2.000	-1.000
Material technology	-1.500	-0.750
No. of instruments*Design complexity	2.500	1.250
No. of instruments* Material technology	-1.000	-0.500

Coefficients.

S = * PRESS = *

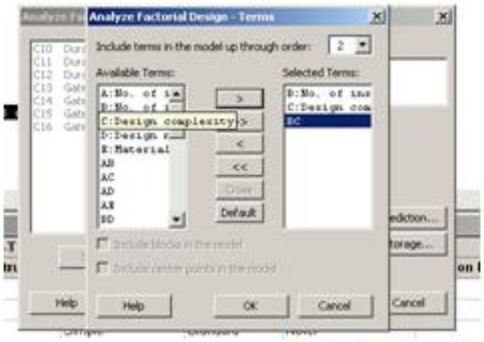
This model may "over fit the data as there are lots of "insignificant factors". We can try removing some of the factors..

Analysing the survey results



Step 33: Go back to "Analyse factorial design"...

Analysing the survey results

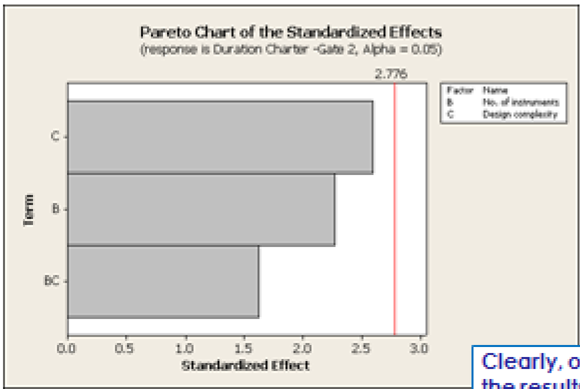


Step 34: Deselect terms not considered significant..they can be re-added later.

Step 35: Click "OK"

Step 36: Click "OK"

Analysing the survey results



Clearly, once noise is removed the results are more significant.

Analysing the survey results

Term	Effect	Coef	SE Coef	T	P
Constant		4.000	0.7706	5.19	0.007
No. of instruments	3.500	1.750	0.7706	2.27	0.086
Design complexity	4.000	2.000	0.7706	2.60	0.060
No. of instruments*Design complexity	2.500	1.250	0.7706	1.62	0.180

S = 2.17945 PRESS = 76

R-Sq = 78.41% R-Sq(pred) = 13.64% R-Sq(adj) = 62.22%

78.41 % of variation in the response can be accounted for with the terms in the model

R-Sq (adj) adjusts this figure for the number of terms and is the number we are interested in. The higher the R-Sq adjusted value, the better the model. We can add and remove terms using steps 33 – 36 to inflate this number to its maximum level.

Transferring results to predictive tool

Term	Effect	Coef	SE Coef	T	P
Constant		4.000	0.7706	5.19	0.007
No. of instruments	3.500	1.750	0.7706	2.27	0.086
Design complexity	4.000	2.000	0.7706	2.60	0.060
No. of instruments*Design complexity	2.500	1.250	0.7706	1.62	0.180

S = 2.17945 PRESS = 76

R-Sq = 78.41% R-Sq(pred) = 13.64% R-Sq(adj) = 62.22%

Once we have inflated the R-Sq (adj) value as much as possible, we can transfer the coefficients to the predictive model.

Transferring results to predictive tool

Term	Effect	Coef	SE Coef	T	P
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R-Sq = 78.41% R-Sq(pred) = 13.64% R-Sq(adj) = 62.22%

Once we have inflated the R-Sq (adj) value as much as possible, we can transfer the coefficients to the predictive model.

Transferring results to predictive tool

LEVEL 3: INDIVIDUAL FUNCTIONAL MODEL - PROJECT MANAGEMENT

INPUTS

Project characteristics	Please select
No. of implant types	low
No. of instruments	high / medium / low
Design complexity	medium
Design novelty	high
Material technology	medium

Step 37: Create a table for inputs in excel with a drop down table for levels of each factor.

Data>data validation> list.

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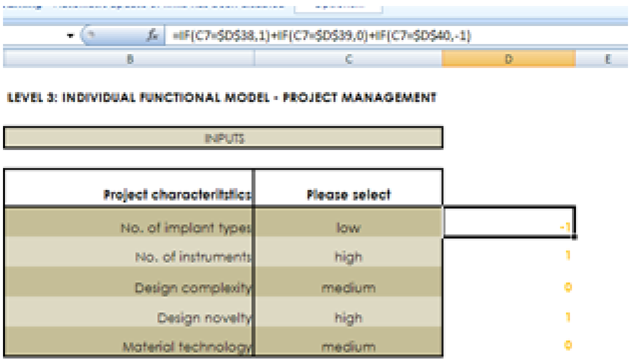
Transferring results to predictive tool



Step 37: Quantify qualitative values using IF function. If low = -1, If high = 1…See step 6.

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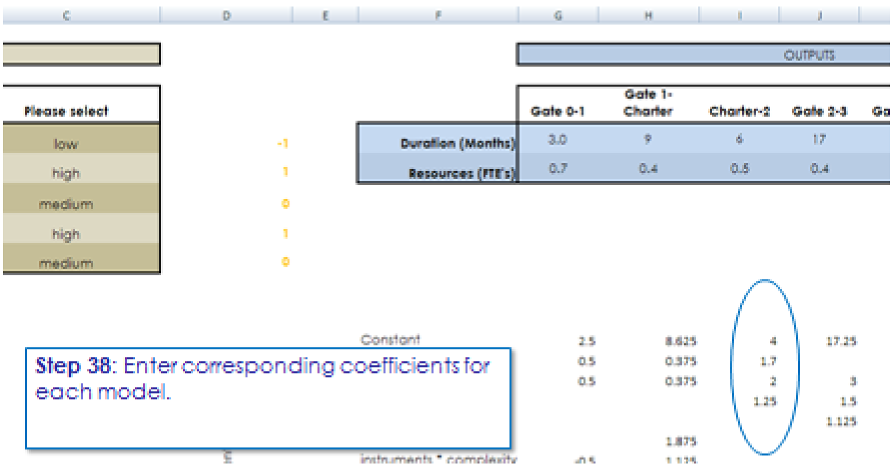
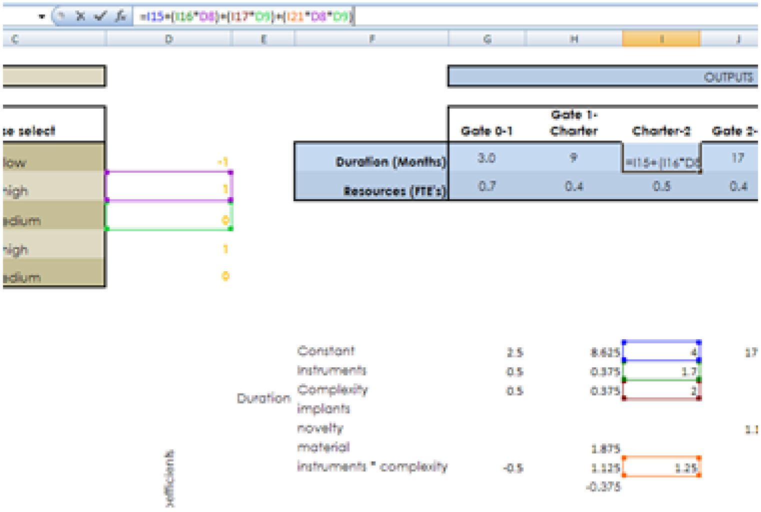
Transferring results to predictive tool



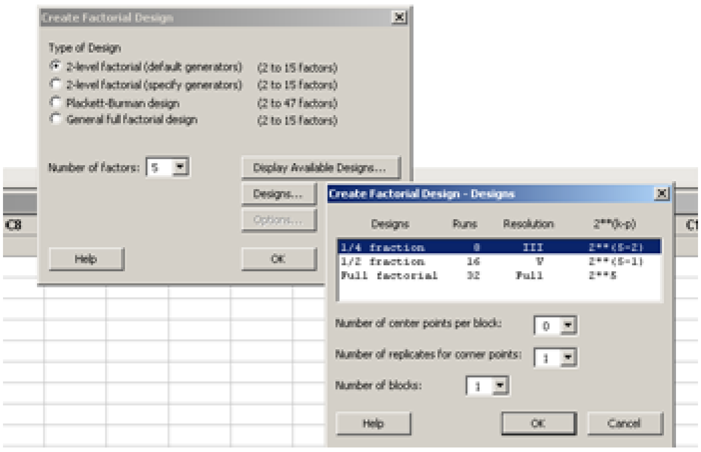
Step 38: Enter corresponding coefficients for each model.

Transferring results to predictive tool



Exceptions #1

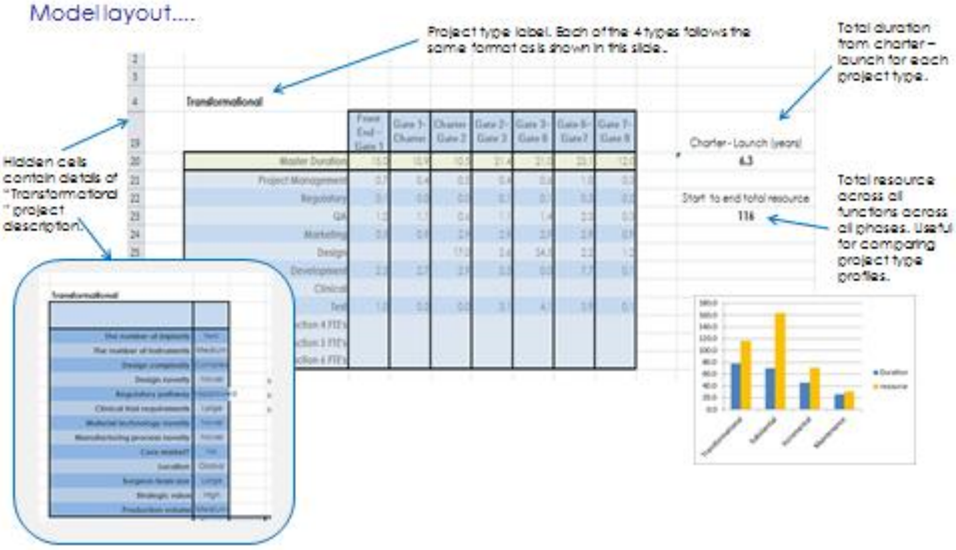
When multiple response have been received they can be analysed together. Providing each included response is carefully considered, This could help eliminate noise. In this instance, select a higher number of replicates per corner points. The will repeat the designed experiment in runs 9-16(for 2 corner points) and again in runs 17-24 (for 3 corner points)…and so on…



APPENDIX 6 AA – CREATING AN EXCEL VERISON OF MODEL

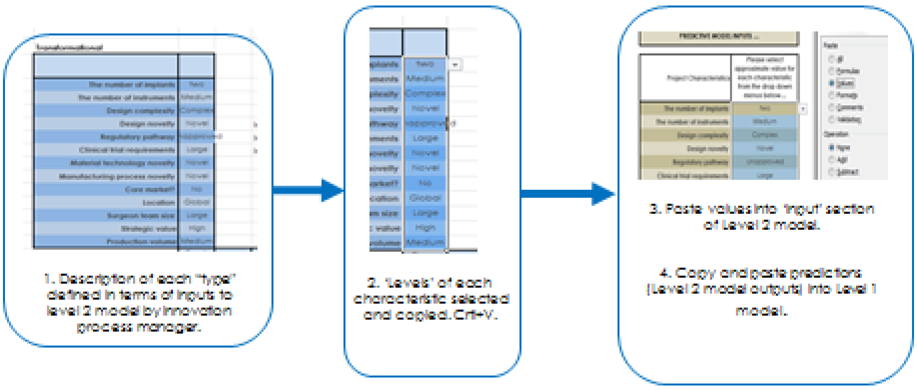
Level 1 model

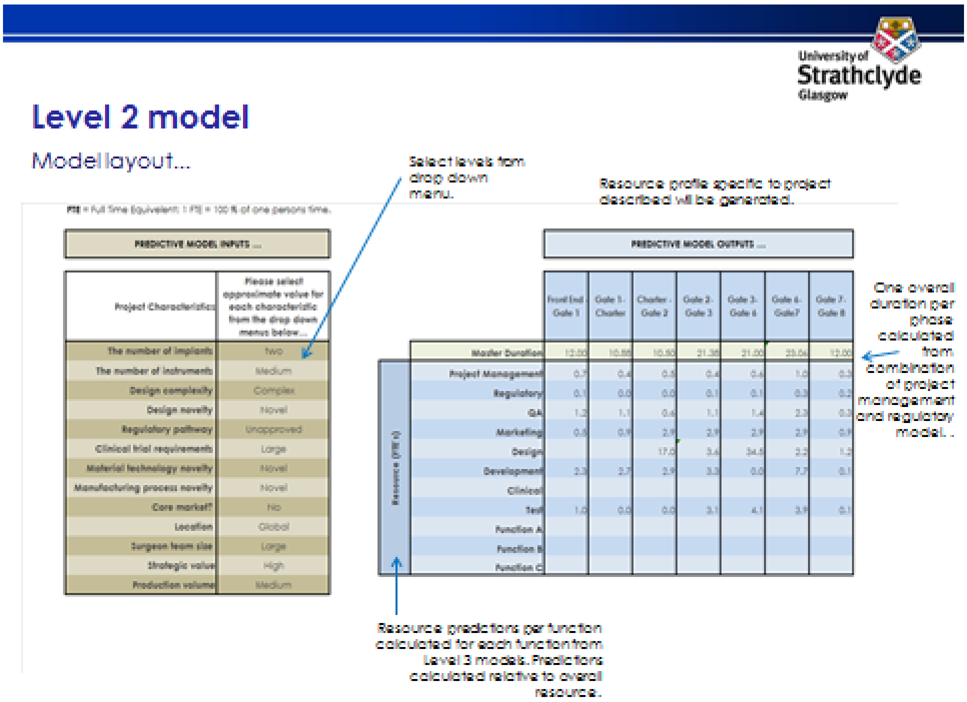
Model layout....



Level 1 model

Process of populating spread-sheet.

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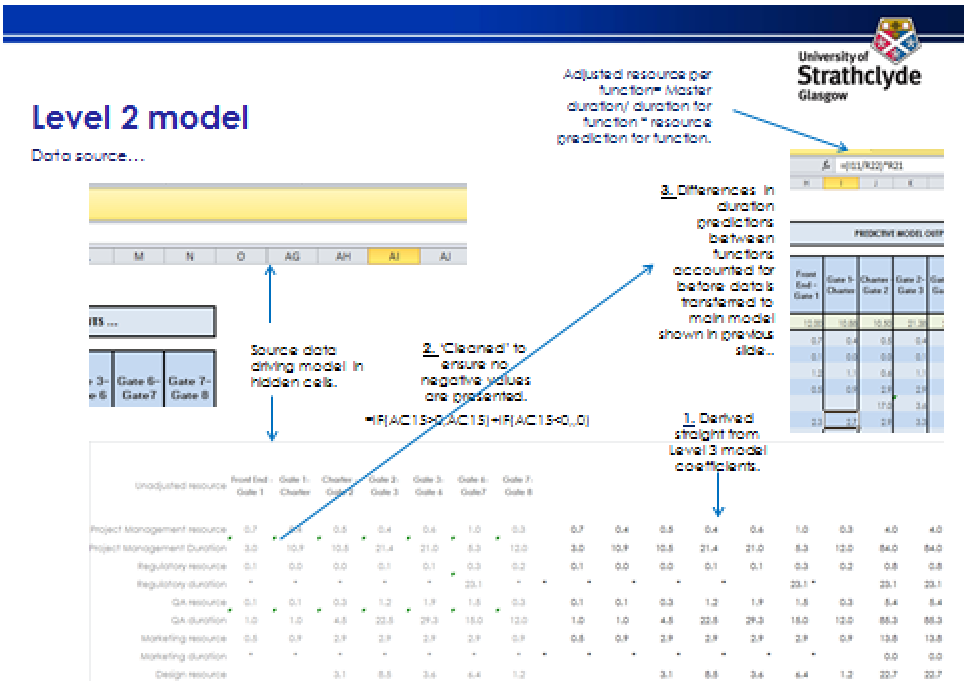
Level 2 model
Model layout…
Select levels from drop down menu.
Resource profile specific to project described will be generated.
PREDICTIVE MODEL INPUTS …
PREDICTIVE MODEL OUTPUTS …
One overall duration per phase calculated from combination of project management and regulatory model. .
Resource predictions per function calculated for each function from Level 3 models. Predictions calculated relative to overall resource.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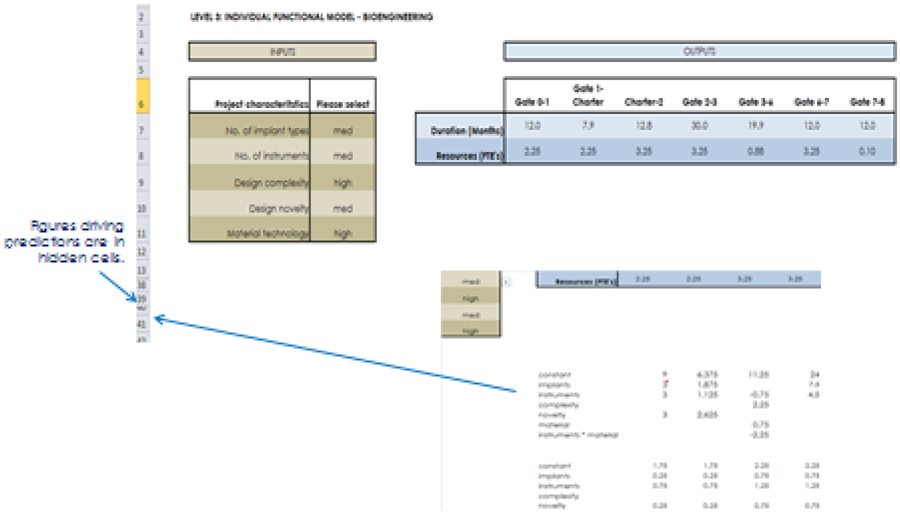
Level 2 model
Data source…
Adjusted resource per function= Master duration/ duration for function * resource prediction for function.
3. Differences in duration predictions between functions accounted for before data is transferred to main model shown in previous slide..
Source data driving model in hidden cells.
2. 'Cleaned' to ensure no negative values are presented.
=IF(AC15>0,AC15)+IF(AC15<0,,0)
1. Derived straight from Level 3 model coefficients.

Level 3 model

Model layout...



Level 3 model

Data source...