ENGINEERING MANAGEMENT: THE SYSTEM-WIDE OPTIMIZATION OF ORGANIZATIONS

by

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Abstract

Broadly speaking, the world in which we live exhibits complex interactions of multi-variate and multidimensional parameters that are implemented by organizations in a global organizational space. Within this space exists numerous organizations in various disciplines and with various objectives, save the common objective of survival. These organizations compete in the environment created by this space, consuming energy, labour and raw materials from the environment and producing energy, finished products and waste back into the environment. The optimization of the operation, structure and existence of each organization in organizational space allows for a structured approach to symbiotic survival and the common achievement of a multitude of organizational objectives; providing for the avoidance of the depletion or extinction of resources, materials and energies within the space.

If the world as we know it holds organizational space as one of its facets, then the global system is at the mercy of the operations of each organization, amongst others. The world then contains the embodiment of each system in some or other dimension. It allows for the training of the mind of the set of human systems to seek out that which allows for the progression of the common interest of the global system and thus the survival of each system it contains, ultimately leading to its own survival.

Engineering management allows for the formalization of a relationship between two disciplines that can greatly impact the operation of the global system. It is not true that this is the most important of all disciplines; but what can be said to be true is that successful completion of the objectives of each discipline allows for the achievement of the overall system objectives. Together with all other disciplines, engineering management calls for both the consideration of organizational space as a whole and the consideration of each organization within the space.

The consideration of all organizations as an open, self-contained system allows for the satisfaction of the latter consideration by finding the solution to the question: "If I was a system, how would I want to be controlled and optimized?" An organizational system contains a set of components, inputs, energies, processes and outputs in one or other formation. Probably one of the most important elements of the component set is the set of human beings – a component which exhibits non-linear and time variant response characteristics. The successful modeling and optimization of a system as a whole requires the modeling of each component and process, and that which poses the greatest difficulty is the human, perhaps because the one responsible for the modeling is itself a component of the same set.

Viewed in light of the greater system, the author is simply a member of the component set of an academic organization interacting within the global organizational space, and this is the accumulation of the research that I respectfully present.

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Declaration

I hereby declare that all information and account of endeavor contained in this report is original, correct and accurate to the best of my knowledge.

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TABLE OF CONTENTS

LIST OF SYMBOLS AND NOTATIONS

$\emptyset$	Empty set.
$\in$	Denotes an element of a set.
$\notin$	Denotes not an element of a set.
$\cup$	Union of two sets.
$\cap$	Intersection of two sets.
$P(A)$	Probability of Event A.
$P(A \vert B)$	Conditional Probability of Event A given Event B.
$F_X(x)$	Cumulative Distribution Functional.
$f_X(x)$	Probability Density Function.
μ_x	Mean or expected value of a random variable.
σ_x^2	Variance or standard deviation of a random variable.
$R_x(t, s)$	Autocorrelation function indicates the dependence among random variables.
$K_x(t, s)$	Autocovariance function between two random variables.

LIST OF FIGURES AND TABLES

Index of Tables

Illustration Index

CHAPTER ONE: INTRODUCTION

Chapter Outline

Chapter Overview

This chapter introduces the research project and provides the objectives of the dissertation. It provides reasons as to why work such as this may be necessary and briefly discusses the scope and boundaries of the dissertation. Deployed research methodologies are discussed and a discussion of content of the chapters to follow brings this chapter to a close.

1.1 Chapter Introduction

With the ever increasing pressures of competition and globalization, most for-profit undertakings are forced into placing higher demands on departments within the undertaking: in order to remain profitable, it is necessary for each business unit to operate and integrate optimally so as to maximize profits.

In countries like China and India, labour is relatively cheaply available allowing mass production and development in inequitable measures. In countries such as the USA and Germany, technologies are readily available to provide support for development and manufacture. The effects of competing in the global market have become apparent on South African horizons as many undertakings have felt the pressures of competition from better prepared competitors, be they abroad or local.

It is thus of importance that undertakings begin investing in sometimes costly, but very often necessary, improvements in organizational structures in order to remain ahead of competition. New market trends, technologies, methodologies, business practices and opportunities have to constantly be identified, explored, understood and then implemented. This often requires a diverse array of skills and techniques that border on both science and art.

It is the purpose of this work to attempt to discover the most appropriate implementation of organizational philosophies to achieve organizational objectives, maximize throughput, realize organizational vision and mission, and remain profitable. Through the course of this work, it will be shown that the application of good engineering practices form the basis for successful business philosophies.

If an organization is regarded as a system, then it will have inputs, processes and outputs, and it is of importance that engineers fulfill their professional duty in positively influencing the immediate environments as they have been taught to understand systems.

1.2 Topic of Discussion

The chosen topic may well be misleading. Why would one classify Engineering Management as bridging the human-technology gap in a multidimensional optimization playoff? Perhaps it is educative to whet the academic taste buds and preempt the content of this work somewhat by means of academic seduction.

Firstly, it is necessary to discover the need for this “engineering management”.

Bennett [1] defines the management process as:

To manage is to forecast and plan, to organize, to command, to coordinate and to control. To foresee and provide means examining the future and drawing up a plan of action. To organize means building up the dual structure, material and human, of the undertaking. To command means maintaining activity among the personnel. To coordinate means binding together, unifying and harmonizing all activity and effort. To control means seeing that everything occurs in conformity with established rule and expressed command.

Liebenberg [2] postulates that an engineer is one who:

Solves technological problems by making products, devices or systems available to society ... designs modern day engineering equipment, develops or builds the same, and operates machinery in an effective and safe manner ... [by exploiting their] sound grounding in scientific and mathematical principles.

According to Morrison[3], engineers are logical, objective and unemotional in decision-making. They are methodical and base their decisions on facts. They thoroughly analyze problems. They understand what motivates other engineers. They are capable of understanding, reviewing and evaluating the work of other engineers, and can participate in technical discussion or debates. They deploy their technical knowledge in verifying information, planning the future, and considering the technology-cost effectiveness playoff.

Bennett [1] states that engineers and managers are both trained to be decision makers in complex resources; and that both are responsible for allocating resources for the operation of existing systems or the development of new systems as they recognize, identify and evaluate the interfaces among system components.

From a training point of view, it seems as if engineers are primarily concerned with decisions involving the material subsystem, whereas managers are deemed to be primarily concerned with decisions involving the human subsystem. From observation, it is true that in practice the boundaries become blurred, and the primary concerns of each may become multi-disciplined.

This said, it is thus possible for engineers to transition to managers, but the converse often proves to be untrue as a result of the stringent legal, academic and background requirements placed on the field of engineering.

The following table (Bennett [1]) elaborates on the role differences between engineers and managers:

Position	Engineer	Manager
Focus	More concerned with things technical / scientific.	More concerned with people.
Decision Making	Makes decisions with much information, under conditions of greater certainty.	Makes decisions often with inadequate information, under conditions of greater uncertainty.
Involvement	Works on tasks and problem solving personally.	Directs the work of others to goals.
Process Outcomes	Work based on facts and quantifiable outcomes.	Work based on fewer facts, less measurable outcomes.
Effectiveness	Depends on personal technical expertise, attention to detail, mathematical / technical problem solving, and designing.	Depends on interpersonal skills in communication, conflict management, getting ideas across, negotiating, and coaching.
Dependency	Experiences role as autonomous.	Experiences role as interdependent.
Responsibility	Individual accomplishment in one project, task, or problem as a time.	Many objectives at once, requiring orchestrating a broad range of variables and organizational entities.
Creativity	Creative with products, designs, materials.	Creative with people and organizations.
Bottom Line	Will it work?	Will it make / save money for the organization?

Table 1-1: Role Differences Between Engineers and Managers [Source: Bennett [1]]

The justification for engineering management is palpable and is the marriage of the elements of the above table: an engineering manager is one who understands the organizational system in its entirety and is concerned with both human and technical entities; is capable of making high-quality decisions irrespective of the amount of information that is available; works on tasks and problems individually and in directing the works of others; exhibits high levels of competency in technical expertise, attentional to details, technical problem solving, designing, interpersonal skills, conflict management and negotiation; is personally responsible for tasks that broad and requires the orchestration of a broad range of variables and entities; is creative with products, designs, materials, people and organizations; is concerned that the task works AND that it saves or makes money for the organization.

From the above definition it should be evident that engineering management is a multidimensional optimization function that requires the integration of human and technological subsystems to solve for the optimal operational parameters of a given system by effectively deploying the convolution of skills derived from both fields of expertise.

So, with the volumes of work contributed to these fields of study, why work on this topic?

1.3 Motivation For This Work

From personal observation, there are many writings published that seek to optimize business vision and implementation thereof. There are also many works that intend to optimize development and production systems. There are others that tend to coach engineers on *how* to be good managers. These books tend to be focused and drill down to a certain well-defined area of focus. There is also resistance from both engineers and managers who see their disciplines as being unique and / or superior.

If the organization is perceived to be a system, and it is understood that the roles, tasks and operations of both engineers and managers are identical, differing only in manipulated subjects, then surely the propagation of skills from one field to the other would be possible. However, it is not the purpose of this work to explicitly debate the need for the combined engineering-management discipline.

With the advancements made in research, analysis and optimization techniques, this work seeks to re-explore the notion of the systems theory approach to management and engineering. Lussier [4] states that systems theory was backgrounded due to its excessively scientific nature and the evolution of socio-technologies that were more focused on the human. Is it possible that systems theory was deprecated too early in its development – perhaps before adequate modeling techniques were available? Systems theory allows for a holistic view at that which is to be modeled, understood, defined, analyzed, created, optimized, maintained, etc. and allows for the incorporation of any and all techniques which will bring forth the required results. Thus it incorporates notions – past, present and future – which apply a *best-fit* type of engineering or management for the application. This means that the system is analyzed and the focus is to determine those methods and/or parameters the system requires to be well controlled – not to force methods of control down on the system. This requires a rather great paradigm shift from the conventional method of management.

The fields of engineering is rather well defined and novel engineering breakthroughs are often completely described and characterized by their corresponding mathematical and scientific interpretations. In recent years, a host of psychological discoveries have been made that will allow for easier modeling of the humans subsystem. From understanding the technological subsystem and the human subsystem, the parameters of both can be integrated into an organization's structural optimization process and more accurate models can be obtained.

Probably the most difficult task of any engineering or managerial endeavor is to understand or *model* the system in question. Engineers are taught to intuitively model systems which are linear, time-invariant and causal (Franklin, Powell and Emami-Naeni [5]) as these systems lend themselves to comparatively easy modeling. The human subsystem poses particular challenges due to the fact that the elements are non-linear (superposition does not hold) and time-variant (a stimulus at t = 0 may produce different outputs to a stimulus at t = 1). This requires other methods of modeling which will be covered later in Chapter 4.

This research does not focus on any particular type of organization, but considers the notion of an organization to be generic and is not restricted to the type of organization (for example, for-profit and not-for-profit organizations). In this way, a template can be created for the modeling of an organization as a system, and the analysis and optimization of the system's processes, structures and internal environment.

1.4 Methods of Research[6]

This dissertation is compiled by deploying a combination of research methodologies. The majority of background information is derived from published literature: books, journals and the Internet have proven to be resources of great wealth.

No new general surveys will be conducted, but where applicable, the results of preconducted surveys will be analyzed and interpreted in terms of their applicability to systems theory: any relevant information that surveys may offer in terms of statistical information or generally accepted opinion or practice may be referenced through the course of this text.

In order to compile case-studies that accurately represent real-life organizations, company profiles will be studied, and both formal and informal interviews will be conducted and the results will be presented within the case study.

The author will take the liberty to highlight any aspects or conclusions that have been derived from the analysis of the results during the course of the compilation of this dissertation.

1.5 Research Objectives of The Dissertation

In order to tackle a dissertation as diverse as this, it is necessary to define the method of research up front. It is important that the available literature is first summarized to provide background theory and provide valid reference to conclusions and assumptions made within this research. This includes brief discussions of the discipline of Engineering Management, the materials subset, the human subset and system's theory. As part of the literature survey, some of the mathematics that can be deployed in modeling the organization are provided. The purpose of all the theoretical background is to allow for analyses conducted within the case studies.

The objectives of this research can be summarized as follows:

- Survey and summarize some of the current literature for information regarding General Systems Theory, Human Behavioural Sciences and Mathematical Modeling.
- Provide a method to model or describe an organization as a system.
- Construct an algorithm that can be applied to a system that will provide a structured approach to system optimization as applied to organizations (in terms of process, internal environment and system structure).
- Apply the algorithm to a real-world organization and theoretically predict the results.

1.6 Scope, Content And Boundaries of This Work

In a work as limited as this, it is not the intention to provide exhaustive information, or extensive derivations as much information can be derived from the available literature. A list of references is provided at the end of this dissertation. Only information that is necessary to reach the conclusions and achieve the objectives of this research will be documented.

This work is founded in the analysis and extension of concepts in existing theory and science. This will allow the research to follow a strictly scientific approach. Where insufficient literature is available, the author's beliefs will be presented together with what is hoped to be a suitable, logical derivation.

In *Chapter 2: Engineering Management*, the connotations surrounding the domains of Engineering and Management in their individuality and union are discussed.

Chapter 3: Systems Theory, provides a description of the approximately 60-year old concept of systems-theory-based management. According to Wikipedia [7] the notion of general systems theory originated centuries ago and was first applied to organizations in the 1950s. At this stage, possible reasons are presented for superceding the concept of systems theory in the management discipline (Lussier [4]), despite it being widely accepted in the engineering discipline (Ziener, Tranter and Fannum [8] explore the notion of systems in the engineering domain).

Based on the conclusions drawn in Chapter 3, *Chapter 4: Defining the Human Component* draws the attention to the inclusion of humans in a manipulated component set (the notion of component sets of a system will be discussed at length is subsequent chapters). Information is derived from the science of psychology in an attempt to extract the most relevant characteristics and definitions for human mental ability, behaviour, personality and intelligence. The aim is to create an abstract definition that will allow for insertion of the human component into a system in a manner that will optimize the operating environment of the component, and thus derive the greatest benefit for both the human and the system.

Chapter 5: Applicable Mathematics and Modeling Techniques provides an opportunity to describe the mathematics required to model, define and optimize systems. This is a general look at the mathematics as applicable from related literature before being applied to this field.

In *Chapter 6: Organizations as Systems*, borrows from the concepts of General Systems Theory (resources available on the WWW [7][9]) in an attempt to model the organization as a system with inputs and a process that converts these inputs into outputs.

Chapter 7: Modeling of Optimization Functions describes how the mathematics in Chapter 5, the components in Chapters 4, and the organization as a system in Chapter 6, can be used to construct a system parameter optimization algorithm.

Chapter 8: Practical Considerations discusses the methodologies behind conductance of tests in real-life applications, as there may be financial implications coupled to the testing phase.

In *Chapter 9: Case Studies* shows how this research may be applied in practice.

Chapter 10: Conclusion and Recommendations for Future Work brings this work to its logical conclusion and provides some recommendations for further research.

1.7 Chapter Conclusion

In this chapter, an overview of this dissertation was provided:

- The research topic was presented: This dissertation discusses the application of general systems theory in constructing an algorithm to optimize the operating parameters (system structure, internal environment and processes) of an organization.
- Motivation was provided for this dissertation: Given the scientific, mathematical, psychological, managerial and engineering advancement that have been made in recent years, it would be feasible to rethink an organization in terms of general systems theory.
- Goals and objectives were presented:
  - Summarize the current literature.
  - Provide a method to model an organization as a system.
  - Construct a system-optimization algorithm.
  - Apply the algorithm to a real-world organization.

- The scope of the dissertation was defined;

In the next chapter, the concept of Engineering Management will be discussed.

CHAPTER TWO: ENGINEERING MANAGEMENT

Chapter Outline

Chapter Overview

This chapter focuses on the notion of engineering management. It contrasts the notions of classical engineering with the notions of classical management, and then briefly discusses the benefits derived from the union of the fields.

2.1 Chapter Introduction

Before delving deeper into the chosen field of research, the existing literature is discussed broadly. The goal is to begin with a broad view and then continuously narrow the focus as the conclusion is converged upon. This chapter is intended to be a simple and short overview of the important and applicable concepts of both domains.

What are the classical views on management and engineering? The formal definitions of these concepts have been provided; and the definitions indicate that the concepts are extremely diverse and yet extremely similar. This apparent contradiction is what has allowed the disciplines of management and engineering to be disjoint, and it is probably this contradiction that will help to integrate these two disciplines. The fusion of these discipline should yield concepts and results that will have benefit for both disciplines: by approaching challenges with a holistic bias, the results obtained should be technically brilliant, socially gratifying, legally acceptable, and financially rewarding. These are some of the benefits derived from a broadened approach.

One of the reasons that managers are restricted from practicing engineering is due to legal academic requirements in South Africa (OHSA [10], ECSA[11]), but the converse is not true. So, the question is: when do engineers make good managers, while remaining good engineers?

As engineers, the complex interactions between various systems and the components thereof are understood. Engineers are generally technically-minded and tend to specialize in non-emotional systems. The successful engineer seeks to explore every system and comprehend it in its entirety, for it is in defining the system that one learns to understand it and in understanding it, one learns to adapt, control and optimize a system to reach its optimally effective and efficient state by exploiting good and innovative design techniques. In order to comprehend a system, one would have to understand the components of which the system comprises, the conversion of inputs into output through the process, and the often complex interactions and inter-disturbances between components of the system, and the system and the outside world.

As managers, the complex interactions between various processes and the constituents thereof are considered. Managers are generally financially-minded and tend to specialize in financial and 'emotional' systems. The successful manager seeks to explore every system and understand it in its entirety in order to optimize it. In order to understand the system, the manager would have to understand the components of the system, and how they fit together. These components are subsets of the financial, process, human, technical and other domains.

In the author's opinion, one of the greatest paradigm shifts that needs to materialize is the realization that the functions of engineering and management are very closely related – in many cases even the equivalent. It is only the manipulated component sets that differ. Hopefully, the following discussion will help to reason this out clearly.

2.2 Notion of Classical Engineering

The history of the concept of engineering stems from the earliest of times when humans began making clever inventions.

Liebenberg [2] says that the term ‘engineer’ has its roots in the writings in A.D. 200 which tell of a battering ram which was used to attack walled defences. The invention was known as an ingenium. 1000 years thereafter, an ingeniator was the man who operated the device of war. The Latin word ingenio means ingenious or creative. An engineer is an “ingeniator” – one who exhibits “ingenio”. In slight contradiction to this, Wikipedia [12] claims that the term engineering was coined for a person occupationally connected with the study, design and implementation of engines; and engine was derived from the Latin ingenium (1250) which means “innate quality, especially mental power, hence a clever invention”. Irrespective of the correctness of the source, the definition of an engineer is still the same: engineering is analysis, design and construction of solutions for practical problems. Wikipedia [12] defines engineering as “the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works, utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behaviour under specific operating conditions; all with respect to an intended function, economics of operation and safety to life and property”.

Engineering is a multi-discipline approach to problem solving. There are many types of engineers and as time progresses, society increases the number of fields for which engineering is defined.

These fields range from the classical electrical, mechanical, civil and process engineers to the more recent software, financial, industrial, aesthetics, ergonomics and so forth engineers. Each engineer applies his or her knowledge to find the most effective and most efficient solution to a given problem or situation.

2.3 Notion of Classical Management [4]

The classical approach to management was an attempt to develop the best way to manage in all organizations by focusing on the jobs and structure of the firm. Interestingly enough, an engineer, Frederick Winslow Taylor (1856 – 1915) is credited as the Father of Scientific Management and he focused on analyzing and redesigning jobs more efficiently in order to find the best way to maximize performance. The scientific management principles that he derived include:

- Developing a procedure for each element of a worker's job;
- Promoting job specialization;
- Scientifically selecting, training and developing workers;
- Planning and scheduling work;
- Establishing standard methods and times for each task;
- Using wage incentives such as piece rates and bonuses.

Another interesting fact was that the Pioneer of the Principles and Functions of Management was French engineer, Henri Fayol (1841 – 1925). Fayol distinguished between managerial and operational activities, defining the five major managerial functions to be planning, coordinating, organizing, controlling and commanding.

Mary Parker Follet (1868 – 1933) stressed the importance of people rather than engineering techniques and contributed to administrative theory, which emphasized the need for worker participation, conflict resolution and shared goals. Chester Barnard (1886 – 1961) studied authority and power distributions in organizations and shed light on the formation of cliques and naturally occurring social groupings within formal organizations.

The classical techniques are still employed in time and motion studies, etc.

In the 1920's, management researchers questioned the classical approach to management, digressing their focus from the job and refocusing on the people who perform the job. These behavioural theorists focused on people to determine the best way to manage in all organizations, and stressed the need for human skills, rather than technical skills.

The human relations movement was pioneered by Elton Mayo (1880 – 1949). The mode of research was to determine how to increase performance by modulating the best work environment and the results suggested that a manager's treatment of a person had an important influence on the performance.

Abraham Maslow (1908 – 1970) developed the much celebrated hierarchy of needs and became of the earliest researchers to study motivation.

The behavioural science techniques are still employed in economic, psychological and sociological organizational roles.

During the 1940's, research turned towards investigating the applicability of quantitative methods to military and logistic problems, which in turn gave birth to management science theories which focus on using mathematics to aid in problem solving and decision making. Mathematic models were used in the areas of finance, management information systems and operational systems and are still being deployed today, particularly as computing power increases.

In the 1950's there was an attempt to integrate the classical, behavioural and management science theories into an all-inclusive view of the management process. System theorists focused on viewing the organization as a whole and the interrelationship of its parts. The basic idea was that an organizational system transforms resources into products. In this view, each sub-division is considered as a system and conceptual skills are needed in order to understand how the subsystems / departments (for example marketing, operations and finance) interrelate and contribute to the organization as a whole. Managers making a decision in one department thus have to consider the effects of this system on other departments. This allows the organizations to be identified as open systems because of the interaction with the external environment (for example laws as in the OHSA

[10]).

In the 1950's and 1960's, the focus turned again to socio technical theories which focused on the integration of people and technology, stating that excluding the one will lower levels of performance. Socio technical theories correlated strongly with the behavioural science theories.

In the 1960's and the 1970's, contingency theory came to the fore and focused on determining the best management approach for a given situation [13]. Tom Burns and George Stalker studied the environmental influence on a firm's organization and management systems and identified two types of environments and two types of management systems. The stable environment is defined as one with little change and the innovative environment is one of great change. The mechanistic management system is is similar to bureaucratic classic theory, and the organic management system more similar to behavioural theory.

Lussier [4] defines a manager as the individual responsible for achieving objectives through efficient and effective utilization of resources where efficient refers to doing things right and effective refers to doing the right thing. The resources include human resources, financial resources, physical resources and informational resources, and the organizational performance is based on how effectively and efficiently the manager uses the resources to achieve objectives.

Management skills include technical skills, human communication skills, and conceptual and decision-making skills.

Management tasks include planning, organizing, leading and controlling.

Managers contain the following characteristics:

- Creative problem solving;
- Good decision making;
- Strategic planning;
- Operational planning;
- Organization of work;
- Delegation of work;
- Change management;

- Human resource management;
- Motivating members;
- Leading teams with influence;
- Good communication skills;
- Financial and human system control;
- Control of operations, quality, technology and information.

2.4 The Union of Engineering and Management

Is engineering management the management of engineers, or is it the engineering of management? Consider that while all engineers can choose a management career path, the converse may not necessarily be true, and that while engineering managers manage engineers, they also engineer management. Freeman-Bell and Balkwill [14] indicate that there is need for both. There is a need for good engineers and for good managers. There is a need to manage good engineers and a need to manage good managers.

Engineering management then, would deal with the effective and efficient operation of a process or system and the optimization thereof. These tasks would include monitoring of quality, performing maintenance, optimizing the process, improving the system, and so forth. It would also deal with management of the technical requirements of an organization. From service delivery to technical application. It includes the management of products and their development, which includes managing the inputs to and feedbacks from marketing, sales, consultation, designs, enquiries, adjudications, etc.

Engineering managers are thus interested in applying their host of skills in providing the best solution to a given problem, and making sure that the most effective and efficient combination of resources, materials, planning, etc. is employed. An engineering manager is thus one who applies himself to understanding the intricacies of technical knowledge, human behaviour, financial procedures, marketing procedures, and so forth, in an effort to derive an acceptable level of self completion; and then uses this well-rounded self to provide solutions to challenging problems and situations, be it in leadership, in technical design, in logistic operation, in process optimization, or in any social or organizational function.

It should be clear that there is correlation between the tasks of a manager and those of an engineer. In fact there are not only similarities, but very clear overlaps. Both need to be able to work with people, finances, leadership, optimization, control, technologies, development, processes, systems, and so forth. Both engineers and managers need to be creative and able to multi-task. Both provide vision and leadership through innovation and creativity.

Engineering management in itself allows for various benefits, including greater cohesion in teams which include both technical and non-technical members. It allows for a better understanding of people and technical aspects which in turn allows for quicker and better decisions and the quick prioritization of information and elimination of redundant or non-important information. Engineering managers should be more able to provide better guidance and assignment of resources in difficult problems. A web page at the University of Texas [15] lists a few benefits of engineering management: engineering managers should have an executive view which allows them to better manage technical, business, and human performance and the achievement of corporate goals; engineering managers should have an understanding of the core business fundamentals in areas such as economics, negotiations, marketing, decision analysis, risk assessment, legal issues related to projects and financing ventures; engineering managers should exhibit expertise in the management of innovation and expertise in the analysis and functional roles of leading and holistically managing organizational change.

2.5 Chapter Conclusion

In this chapter the notions and history of classical management and engineering were discussed. Some differences and similarities between the two have been discussed and the integration of engineering and management was detailed. Finally, the applications and benefits of engineering management were discussed.

In the next chapter, General Systems Theory will provide some of the theory required to envision and model an organization as a system.

CHAPTER THREE: SYSTEMS THEORY

Chapter Outline

Chapter Overview

The notions of General Systems Theory is one of the fundamental theories of this research. An overview of systems theory is provided in this chapter. The notion that an organization can be considered a system is presented together with a definition of system components, and a discussion on component interaction and interferences. Finally a small note on system control and optimization is provided.

3.1 Chapter Introduction

This chapter will focus on the collective theme of this work in defining Systems Theory. This chapter will provide a description for what is meant by Systems Theory in the classical context, broadly define the systems that engineering managers work with, define what is meant by the components of a system, describe some of the interactions between components and the interferences that they are subjected to, and discuss theoretical system optimization methods before reaching its logical conclusion.

3.2 What Is Systems Theory

In order to understand Systems Theory, one must first understand the definition of a system. According to Ziemer, Tranter and Fannin[8], a system is defined as an *input* which goes through a *process* to provide an *output*. Generalization of this definition allows for a set of inputs to go through a set of processes to provide a set of outputs. One needs to take note of the fact that real-life systems are much more complex as they comprise numerous sub-systems: the processes can be arranged in a number of ways providing parallel and series branches in any combination and order; the outputs of one process yield inputs to another; and processes may cross-interfere and introduce disturbances into other processes.[†]

Systems Theory strives to view a system as a generalized, bounded entity comprising multiple sub-systems (each in turn possibly comprising multiple sub-systems) which are constructed from characteristic sets of inputs, processes and outputs[‡]. In Systems Theory, a top-down to bottom-up

† This leads to the conclusion that process inputs may be compromised, which in turn leads to the process being compromised, which in turn yields undesirable and out-of-specification outputs. On the other hand, processes themselves may be compromised [due to equipment wear, for example] which may lead to similar results. In cascaded systems, the effects of sub-system instability are thus propagated to subsequent sub-systems sometimes leading to catastrophic results

‡ Examples of systems could be as simple as a controller to a business organization to something as complex as the world with uncounted sub-systems. The characterization of the behaviour of a system of great magnitude requires exponentially increasing resources do to the exponential (or greater) rise in complexity. The scope of this work stops at the definition of business organizations (comprising all their sub-systems) as the systems in question. I describe the system environment a little later in this literature which allows the definition of any system as being the chosen highest level and thus bearing its sub-systems.

approach is applied first recursively and then iteratively to analyze, model, design, construct, control and optimize the system in question.

An Internet reference [9] describes Systems Theory as follows:

"System theory is the trans-disciplinary study of the abstract organization of phenomena, independent of their substance, type, or spatial or temporal scale of existence. It investigates both the principles common to all complex entities, and the (usually mathematical) models which can be used to describe them."

It goes on to state that a system consists of the following:

- The parts, elements or variables within the system which can be physical and/or abstract;
- Attributes which are the qualities, properties or characteristics of a system and its objects;
- Internal relationships amongst its objects; and
- The system exists within an environment which implies that systems within an environment can affect each other and form a larger pattern which differs from any of the parts.

By definition then, a closed system does not react with its environment as it does not allow for the transfer of information and is thus likely to atrophy. An open system, on the other hand, allows for the bi-directional transfer of information and the dynamic interaction with the rest of the environment, making it more likely to survive and prosper. This allows for communication with the environment to be perceived as an integrated process, not an isolated event. Figure 3-1 [16] depicts the perspective of system modeling.

Wikipedia [7] gives the following note on System Theory as applied to organizations:

"The systems approach to organizations relies heavily upon achieving negative entropy through openness and feedback. A systemic view on organizations is trans disciplinary and integrative. In other words, it transcends the perspectives of individual disciplines, integrating them on the basis of a common "code", or more exactly, on the basis of the formal apparatus provided by systems theory. The systems approach gives primacy to the interrelationships, not to the elements of the system. It is from these dynamic interrelationships that new properties of the system emerge. In recent years, systems thinking has been developed to provide techniques for studying systems in

holistic ways to supplement traditional reductionistic methods. In this more recent tradition, systems theory in organizational studies is considered by some as a humanistic extension of the natural sciences."

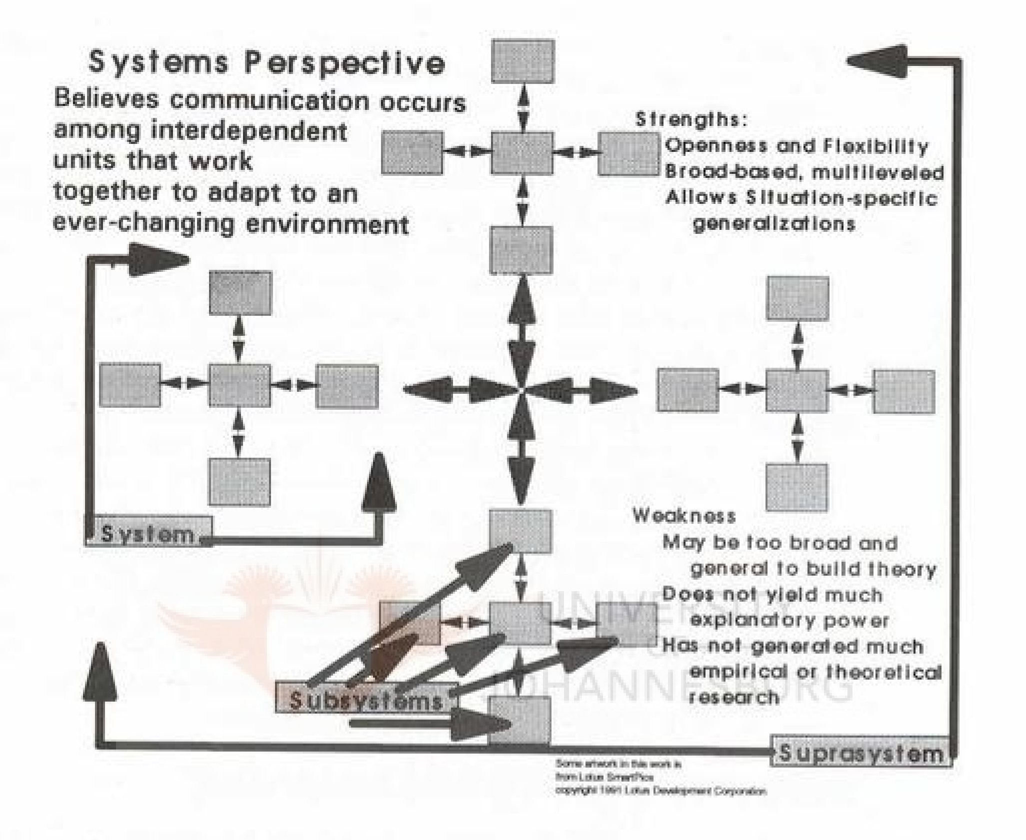


Figure 3-1:Systems Perspective Model [16]

For the purpose of this work, the system is defined to be any generalized organization interacting within the global environment†. As has been noted above, Systems Theory had limited perspective in that it focused primarily on interrelationships and not on elements of the system. Systems Thinking is a spin-off which aspires to look at the system holistically and focuses more dominantly on the human element of the system. There does however seem to be a balance between the two trains of thought that needs to be characterized: it is as important to understand (and model) all the elements within a system (not just human elements) and the interactions between the elements, sub-

† In the age in which we live, it can easily be shown that even organizations who do not envision themselves to be global competitors still interact within the global environment.

systems and environment. This will be the main focus of this work.

3.3 Definition of Applicable Components

It would be an impossible task to enumerate all possible components within a generalized system. A more achievable task would be to define the components of a system to be the set of all subsystems which in turn is generated by the set of all processes, the set of all inputs and the set of all outputs.

Without any loss of generality, the component set of any organization can be defined to include the subsets of all human, technical, operational, financial, and historical resources (time, money, people, assets) that belong to an organization. The above definition demands that all these components are *physical* components. The intangibles that belong to the components set includes knowledge, data, skills, abilities and methodologies. These all serve as inputs to the set of processes that belong to the organization. In other words, a process (which by definition would be intangible) would manipulate the components (both tangible and intangible) to produce outputs that are physical and / or abstract[†].

The human component set merits special attention and will be dealt with the the next chapter.

3.4 System Component Interactions, Interferences and Disturbances

It is important to understand the operating environment for which a component is designed. Generally the human component is the most flexible due to its ability to learn and adapt, but it is often beneficial to match any component with the correct environment. Any component can be stressed beyond its feasible operating region which could lead to catastrophic system failure, depending on how critical the component is.

† Both Engineering and Management can both be considered as processes in a higher system. Both require knowledge, skills and human effort as inputs to design, maintenance, planning, organizing, etc. and go through the said processes to produce required outputs.

It is necessary to define what is meant by component failure: failure does not necessarily imply that the component has been rendered completely useless, but simply that it is no longer able to perform the task that it was assigned to. In other words, if a component doesn't behave as designed, it has failed. Sometimes, failure can be recovered from by repair or modification of various parameters (not confined to any discipline in particular), but may sometimes require complete replacement (depending on the failure mode of the component in question).

Within a system, components can interact with other components or the environment (external disturbances) which may introduce instabilities outside the operating capabilities of the component causing component failure. Examples of this include the classical grapevine phenomenon which can enrage an entire labour force [14]; or a voltage spike on the power grid which could damage sensitive instrumentation causing system failure (depending once again on the failure mode of the components [17]).

Component failure can lead to inconsistencies within the system processes which can result in lower through yield, quality and quantity, and higher number of rejects[17]. The knock on effects of this could include heavy penalties in logistic costs and customer unhappiness[18]. The eventuality is loss in financial profits. The identification, prevention and correction of component failure is thus a critical function of any successful engineer and/or manager.

In real-life practical systems, these interactions and disturbances need to be understood, the failure modes need to be identified and analyzed, and criticality analyses should be performed. Hereafter, risk analyses can be completed and risk management and contingency plans can be formulated to prevent and cater for component and system failure.

3.5 A Note on System Control and Optimization

The author believes, that the optimization of a system as diverse as that of an organization should be any control engineer's dream. From identification of system components to the construction of models, from implementation to verification of the design, the system allows for the application of myriads of mathematical and innovative optimization techniques. Some of J.W. Forrester's [19] work sought to combine the theory, methodologies and philosophies required to analyze behaviour of systems in management, economics, politics, medicine and engineering; leading to him being heralded the "Father of System Dynamics"[20].

However, it is not common for control engineers to diverge from the purely technical control of a system. Is it because management is considered to be purely non-technical, is it that the human and financial components are considered to be a management function, or is it a lack of understanding of these components that lead to the avoidance which is often entertainingly classified as an engineer's social ineptitude? In the next Chapter, characteristics of the human component will be discussed.

It is probably merely the engineer's viewpoint which limits his mind thus posing a great loss to the advancement of the field of engineering and management: all components mentioned belong to a system, and an engineer's training enables him or her to formulate the most valuable and suitable innovations for total system control and optimization. Perhaps it is still plausible through the broadening of understanding to broaden this paradigm and allow the conceived approach to engineering to be one that comprises the complete system.

The notion of Total System Control, Optimization and Management will be discussed in Chapter 7.

3.6 Chapter Conclusion

System theory is also about the trans-disciplinary study of an organization which investigates the principles common to all complex entities and the models which can be used to describe them. Organizations can be classified as systems and should thus be subject to the principles of system theory.

System components, interactions and disturbances were briefly discussed and a note on system control and optimization was provided.

In the next chapter, attention is drawn to one of the most important elements in the characteristic set: the human being.

CHAPTER FOUR: DEFINING THE HUMAN COMPONENT

Chapter Outline

Chapter Overview

This chapter discusses one of the most important components of any organization: the human being. It is necessary to evaluate human behaviour in an organization. Behaviour is determined by the biological makeup, intelligence, personality, character, emotion and value system of the human being. Probability of behaviour, preferred operating environment, disturbances and team dynamics are also discussed.

4.1 Chapter Introduction

The human component is one that merits a great deal of discussion. A complete description and characterization of this component is extremely complex and falls outside the scope of this work. This component is probably one of the few that is common to all organizations, and it is in misunderstanding this component that many systems fail.

Technical components are designed and created to perform a given set of tasks, they can be (comparatively) easily analyzed, modeled, characterized and well described from test results (many components are provided with technical data sheets). Until failure, technical components should continuously produce repeatable and consistent results.

Human components, on the other hand, are the intelligent component – they are capable of learning and self-advancement. This makes it extremely difficult to model the human component: a human is not deterministic, does not conform with super-position, is not time-invariant, and is thus very non-linear. Humans are influenced by four dominating dimensions [21] amongst others [22]: their physical (includes all anatomic, electric, electronic, chemical, muscular, etc. sub-systems), psychological (includes knowledge, IQ, capabilities, skills, experience, etc.), emotional (includes preferences, social attributes, attachments, sentiments, memories, feelings, temperament and character) and spiritual (includes values, beliefs, background and upbringing) build-up. An input or stimulus to a human component on any given day would yield non-deterministic (differing) results or outputs depending on the state of the four-dimensional makeup of the person.

Although science has made many advancements in the modeling of the human component – medicine helps to identify anatomical characteristics [23], psychology characterizes emotion and intelligence , biopsychosociology explores the interconnections between anatomy, psychology and sociology [24] – there are still many factors which remain elusive, even with extensive laboratory tests (this is indicated by the lack of human behaviour and ailment diagnosis models [25]. Understanding that human nature allows for a great deal of variability is important for a manager or engineer. Science does allow one to determine the most probable reaction to a given stimulus, but this is a factor of the human makeup at any given time; and it is important to remember that probabilities of zero may occur and probabilities of one may never occur. The study of probabilities allows one to determine the general optimal operating environmental and the critical failure parameters for a given human component.

Much work has been done by many scientists and psychologists (including Sigmund Freud, H. J. Eysenck, Ivan Pavlov, Abraham Maslow and many others [26]) in analyzing, understanding and modeling humans and the following subsections provide a brief summary thereof. Please note that medical, and personality disorders, etc. fall outside the scope of this work.

4.2 Biological Analysis[27][28][29][30][31]

A person's physiology defines certain restrictions in terms of height, weight, muscle content (for example the amount of mass that can be lifted), strength, speed, stamina, etc. that a specific person is capable of achieving.

Contrary to the beliefs of old [32] whereby the heart was believed to be the center of thought and emotion, it has been scientifically shown that the human body, the brain is an electro-chemical machine responsible for all activity and control of the body. The brain consists of about 100-billion cells known as Neurons which are connected to each other by Axons. The brain controls the central nervous system, cranial nerves and peripheral nervous system directly. Involuntary actions such as body temperature, blood pressure, sensory perception processing, heart rate, respiration, digestion, etc. are controlled unconsciously through the autonomic nervous system, complex mental activity such as thought, reason, abstraction, cognition, perception, interpretation, imagination, memories, language, emotions, etc. are controlled on a conscious level. The human brain appears to have to localized center of control, but various parts of the brain are responsible for the control of various functions.

Medical sciences show that the brain is partitioned into two hemispheres. The right hemisphere is thought to deal with visual activities, associations, organization and grouping of information, and creativity. The left hemisphere is thought to be the analytical part of the brain and analyzes information collected from the right part of the brain. There are various centers of control from movement, sight, hearing, motor control, skin sensation, hearing and language, deduction, and so forth. As this is a dynamic assignment still under much research, it falls outside the scope of this work.

From IQ and EQ tests and simple observation, it is evident that there are significant differences in the operation of the brain from individual to individual. The basic operating principles of the brain remain the same from human to human, and it is unlikely that there are any intra species differences between biologically 'normal' human beings (including all humans without major gene defects, mental anomalies, or neurological damage) on a functional level. However, research shows that there are subtle differences in brain size, evoked electrical potentials, glucose metabolic rate, and inter-cellular pH levels. These subtle differences are thought to contribute towards the variances detected in the execution of various tests. Hence, the neuro-physiological construction of the brain has an influence on mental and emotional ability.

Without going into excessive detail, the following constitutes parts of the brain:

- The brain stem consists of the medulla, pons and mid brain; and controls the reflexes, automatic functions such as heart rate, limb movements and digestion and urination.
- The cerebellum coordinates limb movement by using information from the vestibular system that indicates position and movement.
- The hypothalamus and pituitary gland control visceral functions, body temperature, and behavioural responses.
- The cerebrum (or cerebral cortex) integrates information from all the sense organs, initiates motor functions, controls emotions and holds memory and thought processes.

Below is a diagram of the location of the various members of the brain. More detailed descriptions can be found in the appropriate texts ([33]), but this research is limited to a high-level view of the major functions of the brain.

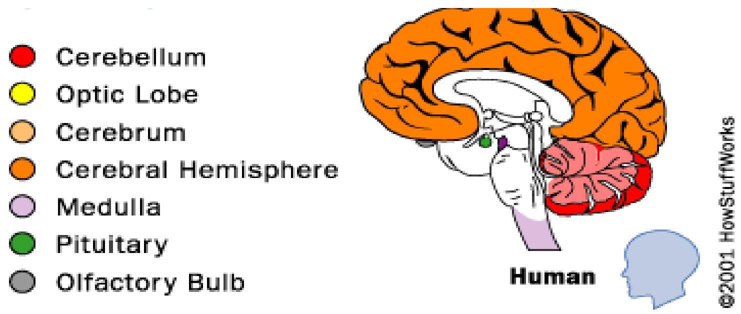


Figure 4-1: Overview of the Brain. Source: [WWW: http://health.howstuffworks.com/brain3.htm]

4.3 Intelligence Analysis [27][34][35][36]

It has long been thought that the sole predictor of one's accomplishment would be their intelligence. A set of standardized tests exist to measure what is known as the intelligence quotient. Originally, IQ was calculated as a ratio given by the formula: $100\times\frac{mental\,age}{chronological\ age}$. In 1939, David Wechsler published the Wechsler Adult Intelligence Scale which bases scores on a standard normal distribution with mean of 100 and standard deviation of 15, rather than an age based quotient. Wechsler later on developed the Wechsler Intelligence Scale for Childern. With modern-day tests, IQ's of between 90 and 110 (median plus or minus 10) indicate average intelligence, IQ's above 130 indicate exceptional intelligence and those below 70 may indicate mental retardation.

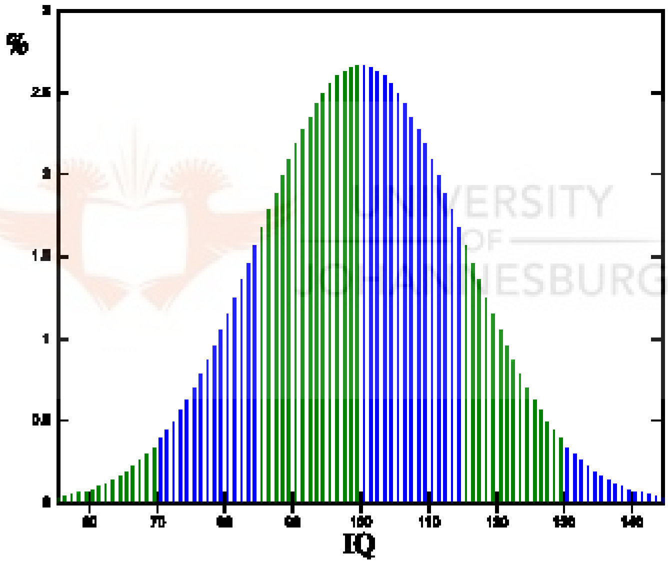


Figure 4-2: IQ Distribution with a Gaussian mean of 100 and standard deviation of 15 [Source: http://en.wikipedia.org/wiki/IQ]

Numerous other tests exist to measure IQ, and organizations deploy those tests that are most pertinent to their line of business to identify the candidates who show acceptable levels of mental ability.

In general, IQ tests are used to measure some or all of the following:

- Spatial ability: the ability to visualize manipulation of shapes.
- Mathematical ability: the ability to solve mathematical and scientific problems.

- Logic ability: the ability to apply logic to arrive at a conclusion.
- Language ability: the ability to complete sentences, recognize or describe words, comprehend passages, fluency and interchangeability of language.
- Memory ability: the ability to recall things presented either visually or orally.
- Ability to solve problems, understand concepts, reason, perceive relationships between things and store and retrieve information.

IQ tests measure ability to understand ideas, and not the quantity of knowledge. It is thought that in general, testing any one of the elements of IQ gives sufficient information for the prediction of the overall IQ (failure of this hypothesis would indicate learning deficiencies such as autism). Ideally, then an IQ test measures the general factor of intelligence, known as the *g factor*.

It is thought that IQ is hereditary, but the effect of genes on IQ is not yet fully understood. Other factors that may influence IQ are environment (such as work or school environment), family environment, fetal development, the Flynn effect (which postulates that the average IQ increases by about 3 points per decade due to improved nutrition, smaller families, better education, and greater environmental complexity), and construction of the brain which is also not yet fully understood.

It seems to be generally accepted by organizations that the measure of a person's IQ will yield sufficient information to provide indication of the mental strengths and weaknesses that he or she would offer to the organization. Upon successful engagement of a contract of employment, this analysis allows for the deployment of the human to the most suitable role – one in which value will be attributed to both the organization and the component.

4.4 Personality and Emotional Analysis [31][34][37][38][39][40]

For decades, a primary emphasis was placed on IQ, and it was thought to be the sole predictor of academic performance, and professional and personal success. However, some with very high IQ scores were performing very poorly in life (for example in a social or organizational environment) while some with mediocre IQ were performing exceedingly well in life.

It is only in recent years that the notion of Emotional Intelligence Quotient has been considered and in organizational testing, it is still not widely used, understood or accepted. This is probably due to the fact that there is yet considerable amounts of work to be done in this field. From studying the references, there appears to be differences of opinion and lack of standardization.

The general idea behind emotional intelligence is encapsulated in the following:

- Self awareness entails knowing your emotions, recognizing feelings as they occur and discriminating between them.
- Managing relationships entails handling interpersonal interactions, conflict resolution and negotiation.
- Empathy entails recognizing feelings in others and understanding the message in the spoken and unspoken language.
- Self-motivation entails directing one's self towards a goal, despite self-doubt.
- Mood management entails handling feelings in a way that is appropriate to the given situation.

This poses a totally different set of abilities than those measured by intelligence – it is the set of emotional stability and communication. According to Daniel Goleman [38], *"Emotional Intelligence is a master aptitude, a capacity that profoundly affects all other abilities, either facilitating or interfering with them."*

There are various personality tests that define personality types in different formats. The more common of the personality theories include the Enneagram of Personality, Four Temperaments, DISC Assessment, Myers-Briggs Type Indicator, Socionics, Type A and B Personality Theory. The first three will be discussed for the purposes of this document.

4.4.1 Enneagram of Personality[41]

The Enneagram of personality defines the following 9 types:

Ones: Reformers, Judges, Perfectionists. These are focused on personal integrity and are considered to be wise, discerning and inspiring and dissociate themselves from what they see as flaws. The ultimate goal is perfection.

Twos: Helpers, Givers, Caretakers. These are compassionate, attentive, generous and caring but can be prone to neediness and manipulation. They want to be loved and needed.

Threes: Achievers, Performers, Status Seekers. These are able to adapt and change easily. The common goal is to succeed, or be seen as successful.

Four: Romantics, Individualists, Aesthetes. These want to understand themselves and find a place in the world. They are creative, intuitive and individualistic. They are known to withdraw and be introspective and are prone to depression.

Five: Experts, Thinkers, Investigators. These are motivated by the desire to understand the facts about the world around them and believe they are worth what they contribute. They fear incompetency and want to be capable and knowledgeable.

Six: Loyalists, Heroes / Rebels, Defenders. These enjoy safe stability. They are loyal and responsible, and are slow to trust once betrayed. They are prone to fearful thinking and emotional anxiety as well as paranoia and phobia.

Seven: Enthusiasts, Adventurers, Sensationalists. These are adventurous and constantly busy with activities demanding lots of energy and enthusiasm. They embrace a life filled with variety, but may be impulsive and fear disappointing themselves by being unable to provide for themselves to experience life.

Eights: Bosses, Mavericks, Challengers. These value their own strength and desire to be powerful and in control. They are concerned with self-preservation and are natural leaders. They range from friendly and charitable to dictatory and manipulative. They seek to control their own destinies and fear being controlled by others or being harmed.

Nines: Mediators, Peacemakers, Preservationists. These are ruled by empathy as they are receptive, gentle, calming and at peace with the world. They may withdraw and fear conflict.

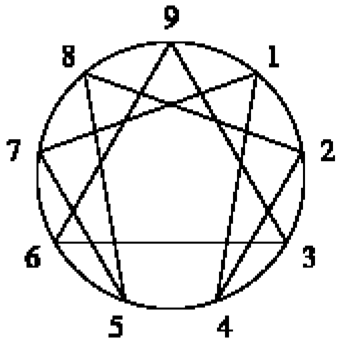


Figure 4-3: Enneagram of Personality. [Source: http://en.wikipedia.org/wiki/Enneagram_of_Personality]

It is hypothesized that a personality is only made up of one fixation, but that the other eight may influence this one. If one were to accept this premise as fact, then surely it would have to hold for every case imaginable; so the premise may be shown to be flawed by obtaining only one false result from any attribution. ([??] states that for a logical argument to be considered true, it should hold for every case; but if there is only one case for which it does not hold, then it is false.) I tend to differ with this teaching and believe that an individual's personality is made up of a weighted average of each of the fixations. Could this imply that a personality would not exist at any of the extremities of the circle displayed above, but would be somewhere within the circle, depending on the 'gravitational pull' or weight of each fixation? Consider the case of the generally accepted 'ideal' presidential candidate: he or she is one that should be a reformer, judge, helper, giver, achiever, individualist, loyalist, boss, and mediator amongst others[???] – clearly the demands of a well balanced personality which borrows heavily from each of the extremes and finds itself lingering somewhere closer to the center of the enneagram than an extremity would demand.

4.4.2 Four Temperaments [42]

Temperament theory stems from the theory of Hippocrates, who believed certain human moods, emotions and behaviors were caused by body fluids: blood, yellow bile, black bile and phlegm. This theory was adapted by various psychologists, and the following four personality types were defined:

Sanguine [Blood]: refers to the season of Spring and the element of air. It indicates an arrogant, indulgent and confident personality which can be a day dreamer to the point of not accomplishing anything, but can also be impulsive.

Choleric [Yellow Bile]: refers to the season of Summer and the element of fire. It indicates a leader with ambitious, energetic and passionate personality who can sometimes dominate other personality types and can also be easily angered or bad tempered.

Melancholic [Black Bile]: refers to the season of Autumn and the element of earth. It indicates a pensive, creative, perfectionistic and artistic personality who can be easily depressed through tragedy or cruelty.

Phlegmatic [Phlegm]: refers to the season of Winter and the element of water. It indicates a calm, unemotional, generally self-contented, consistent, relaxed, rational, curious, observant, kind and shy personality who inhibits enthusiasm, may be lazy, and is resistant to change.

It is believed that an individual will generally have a blend of the personalities to construct their unique personality.

4.4.3 DISC Analysis [40]

The DISC analysis is more a behavioural analysis technique rather than a personality test. It can be used to identify the elements of an individual's personality, but is often used to provide more meaningful information. DISC is a four-quadrant behavioural model developed by William Marston to examine the behaviour of individuals in their environment.

A strength of this method is that conversation or observation provides sufficient basis for human behavioural analysis and allows for refinement with time.

The four quadrants are defined as follows:

Dominance (High-D): relates to control, power and assertiveness. These personalities are effective in dealing with problems and driving objectives. They are demanding, forceful, egocentric, strong willed, determined, ambitious, aggressive and pioneering. These are the “Let's do it my way” type of people, and they are the action people in a team. They tend to get the job done, but can be very difficult to work with. This personality fears being challenged or not being in control.

Low-D's are conservative, low keyed, cooperative, calculating, undemanding, cautious, mild, agreeable, modest and peaceful.

Influence (High-I): relates to social situations and communication. These personalities tend to influence through talking, activity and emotion. They are convincing, magnetic, political, enthusiastic, persuasive, warm, demonstrative, optimistic, outgoing, trusting and optimistic. These are the heart-of-the-party type of people. They are sometimes more distracted by what people think of them than by getting the job done. This type of personality can be superficial but, if applied correctly, can be the 'glue' that keeps the team motivated and in harmony as they are capable of selling an idea. This personality fears being alone or rejected. These are the “let's do it the group's way” type of people.

Low-I's are influenced by data and facts and not with feelings. They are reflective, factual, calculating, skeptical, logical, suspicious, matter-of-fact, pessimistic and critical.

Steadiness (High-S): relates to patience, persistence and thoughtfulness. These personalities tend towards steady pace and security. They are resistant to sudden change. They are calm, relaxed, patient, possessive, predictable, deliberate, stable, and consistent. These are the type of people that believe in one-on-one close relationships. They are caring and can be of great help in traumatic times. In a team, they are good and resolving conflict by understanding others. They are generally soft people who would rather step down than offend others, unless they believe that another individual would gain. These are the “let's do it your way” type of people. They can be prone to depression and withdrawal.

Low-S's can be restless, demonstrative, impatient, eager and impulsive.

Conscientious (High-C): relates to structure and organization. These personalities tend to adhere to rules and regulations. They like quality and get things done right the first time. They are careful, cautious, exacting, calculating, neat, systematic, diplomatic, accurate, tactful and perfectionistic. These are the type of people that believe on finding the best method of implementation despite the cost. They can give direction and vision and are worth listening to, but can sometimes get bogged down in the facts. They will try to determine their best role in the team and adapt to fulfill that role.

Low-C's are independent, self-willed, stubborn, opinionated, unsystematic, arbitrary and careless with details.

Once again, an individual's personality would be made up of the weighted sum of each of the constituents of the various personality type. There is no better or worse type of personality makeup. Each type would be suitable to a specific type of task. The most balanced individual would display traits from each personality and would have the wisdom to know when to use which. Where applicable in the rest of the text, the DISC personality and behavioural classification method is referred to. The applicability of human behaviour to organizational optimization should become more evident in Chapter 4.8: Team Dynamics.

4.5 Spiritual, Motivational and Value System Analysis [43][44][45]

The spiritual beliefs and value systems of an individual play a fundamental role in behaviour. While some scientists dispute any direct correlation between spiritualism and emotions or physical build, there are constant accounts of such occurrences and these are filed under 'paranormal' sciences.

Apart from any direct or indirect influence that this may have on an individual, there is also the case of morals, value systems and beliefs that would affect the way a person behaves. An individual's value system is the conglomeration of the values imparted to him / her from the family during upbringing, through social networks, through society's generally accepted customs, legal requirements, religious requirements, personal observation and values, and so forth.

While these beliefs may induce certain behaviour, for a large number of occurrences, they tend to provide boundaries on behaviour. In other words, they tend to be prohibitive. These values need to be identified, understood and respected within an organization, irrespective of whether or not they prove to be the organizational norm. Where the value system drastically differs from society morals and organizational culture, these should be handled as exception cases and dealt with great sensitivity and transparency so as not to induce disturbances into the system.

Another important aspect which affects the value system is that of perception. Human components tend to react on perception. If a human perceives that he or she is being treated unfairly by an organization, it will induce changes in the human's value system and hence in behaviour.

4.5.1 Human Motivational Factors

Motivational factors have particular influence on the value system of an individual. There are various content motivational theories[4], including Maslow's Hierarchy of needs (Physiological needs, Safety needs, Social needs, Esteem needs and Self-actualization needs), ERG theory (existence, relatedness and growth), Two-Factor Theory (low-level needs are maintenance factors, high-level needs are motivators), Acquiring Needs Theory (Need for Achievement, Need for Power, Need for Affiliation). There is no one theory which fully describes all motivational factors, but using the combination of these theories, the motivational factors in the value system can be determined.

4.6 Statistical Behavioural Analysis[31][46]

When one analyses behavioural patterns or personality traits by means of testing or observation, one would normally expect a Gaussian (Normal) distribution in any and each of the random variables being measured. This would be a population specific trait that is independent of the measurand, be it cognitive skill, motor skill, personality characteristic, social skill or any other parameter. The implication is that the majority of the population should be biased around the average with the bell shape curve showing the number of occurrences at the extremities to be significantly lower than the mean.

It makes sense to state that an individual's intelligence would accept a certain set of inputs, process them through the processor, and provide a certain set of outputs or actions. It would also make sense then to say that the processor is constructed out of the influence of the individual's specific Biology, IQ, EQ, Personality, and Value System. Knowing the makeup (which is predictable through observation of behaviour to various stimuli) allows for the prediction of the probability of the individual initiating an action given a certain set of stimulus. This probabilistic prediction can be refined as a greater knowledge of the candidate is gained.

Taking it a step further, one could hypothesize that at any given time, any of these factors would be in a different state, which implies that they would each be a function of time. This allows one to invoke statistic's special field called stochastics.

The branch of statistics merits a note of caution: Events with a statistical probability of zero may still occur and those with a probability of one may never occur. This implies that while determination of the statistical distribution of a random variable allows for the determination of the risk profile, it does not prevent the risk of occurrence.

By correlating the individual's statistical distribution with that of the generally accepted norms and standards of the society and organization, one would be able to determine the standard deviation from the organization's distribution and determine the amount of compliance to organizational norms and probability of meeting personal and organizational objectives.

4.7 Operating Environment and External Disturbances

The human component is built to operate in a diverse array of environments, but there exists very tight restrictions in terms of boundary conditions and the intrusion of the boundaries may cause component failure ranging from mild, partial debilitation to severe catastrophic component failure such as fatality. Boundary conditions could be excessive working hours, excessive temperatures, excessive stress, and so forth. It is important to recognize that humans (like any other component) have limits within which they can operate despite them being able to learn and adapt.

Another problem amongst the human component is that of cross-pollination of motivation: a single unmotivated employee can demotivate the entire workforce and same can be said of a single highly motivated employee [47]. There are a number of external disturbances which would interfere with behaviour and motivation of an individual including but not limited to:

- Extrinsic motivators like reward or reinforcement;
- Intrinsic motivators like hobbies, goals, personal values, religion and beliefs;
- Coercion and self-control;
- Electro-chemical changes in the brain and body (for example hormonal changes);
- Social and family standing and circumstances (for example stress at home or trauma);
- Stress levels and motivational factors at work (for example changes at work);

- Financial difficulty;
- Gossip, grapevine and broken telephone talk (the effect hereof should not be underestimated!)

A number of theories attempt to define human motivators, including Maslow's Hierarchy of Needs, Drive Reduction Theory, Leon Festinger's Cognitive dissonance theory, McClelland's Achievement motivation theory, Herzberg's two factor theory, and so forth.

While the human will be able to adapt, it is important to realize that the adaptation may cause variations in behaviour.

4.8 Team Dynamics [14]

A common mis-conception in industry is that the best team would be members who are the best in their respective fields. For example, it would seem correct to think that if one had to construct a four-membered team out of a High-D, High-C, High-I, and High-S that the team would be fully balanced (See section 4.4.3 for a description of each behavioural trait). On the contrary, the team's chances of success could be rather slim. In the extreme case, this is due to the probabilities that the D would attempt to dominate totally, the C would conflict or withdraw and get bogged down in the facts to prove correctness, the S would constantly try to put out the fire and the I would be constantly trying to convince the team to work together. If the team manages to survive, it is debatable as to whether the objectives would be achieved or not. A team with mediocre members would probably exhibit higher probabilities of success.

A good team would be one in which members who are very mentally capable (high IQ and EQ) are brought together to produce a team with a balanced personality. This implies that members that exhibit high scores in one type of personality will exhibit sufficient scores in the other personality types to make them team players (for example, a High D could also show High I characteristics albeit with lower scores). These members should be deployed to suitable roles to fulfill the strengths of their personalities and work on the weaknesses.

In any team, communication and mutual respect should be parameters that play a big role in determination of the team. It should also be appreciated that members with similar personality types may not work well together, depending on their value systems and sensitivity should be shown during selection of the team. It is also important that the team visions and goals be clearly understood by each member so that the team can be pull together in the same direction.

As a last point, it is important to understand that in team management, there are those managers who are very concerned with objectives (Dictatorship-Type), those who are very concerned with humans (Human-Centered), those who are not concerned with either (Impoverished), those who are partially concerned with both (Mid-Way), and those who are fully concerned with both (Team Managers).

4.9 A Note on Management of Humans [48]

Abraham and Flippo [48] have provided a framework to management of humans through a life-cycle approach. The life-cycle approach details the entry of human resources into an organization's internal environment and ends with the separation and return of the same to the outer environment.

The following is detailed:

- The procurement of human resources has a broad connotation which encompasses long-range strategic planning, organizational and job design, and compliance with laws.
- Development of human resources through training and education, and evaluation through performance appraisal. Both organizational and career development are characterized as part of this function.
- Compensation ensures equity and motivation, and poses three motivations
    - Compensation for job assigned in the form of base pay (for example basic salary);
    - Compensation to motivate toward high job performance (for example perks and bonuses);
    - Supplementary compensation to maintain organizational membership (for example competitive market-related packages).

- Integration of interests entails the integration of the organization's interests with the employee's interests and those of the labour union.
- Maintenance of the workforce. The suggestion is made that the performance of the first four functions should produce a workforce that is both able and willing. However notice is made of the need to maintain positive attitudes, physical and mental conditions of employees, communication, counseling and health and safety programs.
- Separation of human resources and their return to society is presented with the preferred method of termination of services being retirement. However, the acts of resignations, layoffs and discharges cannot be overlooked. It is the role of the organization to have methods in place to effect a smooth transition from human resource to ex-resource.

4.10 Chapter Conclusion

Total human intelligence at any point in time can then be defined as the sum of the following factors: Biological Makeup, Intelligence Quotient, Emotional Quotient, Personality and Behavioural Makeup, Spiritual and Value System Beliefs. It is important to note that each of these would be a function of time. This gives rise to the special field of statistical analysis known as stochastic theory. Based on the value system, certain environments appeal more to the motivation aspect than others do. There are certain disturbances that affect some humans more than others. Management of humans sometimes poses a difficult task, and knowledge from the science adds value to the art of understanding people.

The construction of a team requires careful consideration and evaluation of the team objectives and match of each member of the team to the achievement of the objectives.

Before discussing system optimization, there are two steps missing. In the next chapter the mathematics required for system modeling and optimization is presented.

CHAPTER FIVE: APPLICABLE MATHEMATICS AND MODELING TECHNIQUES

Chapter Outline

Chapter Overview

Set theory allows for the assignment of objects into groups based on common properties. Statistics allows for the application of mathematical constructs to the determination of the probabilities of occurrence of phenomena in the calculation of risk and expectation during evaluation of system performance and efficiency against predefined objectives and criteria. Linear programming entails the determination of a feasible region and optimal operating points against a cost function in a multivariate linear problem using the simplex method. Genetic algorithms detail a solution for the the determination of the same operating points within a multivariate linear or non-linear problem.

5.1 Chapter Introduction

In any scientific and mathematic modeling work, it is advantageous to first discuss the mathematics that will be applied in the optimization process. This research is by no means an exhaustive work and the mathematics can be studied in greater depth in other texts [46][49][50][51][52][53].

Set theory is the theory of sets, partitioning, grouping and mass analysis on these partitions. Applied mathematics is the branch of mathematics that focuses on practical application. Applied statistics is that branch of mathematics that focuses for example on probabilities as applied to the sets. Multidimensional optimization focuses on optimizing a complicated sets with multiple parameters or of higher order.

5.2 Set Theory [49][50]

A set is a collection of objects or elements. Given a set *A*, and element, a in set *A* is denoted as $a \in A$. If *a* is not an element of *A* then this is denoted as $a \notin A$. *A* is a subset of *B* is denoted as $A \subseteq B$. Two sets are equal if all elements in *A* are in *B* which implies that *A* and *B* are subsets of each other. The union of two sets, *A* and *B* are denoted as $A \cup B = \{a : a \in A \, or \, a \in B\}$ and the intersection as $A \cap B = \{a : a \in A \, and \, a \in B\}$. By definition, any operation applied to a set will be applied to every element within the set. This allows for a clear, concise and compact method of communicating operations on a large number of elements. In this text the i^{th} element of an ordered set, *A*, will be denoted as A_i. This text defines the empty set as that set which has no elements and is denoted as $\emptyset$.

There are many other branches that one could study in set theory (such as Topology), but these fall outside the scope of this work.

5.3 Applied Statistics[46][49]

The Sample Space is defined to be the set of all possible outcomes of a random experiment and denote this set as *S*. Any subset of the sample space is called an event.

A definition for disjoint sets is: two sets, *A* and *B* are mutually exclusive (disjoint) if they contain no common element.

Based on the definition of relative frequency, if event *A* occurs *n(A)* times out of *n* observations, then the probability of event *A* is defined as:

$$P(A)=\lim_{n\to\infty}\frac{n(A)}{n} \qquad (5.1)$$

It follows that equally likely events will have the same probability. The conditional probability of an event *A* given event *B* is defined as:

$$P(A|B)=\frac{P(A\cap B)}{P(B)} \qquad (5.2)$$

Two events are statistically independent if and only if:

$$P(A\cap B)=P(A)P(B) \qquad (5.3)$$

There are various elementary properties of probability which can be found in statistical texts and are not replicated here.

A random variable, *X*, is defined as the real function that assigns a real number (value of *X*) to each sample point in the sample space.

The cumulative distribution function of *X* is defined as as:

$$F_X(x)=P(X\leq x);-\infty<x<\infty \qquad (5.4)$$

The probability density function is defined as:

$$\mp\mp\square\, f_X(x)=\frac{dF_x(x)}{dx} \qquad (5.5)$$

The definition of the mean or expected value of a random variable is:

$$\mu_x = E(X) = \begin{cases} \sum_k x_k \, p_x(x_k); & X : discrete \\ \int_{-\infty}^{\infty} x f_x(x) \, dx; & X : continuous \end{cases} \tag{5.6}$$

The variance of a random variable is defined as:

$$\sigma_x^2 = Var(X) = E\{[X - E(X)]^2\} \tag{5.7}$$

Of great interest is the Gaussian (Normal) Distribution. A Gaussian random variable has a probability distribution function defined as:

$$f_x(x) = \frac{1}{\sqrt{2\pi\sigma}} \mathrm{e}^{\frac{-(x-\mu)^2}{(2\sigma^2)}} \tag{5.8}$$

All the above can be extended to multi-variate random variables.

The field of stochastics is defined for a random, time-based process. It was first developed in connection with the study of fluctuations and noise in physical systems. Stochastics provide useful models for the studies of fields such as statistical physics, communication and control, time series analysis, population growth and management sciences.

The idea of a random variable is extended now. A random process is a family of random variables $\{X(t, \zeta), t \in T, \zeta \in S\}$. Fixing *t* allows for variation of a single time value over the sample space, and fixing zeta allows for variation of a single sample space element over time.

The mean is defined as

$$\mu_x(t) = E[X(t)] \tag{5.9}$$

A measure of the dependence among the random variables of X(t) is provided by its autocorrelation function defined as:

$$R_x(t, s) = E[X(t) X(S)] \tag{5.10}$$

The autocovariance function of X(t) is defined by:

$$K_x(t, s) = R_x(t, s) - \mu_x(t)\,\mu_x(s) \tag{5.11}$$

Lastly, a random process is defined as stationary if

$$F_X(x_1, \ldots, x_n; t_1, \ldots, t_n) = F_X(x_1, \ldots, x_n; t_1 + \tau, \ldots, t_n + \tau) \tag{5.12}$$

This implies that $F_X(x; t) = F_X(x; t + \tau) = F_X(x)$, $f_X(x; t) = f_X(x)$ and $\mu_X(t) = \mu$.

We shall leave the theory of statistics here for now and draw from it where applicable.

5.4 Multidimensional Optimization Algorithms

5.4.1 Linear Programming[51][52][53]

A Linear Programming problem tries to identify extreme (minimum or maximum) point of a function $f(x_1, x_2, \ldots, x_n)$ which satisfies a set of constraints $g(x_1, x_2, \ldots, x_n)$. The success of the algorithm demands linearity of both the objective function, *f*, and the problem constraints. Linear programming is an optimization tool allowing for the rationalization of managerial and technological decisions. The Simplex Algorithm (developed by George Dantzig in 1947) allows for fast solutions to large-scale applications including hundreds of thousands of possible variables [52]†.

In general, one could consider the linear programming problem in which $c^T x$ is to be maximized subject to $Ax \le b, x \ge 0$. Presented as a matrix, provides the following:

$$\begin{bmatrix} 1 & -c^T & 0 \\ 0 & A & I \end{bmatrix} \begin{bmatrix} Z \\ x \\ x_s \end{bmatrix} = \begin{bmatrix} 0 \\ b \end{bmatrix}, \qquad x, x_s \ge 0 \tag{5.13}$$

x are the variables from the standard form, x_s are the introduced slack variables, *c* contains the optimization coefficients, *A* and *b* describe the system of constraint equations, and *Z* is the variable to be maximized.

† The Nelder-Mead method is also known as the downhill simplex method and is commonly used as a nonlinear optimization algorithm. It is a numerical method for minimizing an objective function in a multi-dimensional space. We omit the discussion on this method as being outside the scope of this work.

At any iteration of the algorithm, the following will be exhibited:

$$\begin{bmatrix} 1 & c_B^T B^{-1} - c^T & c_B^T B^{-1} \\ 0 & B^{-1} A & B^{-1} \end{bmatrix} \begin{bmatrix} Z \\ x \\ x_s \end{bmatrix} = \begin{bmatrix} C_B^T B^{-1} b \\ B^{-1} b \end{bmatrix} \tag{5.14}$$

where c_B are the coefficients of basic variables in the c-matrix, and B is the columns of $[A\ I]$.

The algorithm is defined as follows:

- Choose an initial basic feasible solution whereby B is the identity matrix and c_B is a zero vector
- While the solution is non-optimal:
  - Determine the direction of the highest gradient

    Choose the variable associated with the coefficient in $C_B^T B^{-1} A - c^T$ that has the highest negative magnitude.
  - Determine the maximum step length

    Use the $\begin{bmatrix} B^{-1} A & B^{-1} \end{bmatrix} \begin{bmatrix} x \\ x_s \end{bmatrix} = B^{-1} b$ sub-equation to determine which basic variable reaches zero first.
  - Rewrite the problem

    Modify B and c_B to account for the new basic variables.
  - Check for improvement

    Repeat until no further improvements are possible. This is the case if the coefficients of $c_B^T B^{-1} A - c^T$ are all positive. If all coefficients are zero, the algorithm has walked a circle and visited a previous step.

5.4.2 Non-Linear Programming[54][55]

According to Wikipedia, nonlinear programming is the mathematics required to solve a system of constraints along an objective function to be maximized or minimized where either the objective function or the constraints (some or possibly all) are non-linear. Various approaches exist in solving non-linear programming problems, but it is not the purpose of this text to discuss them in great detail. In section 5.4.3, genetic algorithms, which allows for the solution to both linear and non-linear problems, will be discussed briefly.

J. E. Beasley [55] describes a heuristic algorithm†, called separable programming, which creates a linear approximation of the non-linear problem by constructing a linear piece-wise defined function (or a number of linear functions uniquely defined over certain intervals formed by partitioning the feasible non-linear interval) that approximates the non-linear function (independent of whether or not it is the constraint or the objective function which is non-linear). The accuracy of the solution (should one be found) depends on the accuracy of the approximation.

More information on the solution of non-linear optimization problems can be found online at the following sources: [56][57][58]

5.4.3 Genetic Algorithms[51]

Genetic algorithms are specifically designed to treat problems involving large search spaces containing multiple local minima and have been applied to a large number of optimization problems.

A genetic algorithm is an evolutionary method which draws inspiration from the natural search and selection process. This results in the survival of the fittest. It is often a brute-force type method in that starts with a population (or farm) of individuals (or animals) composed of genes which may take on a number of values (or alleles), generally 0 or 1. The individual is then represented as a binary string of fixed length. Each individual represents a search point in the space of potential solutions to a given optimization problem. The optimization problem provides quality information (referenced against a fitness or optimization function) for individuals and the selection process favours individuals of higher fitness to transfer their information to the next generation. Random operators model selection, reproduction, crossover and mutation.

In general one would define a fitness function (or cost function) which represents the quality of the solution. The solution with the lowest cost or highest fitness will be the most optimal solution.

There are three categories of search techniques which can be defined: Classical, Enumerative and

† A heuristic algorithm is one which does not guarantee that the optimal solution will be found.

Random. *Classical* uses a deterministic approach to find the best solution and applied best to well-behaved scientific problems in which case knowledge of the various ordered derivatives is required; but it can also be applied to abstract problems in which case experience, knowledge and the application of probabilities are possibly required to make educated decisions. Often small, atomic changes are effected to the genomic structure and these are used to guide the evolutionary process towards the localized optimal solution. A limitation presents itself when verification of the multiple localized solution points result in the convergence to an optimal solution which may not necessarily be the global optimal solution. The *Enumerative* method requires the generation of every possible permutation of solutions and then testing each solution against the fitness function to find the optimal solution. Although this method presents itself as a brute-force method which will find the global minimum or maximum point, it does require excessive computation in problems which involve a large number of variables. The *Random* method is deployed when only a 'good-enough' solution is required and may not result in the most optimized solution, but any solution above a certain fitness level will survive.

The case study in section 9.3 shows how the Enumerative method can be used to achieve this. Although all permutations are not generated, all unique combinations are as described in the chapter.

5.5 Chapter Conclusion

Mathematics is necessary for the successful modeling of a system. Due to the diverse knowledge on Mathematics, it was necessary to define the mathematics that is applicable to this research.

Set Theory allows for the compact representation of a group of objects that have similar properties. It also teaches methods for performing operations on the entire group as opposed to the individual elements. Applied Statistics equips one to determine the probability of occurrence of a certain event and hence predict the possible outcome with a certain level of confidence. The simplex method is a linear programming algorithm whose task is to determine the optimal operating region of a number of parameters, given a number of constraints in a multi-variate and multidimensional problem. The points which maximize a given profit function or minimize a given cost function are considered optimal. While the simplex method is generally limited to linear functions, genetic algorithms provide a somewhat brute-force method to determine the globalized maxima and minima in a wide and diverse search space and is not limited to only linear functions.

In the next section, the notion of an organization as a system will be discussed in more detail.

CHAPTER SIX: ORGANIZATIONS AS SYSTEMS

Chapter Outline

Chapter Overview

This chapter focuses on the description of an organization as a system. The organization is decomposed into its building blocks, organizational objectives and results are discussed, and an argument the need for an optimization function is provided.

6.1 Chapter Introduction

In chapter three, a definition of an organization as a system was provided without going into any great depth. The notion that an organization is a system comes naturally from the view that an organization takes a set of inputs (raw materials, finances, human resources and energy) and converts it into a set of outputs (finished products, services, waste, alternate energy and financial profits) through a set of processes (technical, operational, production, maintenance, services, administrative, logistic, supportive, etc.). An organization (from something as simple as a local retail store to as complex as a global manufacturing entity comprising numerous distributed branches) is a system which comprises many subsystems, components and processes; and competes and co-exists in a complex global environment. According to general systems theory, it is that ability to adapt and co-exist within the operating environment which allows a system to survive. Failure to adapt could result in the system's eventual demise.

6.2 The Classical Organization and Systems Theory[59]

In its purist form, an organization is an establishment founded to achieve its mission. The mission statement is a tabulation of all objectives that the organization will try to achieve in during its life cycle. The mission could be to make suitable profits, become world leaders in manufacture of a certain commodity, or to achieve a notable cause as in the case of a non-profit organization. Survival of the organization results from keeping clear enough vision to allow for the evolution of the mission statement to survive in a constantly changing world.

An organization is generally born as a dream in the mind of an entrepreneur. It is independent of discipline or nature and its very essence is the satisfaction of a need. An organization is hence a social device for efficiently accomplishing, through group means, some stated purpose.

An open system is one which recognizes the close relationship between structure and its supporting environment; considers the inclusion of different levels of systems and their interrelationships; and emphasizes throughput which is the processing of production inputs to yield an outcome that is used by an external system.

An organizational system can be defined by the following characteristics:

- Importation of energy: This is the extraction of energy in some or other form from the external environment and the inclusion of this energy in the operation of the system. Systems are generally not self-sufficient or self-contained and require stimulation from the external environment. So too, should an organization draw renewed supplies of energy from other organizations, individuals and the environment.
- Throughput: This is the achievement of an organizational goal (for example the creation of a new product, processing of materials, training of people, provision of a service) which requires some reorganization of inputs and the transformation of energy to perform work within the system.
- Outputs: Organizations export products into the environment and the continuous nature hereof is dependent on the receptivity of the environment.
- Systems as cycles of events: The energy reinforcing the cycle of activities can be derived from some exchange of the product in the external world (as in the case where an industrial organization processes raw materials and labour in the production of an output which is sold and the financial gain used to obtain more raw material and labour to perpetuate the cycle of events) or from the activity itself (as in the case where a voluntary organization provides satisfaction to its members to that the energy renewal comes from the organizational activity).
- Negative entropy: Negative entropy opposes the natural law which states that all forms of organization move towards disorganization or death. In the long run, systems are subject to the law of entropy as they lose inputs and the ability to transform them, and die. During their life, the entropic process is reversed through the cyclic input, transformation and output which are all essential for survival. Successful organizations seek to improve their survival position and to acquire reserves to allow a comfortable level of operation; and hence ride through interruptions in the cycle.
- Information, feedback, and the coding process: Not all systemic input is physical or energetic, some is informational. The reception of inputs into a system is selective and not all energetic inputs can be absorbed into every system. Coding is used to describe the selective mechanisms of a system by which incoming materials are rejected or accepted and

translated for the structure.

- Steady state and dynamic homeostasis: Steady state symbolizes the continuous inflow of energy from and to the external environment and the continuous exports of the system, whereby the ratio of the energy exchanges and the relations between parts remains the same. Fundamentally stated, the achievement of steady state indicates the preservation of the character of the system. The homeostatic principle is indicative of the counteraction of entropy whereby a system moves toward growth and expansion. Through the symbiosis of steady state operation and dynamic homeostasis a new, more complex, more comprehensive equilibrium is achieved. Systematic growth allows for the insurance of survival by the acquisition of a margin of safety beyond immediate levels of existence. Adaptation to a changing environment encourages systems to cope with external forces by ingesting or controlling them, thus resulting in growth (for example, an organization will incorporate external resources essential for survival. Finally, homeostasis allows for reaction to change and reaction to the anticipation of change through growth of the system.
- Differentiation: System move in the direction of differentiation and elaboration. Organizations move toward the multiplication and elaboration of roles with greater specialization of function.
- Integration and Coordination: Differentiation is countered by the process which requires unification of system functioning through shared norms and values. Large organizations use coordination, rather than integration to provide orderly and systematic articulation. They deploy methods such as priority setting, the establishment and regulation of routines, timing and synchronization of functions, scheduling and sequencing of events, etc.
- Equifinality: is the principle whereby a system can reach the same final state through a variety of paths from differing initial conditions.

While the this research indicates the conscious need to optimize an organization through the achievement of organizational objectives, it must be borne in mind that the primary goal of any system is a subconscious, intangible, and sometimes non-verbalized one: survival!

6.3 Breakdown of the Organization

An organization is generally broken down into various logical operational units. Due to the spread of different types of organization, there is not a one-size-fits-all structure, but the organization is arranged by deploying a method that would allow for successful competition. Structures may range from a very well defined global-spanning hierarchy to a loosely knit band of co-owners with a common goal.

As an example, in the former case, the organization may employ a board of directors who provides vision for the executive management who in turn command senior management drilling down to middle-level and junior management, and then further to supervisors, and laborers. Depending on the size of the organization, the hierarchy will define numerous levels each with their relevant goals and objectives. The organization could be partitioned into logical process units (sub-systems), or could be based on geometric positioning or functional specification. On the other hand, an organization may be a one-man work-from-home type organization who trades globally on the Internet.

The scope of this work is not to distinguish between various types of organizations, but to attempt to establish general guidelines that could be followed to optimize an organization irrespective of the operating philosophies employed. Naturally, the complexity of the organization will increase the complexity of the solution, but the recursive nature of the algorithms covered later in this text should cater for this.

6.4 Downward Thrust of Organizational Objectives

It is important that the visionaries within an organization (typically those who aspire to executive status) formulate the mission statement for the organization, and provide direction wherever necessary. The mission statement should be a clear depiction of organizational objectives. In larger organizations (those with hierarchical levels greater than or equal to 2), these objectives become part of the vision that each sub-unit (department) should achieve. From the organizational objectives, the departmental mission statement is constructed, and so the objectives for each department can be defined and tabulated. The objectives should comply with the SMART principle [60] (Simple, Measurable, Achievable, Realistic and Time-Based).

The definition of objectives at each hierarchical level allows for the decomposition of the often complex and sometimes seemingly unachievable vision of the organization into smaller more tangible and manageable goals and objectives.

It is important for each departmental member to understand the necessity of achieving and superceding the departmental objectives as the achievement of each objective by each department allows for the achievement of the organizational objectives and ultimately, the organizational vision. In this way, the strength of an organization is that the whole is far greater than the sum of the individual parts.

The reverse propagation of organizational objectives is permitted and occurs in somewhat different manner. While objectives that are derived from parent systems are to be enforced, objectives derived from child systems are mutators of the parent's set of objectives. Typically, these objectives will be propagated upward and then considered by management at the parent level. The parent-level management has the freedom to accept or reject these objectives. The rejection simply nullifies the application, but the acceptance allows for the inclusion of new objectives or modification of existing objectives at a parent-level. The updated set of objectives is then propagated back down to the child system for enforcement.

From the above, it should be clear evident the definition of the objectives in the mission statement should be concise and simple enough for all members within the organization to understand. It should also be clear that the mission statement should be a living-document until its formulation correctly models the organizational vision. At this stage it should be 'set in stone' until such time as the vision is re-evaluated.

6.5 Upward Thrust of Organizational Results

In any real-time system, feedback is very important. Atomic data (which includes everything from financial results, trade transactions, manufacturing data, investigations, etc. depending on the nature of the organization) is constantly sampled, stored and then compiled into formats which indicate the degree to which sub-departmental objectives have been met. These results are then thrust upwards to the higher-level departments and are used in conjunction with other sampled data to determine the degree to which these departmental objectives have been fulfilled. The process continues until the results of each department have been filtered upward to the executives and board of directors and the eventuality is the construction of a set of results which determine to what extent organizational objectives have been met.

This form of feedback is used to verify the integrity and achievability of the organization's objectives and to modify and improve where required. It is also used to re-bias parameters used in the calculations of targets set in the objective statements. It gives life to the old adage: “Today's record is tomorrow's target”!

The reverse, or downward, propagation of organizational results is possible and is encouraged as they allow for each department to realize the effect that their operation has on the organization's performance. This allows for a level of transparency which promotes the spread of knowledge amongst members of the organization and the sense of inclusion in the organization's well-being.

6.6 Organizations as Systems

This section is based on the author's deduction and observation in practice. These definitions are specific to this work and are used as such henceforth.

If the above is taken and put together, one is left with the organization as a system with many sub-systems. Each sub-system receives direction from and reports results to the parent system, and in itself may be a parent to a sub-sub-system. This structure will propagate indefinitely until the organizational structure has been completely traversed.

If one were to define the set of all organizations in the world as a set of systems co-existing and competing in a global environment then

$$O := \{S_i,\ i := \text{an index assigned to each system}\}$$

Each organization (system) can be defined as a set of all sub-systems pertaining to that system:

$$S_i := \{s_{ij},\ j := \text{an index assigned to each sub-system}\}$$

Each sub-system can then be defined as the set of all sub-sub-systems pertaining to that sub-system:

$$s_{ij} := \{s_{ijk},\ k := \text{an index assigned to each sub-sub-system}\}$$

and so forth until the organization is totally characterized as a multi-dimensional system.

Each subsystem would have inputs, processes and outputs. Information is a bi-directional protocol through which instructions and reports are conveyed.

In a previous work[61], the interactions between various sub-systems where each sub-system is defined as a department were depicted.

It should be clear from the above that if the world is the environment in which each organizational system interacts, then the organization is the environment in which each departmental sub-system interacts and the department is the environment in which each sub-sub-system interacts, and so forth.

This definition is easily identifiable in practice, with the addition of one phenomenon: that sub-sub-systems can interact with sub-sub-system in another sub-system or another system for that matter. This adds a degree of complexity which one can circumvent at this stage by simply defining the interaction channel between any two systems as being the sum of all interactions transferred between all sub-systems to the outside world. In other words, if a child-system wants to 'speak' (interfere with) to another sub-sub-system, the model will allow for the mutation of the parent-system's interaction bus to allow for the modeling of interactions between the parties involved.

By means of example, consider a small organization, S_1 with marketing department s_{12} which interferes with a bigger organization, S_2 with a marketing department s_{23} and sales department s_{231}. So then, s_{12} interferes with s_{231}. However the classification of every permutation of possible interference compounds the complexity greatly. It is much more beneficial to define the interferences to between S_1 and S_2 to be the sum of all interferences between the two systems (including s_{12} with s_{231}). Often, this is the more practical approach as a black-box system may pose a threat to another system. In identifying the root cause of the threat, the interference set can then be characterized as all child-systems which interact with each other, as opposed to the permutation of all child-systems; allowing for a more elegant solution to the complex interactions.

6.7 The Need for an Optimization Function

In defining and optimizing a system, it would be wise to apply a top-down, bottom-up approach. By starting at the visionary level of the organization, the objectives are recursively pushed down to each sub-system, which gives direction for the optimization of each sub-system and sub-sub-system and so forth. The optimization of each sub-sub-...-system occurs at an atomic level and then propagates upward in a re-sweep of the optimization parameters. The re-characterization of each of the parameters allows for multiple iterations to achieve the required results until the best implementation is found that allows for the entire organization to be optimized against a fitness function which allows the achievement of objectives. As has been stated before, the whole is greater than the sum of all parts, and the recursive iterations cater for this in allowing various optimization functions depending on the level being optimized.

Optimization of a system within any given environment allows for the system's efficient operation and mutual inter-system co-existence. It also allows for the minimization of systemic side-effects on the environment by reducing the demand that the system places on the latter. This optimization or streamlining of systemic function allows for preservation (or at the very least a reduction in consumption) of environmental resources and the mutual coexistence allows for consideration and attribution of rights to each system within the environment and to the environment itself. A classic example hereof would be laws that have been instantiated by government systems in response to wildlife preservation organization's requests to prohibit feeding on, hunting for or relocation of endangered species and thus prevent extinction of the plant or animal. Another consequence of inter-system interaction has been the passing of laws and guidelines in the creation of environmentally friendly products and the consideration of the effects of waste mismanagement by a system on the environment.

Examples of this are provided in Chapter 9.3.

6.8 Chapter Conclusion

An organization is an establishment founded to achieve its mission. The organization's mission is defined in the mission statement and broken up into objectives. An organization can be viewed as a system competing to survive in a global environment. The system consists of sub-systems, and the sub-systems of sub-sub-systems, etc. Each system and sub-...-system contains processes, inputs and outputs.

The organization can push objectives down on departments and departments on sub-departments, and sub-departments can request new or modified objectives from departments and departments from the organization.

Sub-departmental results are filtered upward to the parent department and merged with other sub-departmental results before being filtered upward to the organization-wide level. The analysis of the results as a measure of how well the objectives have been met is then performed and the outcome hereof filtered down to the department and back down to the sub-departments[†].

The inefficient operation and function of a system places a greater demand on the environment in

† Some organizations offer bonuses to departmental and sub-departmental members depending on how well the organization has performed in a cycle (perhaps a month or fiscal year). These bonuses allow for the distribution of the wealth acquired by the organization to the employees that have helped make the organization successful and instill a sense of inclusion in and ownership of the organization's performance.

terms of resources required and waste produced. Optimized operation has direct and probably favourable consequence for the system itself, for the environment in which it interacts, and for ultimately for each of the other systems within the environment too.

The need for organizational optimization has been discussed and the modeling of these optimization functions will be discussed in the next chapter.

CHAPTER SEVEN: MODELING OF OPTIMIZATION FUNCTIONS

Chapter Outline

Chapter Overview

This chapter concentrates on system optimization and the control and management thereof. The cumulation of all ground work detailed together with the modeling techniques detailed in the description of a generalized optimization algorithm and a discussion on how the application of practical measures can be effected to configure elements from an atomic level upward. A discussion of steady-state operation, organizational growth and the effects of globalization on the organization is also offered.

7.1 Chapter Introduction

In the previous chapters, the foundation was laid for that which is hoped to be pieced together in this chapter: systems theory, component sets, applicable mathematics, the human component, and finally the organization as a system has been studied.

A concept that will be introduced is that of Total Systems Control, Optimization and Management: that an organization should be managed with total system optimization in mind. The concept of system modeling and the notion of recursive and re-iterative optimization are then approached.

As part of the discussion on system modeling and optimization, the manipulation of operating parameters to optimize component performance will be discussed. Configuration of the process, sub-system and system for optimal performance will also be discussed.

This chapter will be concluded with a note on the effects of globalization.

7.2 Total Systems Control, Optimization and Management (TSCOM)

Total Systems Management includes the Engineering Management of the organization from a system-wide perspective.

A common mis-application of knowledge exists in industry: because a solution has worked before somewhere else, people are prone to applying the same technique to a different system; or a person would be prone to enforce his or her view of how the system operates down on the system. Failure of the system, or reduction in performance could ensue. One should determine what the system requires to function optimally. It is important to realize that every system (organization) is *very* unique. From the characteristic set of each component within the component set, to the modeled set of processes, no two organizations can be said to be entirely the same.

In order to manage and engineer a system, the system should be modeled and understood in its entirety. The knowledge that sub-systems and components disturb each other needs to be understood †. The notion that the optimization of each sub-system does not necessarily lead to the optimization of the entire system, but that an unoptimized sub-system can lead to system inefficiencies or failures, needs to be understood. Intricate knowledge of processes and components, and the integration of each should be understood.

The modeling of a system in its entirety is no easy task and will often require a number of iterations and recursions to gain sufficient knowledge of the system. Furthermore, unavailability of the most suitable component results in replacing failed components with sometimes non-ideal components (characteristic behaviour falls outside acceptable boundaries), which may possibly cause greater system-wide disturbances ‡. Another complication is that the system is a dynamically changing (almost living) specimen. The changes are often as a result of restructuring, growth, adaptation to environmental changes, retirement, and so forth. Yet a further complication would be the effects of multiple, time-based interferences (for example the cyclic nature of earth metal demand influences instantaneous profit margins) which requires integration over a period of time to determine the projected nett effect. If the period is too short, system changes may be implemented too quickly in reaction to perceived disturbances, resulting in further system instabilities (the introduction of greater oscillations in classic control). If the period is too long, system changes may be implemented too slowly, resulting in a very over-damped system which may not respond in time (typically, if the market has surpassed the system, forcing an organization into liquidation).

From our current knowledge of classical control of systems, one would want the overall system response to be critically damped. However, a number of problems exist when one considers the lag time before the system reacts, let alone stabilizes (for example, if the overall output is profit, one may only notice changes in profit by the end of the month; if the output function is personnel effort and motivation, changes can be seen within a number of days). Furthermore, a number of time periods would have to elapse (this could be as long as a number of months) before accurate conclusions can be made in terms of the reaction of the system. Apart from it being difficult to determine the optimal system parameters that will result in critical damping, a further problem with

† A classic example of this is distortion of information through the proverbial grapevine and the broken telephone principle whereby human components from various sub-systems can cause disturbances and even lead to catastrophic system failures in the form of strikes and / or riots, which have proven to be destructive in nature, and result in tremendous financial loss.

‡ This is particularly visible in South Africa at the present time where a shortage of skills results in the employment of non-ideal candidates, resulting in system instabilities.

critical damping is that the components may be over-stressed as the system tries to achieve the set point. This may result in component failure, which may cause system failure, depending on the criticality of the component (the criticality of the component can be determined by performing an Failure Mode Effect and Criticality Analysis). Depending on the nature of the system one may want a slightly over, or under damped system but this will take time to establish.

It is clear that this process requires a dynamic model to suitably describe the system as it changes with time. As the model varies, it is important that it is constantly run against the fitness function to determine the projected impact of the variation on system performance, probability survival, financial indicators and risk profiles (and the related contingency plans) [62].

7.3 Modeling Techniques, Practices and Principles

Due to the complexity of modeling a system as large and diverse as an organization, it would be prudent to partition the system into a set of sub-systems (departments). This partitioning is generally not unique, and can be achieved in any number of ways: logical process partitions, geometric layout, available skills set, and so forth. As it will be shown below, it would be wise to start off with a basic partition philosophy, run it through the fitness function and then manipulate the partitions to achieve better results in every iteration. This allows for the decomposition of a very complex system into a number of sub-systems. Please note that this process can be performed recursively by partitioning a sub-system into a number of sub-sub-systems, and so forth.

Genetic algorithms lend themselves to well structured systems. As an organizational applicative example, the fitness function could be the probability of survival which incorporates the nett profits (gross profits less expenses) versus changes in economy (for example changes in inflation, cyclic nature of interest rate fluctuations, probability of recession, etc.) over a 5, 10, and 15 year period. The fitness function can be defined for each subsystem using a top-down approach.

At a high level, one could apply the algorithm to determine the optimal system (organizational) structure. This can then be recursively defined and deployed to each sub-system within the organization, based against the sub-system's own fitness function. The bottom-up approach can be used to find global maxima or minima over the range of localized solution points.

The fitness functions would be a variable of system and sub-...-systems objectives as these are the ultimate metrics against which the performance of the system and sub-...-systems will be measured. It has already been discussed that objectives should be formulated and imposed using a top-down approach, and that performance results should be compiled and presented using a bottom-up approach (the reverse is also possible in both directions, but poses an additional degree of complexity. The possibility hereof should be born in mind, during early phases of analysis, but should be considered during the later phases, once the system is behaving stably.)

To reiterate the notation deployed:

O := {S_i, i := an index assigned to each system} is the set of all systems (organizations) competing in the global environment.

S_i := {s_{ij}, j := an index assigned to each sub-system} is the set of all sub-systems (department) within each system.

s_{ij} := {s_{ijk}, k := an index assigned to each sub-sub-system} is the set of all sub-sub-systems (sub-departments) within each sub-system.

And so forth.

7.3.1 Defining a sub-system (s_{ij})

Once the fitness function has been defined for each sub-system (the same is applied to sub-...-sub-systems), the person or team (typically the engineering managers) who are optimizing the specific unit (or system as a whole) should determine the following at the most atomic break down available per level:

1. The component set (c_{ij}): This is the complete collection of each of asset, resource or equipment under the employ of the subsystem (typically the inputs to the process). It includes human components, financial components, software, equipment, knowledge bases, administrative components†, and all other components that have an impact on the system

† A note of caution is offered on the compilation of the component set: while the component set would include the asset register, it would suffice to group equipment by its functional role. For example, while it would be more complete, it would be too tedious a task to list every bolt on a piece of simple equipment, depending on the criticality of the equipment on system performance. Should it be a very critical piece of equipment though, it may be instructive to list all critical components. I suppose that the deciding point is determining how critical, easily replaceable and easily obtainable something is so as not to increase the level of complexity beyond that which is

and whose omission would result in loss of information during the optimization.

2. The component characteristic sets: Taking into consideration each of the elements in the component set, one would attempt to define a set of pertinent characteristics per component. For each element in each of the characteristic sets, one would define the operational range, and preferred operating point if these are known (if they are not known, the logical deductions can be made). If one would consider the human component as an example, the characteristic set defined per human would include personality profile, IQ and EQ profiles, stress points, medical anomalies and expected behavioural patterns if these are known.

3. The process set (p_{ij}): This is the set of each process required within the sub-system. It could be a production process, a design process, an administrative process, a financial process or any other process within the sub-system.

4. The process characteristic sets: Taking into consideration each of the elements in the process set, one attempts to define the set of inputs, outputs, known disturbances, operating ranges, environment, mathematical model and so forth in an attempt to define the process.

5. The input sets (i_{ij}): This is an enumeration of the raw product or input to each of the processes. It is clear that the input sets would each be a subset of the component set, but the value that is added is that one could define a range of parameters for each input to a process and use this for quality control of raw materials.

6. The output sets (o_{ij}): This is an enumeration of the finished product or output of each of the processes taking into consideration that which is considered to be optimal. The main function of this set is for quality control: it allows for monitoring the sub-system's performance.

7. The fitness function (cost function): This is the multidimensional function based on the sub-system's objectives against which the performance of the sub-system will be measured. The function may be defined as a purely mathematical equation, as set of ranges, or any other measurable and determinable set of metrics against which the sub-system can be measured.

required.

7.3.2 Defining the system (S_i)

The task of defining the system from a high level follows a similar approach to that of defining a sub-system in that the sets are the same, but there are subtle differences in the definition of the elements:

1. The component set (c_i): There are two methods of definition for the component set. The one would be defined as the union of each sub-system's component set: $c_i = \cup_j c_{ij}$. The other method of definition would be to view each sub-system as being a component to the overall system. $c_i = \cup_j s_{ij}$. It would seem that the latter would be the more educative method of definition.

2. The component characteristic sets: Once again the characteristics of each element of the component set will be defined.

3. The process set (p_i): This is the set of each process required within the system. These are typically high-level processes such as managerial, change management, legal compliance, and so forth, but it depends greatly on the nature and size of the organization.

4. The process characteristic sets: Once more, the characteristics of each element of the process set will be defined.

5. The input sets (i_i): This is an enumeration of the raw product or input to each of the processes. At a system-wide level, the main element (if not the only element) of the input set will be the organizational objectives and metrics. This allows for quality control and re-consideration of the objectives as part of the algorithmic approach to the problem.

6. The output sets (o_i): This is an enumeration of the finished product or output of each of the processes. The main function of this set is for quality control: it allows for monitoring the system's performance. The main element (if not the only element) would be the results achieved in compliance with the organizational objectives and metrics.

7. The fitness function (cost function): This is the multidimensional function based on the system's objectives against which the performance of the system will be measured. The same applies as above.

7.4 Recursive and Re-Iterative Optimization Algorithms

The definition of the system allows for the deployment of the mathematical methodologies described above. Next, one would determine whether to use the genetic algorithm method, or the simplex method (or any other method for that matter) to determine the optimal structure of the system.

If one were to use the linear programming (simplex) method, provided the system is well defined and modeled, the optimal structure will present itself by the end of the analysis. Where greater complexity is involved, if the system is not well modeled (understood), or if greater non-linearities exist one would be tend towards using a genetic algorithm in which each structure is considered to be a genomic individual within the population of all possible individuals. Each structure is then tested against the fitness function until the optimal solution is finally obtained. Statistics are used to determine the probability of success (or failure) and helps with the generation of a risk profile.

The following would be an optimization algorithm that could be applied to optimize each sub-system as well as the system with their respective optimization requirements (objectives).

A pseudo-definition for the system data-type (note that a subsystem is itself a system) could be the following:

```
type set
{
        long size;                                  // Number of elements in the set
        object element (0 ... size – 1)             // Set of elements within the set
        *object characteristics (0 ... size – 1)    // Pointer to each element's characteristic set
} end type;
type system
{
        set component;                              // system's component set
        set process;                                // system's process set
        set input;                                  // system's input set
        set outputs;                                // system's output set
        function fitness_function;                  // system's optimization function
```

```
} end type;


Function Optimize (object) returns Optimized_System_Structure
{
        If object = Component, then
        {
                Analyze(Component);        // Analyze is any function which analyzes the component and returns the optimized
                                           // characteristic set
                Return Component_Optimum_Characteristic_Set;
        }
`       Else if object = Process, then
        {
                Analyze (Process);         // Analyze is any function which analyzes the process and returns the
                                           // optimized characteristic set
                Return Process_Optimum_Characteristic_Set;
        }
        Else if object = system, then
        {
                For each Component (Ci) in System do
                {
                        Component_Optimum_Characteristic_Set = Component_Optimum_Characteristic_Set * Optimize (Ci);
                        // * is defined as an operator that may include the union, intersection, or any form of operation that will yield the
                        // global component optimum characteristic set.
                }
                For each Process (Pi) in System do
                {
                        Process_Optimum_Characteristic_Set = Process_Optimum_Characteristic_Set * Optimize (Pi);
                        // * is defined as an operator that may include the union, intersection, or any form of operation that will yield the
                        // global process optimum characteristic set.
                }
                // Analyze is any function which analyzes the system and returns the optimized characteristic set
                Analyze (Component_Optimum_Characteristic_Set, Process_Optimum_Characteristic_Set, Fitness_Function);
                Return Optimized_System_Structure;
        }
}
```

The above algorithm allows for the entire system data structure to be passed in as a parameter. The algorithm will then perform a series of recursive calls as it iterates through each entry in the data type to determine the optimal system structure. Note that the analysis and optimization occurs in a bottom-up manner. For example, suppose system $S_1=\{c_1=\{s_{11}, s_{12}\}, p_1, i_1, o_1, f_1\}$;

$s_{١١}=\{c_{١١}, p_{١١}, i_{١١}, o_{١١}, f_{١١}\}$; $s_{١٢}=\{c_{١٢}, p_{١٢}, i_{١٢}, o_{١٢}, f_{١٢}\}$.

Then $S_١$ would be passed to the algorithm. $s_{١١}$ Would be the first object to be optimized and its component and process sets would be optimized against its fitness function. $s_{١٢}$ Would be the second object to be optimized in like manner to the first. $p_١$ Would be optimized next. Thereafter, these optimized objects are returned, the system is analyzed against its fitness function $f_١$. One would have various structures in mind (say systems $S_{١,} \ldots, S_n$) and each one would be passed to the algorithm until the system which scores the highest (or lowest, depending on the criteria) survives.

The function *analyze* should provide all information that fully defines the operation and behaviour of the component in question. The case study in section 9.3 includes examples of classifications that could indicate the information derived from the analysis of specific components.

7.5 Massaging Operating Factors for Optimal Component Performance

Every component has an optimal or preferred operating environment. Some parameters are within the engineering manager's control, while others are not. For example, computers can operate continuously – 24 hours per day, 7 days per week, 52 weeks per year – throughout their lifetime. Humans, on the other hand cannot. They require rest, time to spend with families and friends, time to perform religious duties and to enact a balanced life.

Often, the operating environment of technical components can be easily understood as the component is generally specified and chosen for a certain environment. The operating environment of a human may not be as well understood. Furthermore, a technical component that does not meet expectations may simply be replaced. A human component may not so easily be replaced as a number of negative effects may pursue: in South Africa, laws dictate what is considered to be unfair dismissal and the CCMA will be consulted in such cases; human components become emotionally attached to each other causing the replacement of one to upset the others.

In order to circumvent such problems, it is important for management to maintain open communication channels and transparency of decisions and inter-actions. In this way, as the human's expectations change, a mutual re-alignment between organizational and employee's expectations can occur [48].

Motivation is an important factor for performance [4]. The *Analyze* function above can provide meaningful interpretation of the factors (and factor ranges) that motivate a component. Those that fall within the scope of organizational expectation should be easily achievable, for example: remuneration with competitive market-related salaries, allowing the satisfaction of the need for personal achievement through self development programs, allowing the satisfaction of the need for status through promotion. There are those that fall outside the scope of organizational expectation, and these should be considered on merit as each case may pose different challenges. An employee whose spouse becomes ill may require more flexible work hours than the rest of the workforce. In the case of a flexi-hour modus operandi, this would not be a problem; but where strict work hours are enforced, special allowance needs to be made for such an employee. In this way, the organization moves away from being a 'feeling-less' machine to a system which takes care of its components and ultimately, itself.

7.6 Configuring Processes for Optimal Deployment of Component Resources

During the optimization process, each system process is modeled and deficiencies within the process are identified. The operation of a process does not imply optimization of the process. Physical production processes are often easier to identify than support and administrative processes are within an organization as they are more visible – management is very quickly made aware of bad quality product and there generally exists a direct effect on profit margins. 'Soft' processes, such as sales and procurement, are somewhat more difficult to streamline as they are abstract processes.

Within the organization, each process should be enumerated under the following headings: production, administrative, financial, safety, health, development, research, training, management, historization, logistics, engineering, planning, organization, etc. and then critically evaluated. Each process should then be characterized in terms of:

- Expected number of repetitions in a cycle (typically a month or a year);
- Expected duration of execution;
- Number of parallel and serial paths within process, and the determination of whether the parallel paths are for redundancy (standby) or operation;
- Outputs of the process;
- Enumeration of components required to accomplish the outcomes of the process within the given duration;
- Expected cost of execution of the process: this is the sum of the costs of raw materials, labour, energy, support, administration, rent, interest, etc. over the duration of execution;
- Expected cost of down-time of the process: this includes the costs of scheduled and unscheduled maintenance, dead-time, effects on production targets, dead-time (this is the cost of the process when it is not operational, for example a stores checkout clerk may be employed on a twelve hour basis, but may only be busy for 8 hours in the day), etc;
- Expected cost of ownership of the process: this is the *(expected cost of execution * the number of executions within a cycle) + (expected cost of down-time * (cycle – (number of executions within the cycle * expected duration per execution))*;
- Expected profit: typically for profit will be derived from the difference between income derived from the process less the expected cost of ownership of the process.
- Risk profile: this is an index derived from the probability of process failure multiplied by the impact or criticality of process failure. Failure detection, prevention and contingency plans need to be compiled to contain any such process failure.
- Efficiency: this is the index or percentage to which measured and actual values meet expected values. It is directly related to process throughput.

In administrative processes (for example the health and safety processes), this parameter is more difficult to measure as they don't always directly make any profit, but failure of this process could cause failure of other processes, resulting in indirect loss of profits (for example lost time injuries). The processes thus form support functions to main processes: their effects on organizational objectives may not always be visible, but effect of their failure or non-optimal operation is very visible.

Having characterized each process, a critical look is taken at each process in turn. It is important to note that this can be a very time consuming process and that it should not be an exercise in finger-pointing, but rather a constructive action by the team to determine the possible failure modes and root cause of failure in the case of process in-efficiency [63]. Brainstorming techniques can be applied to processes where scientific and mathematic models are absent to determine cause and effect analyses. The output of the analysis should result in a set of action steps assigned to certain responsible people and coupled to an implementation time. Where multiple suggestions exist, each should be tried in succession until the optimal solution is found.

7.7 Configuring the Organization for Optimal Performance

Once the optimal operating environment has been defined for each component, and each process has been configured for optimal performance, one should then take a holistic look at the organization as a system. This allows for the determination of bottlenecks within the system. Each bottleneck identified should be handled on merit and it may be necessary to detune a sub-system [5] somewhat to avoid overflow to subsequent sub-systems. As a precautionary note here is that detuning should only be considered once other solution have been exhausted. As has been mentioned before, the whole is sometimes greater than the sum of the parts, and hence the collective output of each sub-system should be tuned to obtain optimal system performance, efficiency and ultimately, profitability.

At each sub-system interface, integration mismatches may occur due to possible oversights and / or undersights. Once again, these are cases that merit special consideration to enforce a smooth transition from one system to another. Sub-system integration is a concept that should be addressed at a design level, and experience shows that standardization increases the probability of smooth integration of sub-systems and system components.

The optimization of a system may require numerous iteration with bi-directional propagation of results between system and sub-system, and the organizational structure can thus be optimized with time. Another note of precaution is that a solution may provide promising results, but high cost of implementation and knock-on effects may ensue. Hence, each solution should be critically investigated in terms of feasibility, system performance and integration modification before actual implementation.

7.9 Organization Steady-State Operation and Growth

During the life-cycle of an organization, one of the primary concerns is to enter into steady-state operation. This should be considered of primary importance before the optimization of the organization is considered. The reason is that production and operation of the organization fuels development and provides resources for optimization. Both work hand-in-hand as optimization increases profit margins, thus allowing more resources for optimization. In volatile systems (particularly new systems which are riding the infant mortality phase of the bath-tub curve [17]) it is important that system steady-state conditions are achieved first as optimization may place high demands on components of the system and cause stresses outside the physically verified operational ranges of the components. It is often the case in new organizations that production is stepped up as confidence is gained in system operation. Furthermore, plans should be compiled for roll-back to previous operating parameters if optimization techniques have exhausted all means, and steady-state conditions cannot be reached. It is thus important to leave a paper trail so that rollback can be executed if necessary.

The growth of an organization is an important matter that can cause imbalances in the organizational environment. Growth management plans should be in place as change in components result in changes in the system component sets which in turn could result in changes in system operation. Change management becomes an important function, and transparency and open communication channels rely heavily on structures that have been put in place before effecting the change [59]. Feasibility studies which are executed before implementation of growth plans are performed by the entrepreneur in determination of the effect on system operation. A playoff may exist in finding the optimal organizational size to efficiency ratio. The higher the ratio, the better tuned the system is.

7.10 A Note on Effects of Globalization[64][65][66]

The global environment is dynamic and complex. In the world today, the organizational threats and alliances exist on a global scale. There are pros and cons to globalization for both the localized and globalized organization, but the purpose of this research is not to argue for or against globalization. The effects of globalization on an organization is tabulated, and deductions are left for the interested reader.

Globalization affects an organization in the following ways:

- Trans-nationalization is the emergence of worldwide production markets and broader product ranges whereby goods are moved within transnational organizations. This allows for acquisition of goods in wealthier nations and acquisition of labour in poorer nations, causing an increase in nett profit.
- Economic influences allow for the exchange of goods and capital on a global scale with the collective positive and negative effects of the particular economy of the interacting countries.
- Political whereby a international laws and custom govern the trade interaction.
- Financial emergence allows for better access to external financing but also requires that one keeps in mind economic effects such as exchange rates and world markets.
- Informational allows for the cross pollination of information and data on a world-wide basis within the global informational village and the world wide web. It allows for organizations to have knowledge of and be at the forefront of development. It also allows for consultation and information transfer to be quick, effective and secure. One of the draw backs of openness of information is the costs of security to keep information from landing in competitor's hands.

- Cultural and Social: details the differences in culture and the fact that what may be deemed as acceptable in one culture may be offensive in another.

Localized organizations need to be aware of the presence of global competition. Globalized organizations need to be aware of the the factors above and other effects of globalization. Ultimately, the point is that organizational system co-exist within global environment and each organization should be aware of allies (and opportunities), competitors (and threats), spectators and observers, parasites and scavengers to survive in the global environment.

7.11 Chapter Conclusion

In this chapter the notion of Total Systems Control, Optimization and Management was discussed, whereby a the need for total system control was offered. A system-wide control, optimization and management strategy begs for the optimization of the entire organization from an atomic, cellular level to the inclusion of the entire system response.

Thereafter, a general method for describing an organization as a system was presented together with an algorithm for optimizing the structure, efficiency, internal environment and the performance of the system. The algorithm allowed for the discovery of the feasible operating region of each component, process and sub-system for applicable parameters and then the determination of the operating point for each parameter that would allow optimal performance and efficient operation of each sub-system.

An argument was presented on the need for detuning certain system parameters to achieve overall organizational optimization. Steady state operation and growth of the organization were then discussed, detailing the need for change management. Finally, the effects of globalization on an organization were presented.

In the next chapter, practical considerations and impacts of attempting to optimize the operation of a system will be discussed.

CHAPTER EIGHT: PRACTICAL CONSIDERATIONS

Chapter Outline

Chapter Overview

In the application of the theory, certain practical complications should be taken into consideration. Prior to applying tests certain decisions must be taken to determine a course of action that will have the least effect on other organizational operations. During the execution of tests, monitoring strategies need to be in place to determine test performance. The results of both a successful or unsuccessful test can be used to the benefit of the test in cementing the changes, changing parameters, updating the optimization functions, or improving on the model by inclusion of practical observation.

8.1 Chapter Introduction

The application of the contents of the previous chapter allowed for a set of parameters that would optimize system performance and efficiency. Blindly rushing in and effecting the changes to the system may cause catastrophic failure. A systematic approach needs to be followed in the implementation of the parameters. Effects such as downtime and loss of production and profits need to be considered and a plan of action should be constructed prior to implementation.

Another complication that may arise is resistance to change as employees may feel that their position or job title is threatened. Furthermore long lag times may exist before the results of the change become apparent, and a number of data points should be captured before analysis on the data is performed.

The purpose of this chapter is to discuss how tests are defined, executed, monitored and results evaluated. Once the results obtained have been verified, they are used to adapt the optimization parameters to determine if a better system structure or operating philosophy can be obtained. Finally, this chapter concludes with a discussion on how the information derived from the tests can be used to evolve the models to more accurately describe the system.

8.2 Defining Tests

From the output of the optimization algorithm, one is left with a number of sets of parameters per sub-...-system and for the system. The parameters described could require changes in one sub-system that would negatively affect another, for example they could detail the transfer of a human component (say a manager) from one sub-system to another due to the unique set of skills that he presents being required within another sub-system. This would leave a gap in the former system which would have to be filled by another human.

It is important that the impact that change has on the system is managed correctly and it would be wise to test the parameters on the system and evaluating the effect before cementing the change. A formal test process is required to achieve this.

8.2.1 Test Definition, Scope and Boundary

Firstly, the test should be clearly and concisely defined: the objectives need to be enumerated and the expected outcomes and results tabulated together with a justification for executing the tests. A list of what is to be performed, how it is to be performed, the order in which it should be performed, the duration of the each step of the test, the role-players that should be present with a declaration of the responsibility of each, and a tabulation of the affected components and processes should be documented together with the test scope and boundaries. A snapshot of the as-is state of the affected components and processes within the system needs to be captured before execution of the tests.

8.2.2 Execution Date and Execution Time

Depending on the nature of the organization, the production plan or business plan should be thoroughly examined to determine the date and time during which execution of the test can be performed with minimum impact on the system.

Changes to process or equipment can be scheduled during shutdowns and changes to staff structure should be phased in during periods of low work load and high system stability if at all possible.

8.2.3 Risk Analysis and Contingency Plans

While planning the tests, the risk of implementation and failure of the tests need to be determined together with the impact on overall performance of the system. The “what if” questions should be asked, for example: what if process A fails during execution, or what if key staff member B becomes ill. There are numerous cases that can be discovered by experienced personnel through a brainstorming session.

Once the risks have been identified, and rated according to probability of occurrence and impact of occurrence, contingency plans need to be compiled to cater for quick and efficient change-over to a 'plan B' if one is available. In the case of the test not allowing for immediate change-over to a backup plan, the contingency plan should detail a method for the efficient rollback to the system snapshot that was taken. The method should be compiled to have minimum influence on system objectives and performance if at all possible. Where high risk, probability and impact of occurrence exists, the fact should be disclosed to more senior and experienced members of the team, and total management buy-in should be sought.

8.2.4 Expected Results for Acceptance or Rejection

A successful test is one which achieves its objectives. Any objective can either be seen as a prove or a disprove objective. As part of the test planning phase, it is necessary to detail the expected results for acceptance or rejection of the test outcomes. For each objective, the range of expected results should be tabulated. Where complex objectives exist, they should be decomposed into measurable metrics which allow for the scientific sampling of the required data. The results can then be mapped to an index through a formula, and the index can be monitored to determine success of the test.

The test plan should detail whether the termination of the test results in roll back of the changed parameters to the snapshot values, or whether it results in formalization of the change.

8.3 Execution and Monitoring of Tests

Before execution of the test, the team should begin preparing for the execution. The amount of preparation time required depends on the length of the test, complexity of the test and size and experience of the team. Each role player should be briefed to ascertain that each responsible person is aware of his or her responsibilities and is capable of executing their tasks. Communication channels should be well defined and authoritative figures should be available for assistance. If the system snapshot has not yet been taken, it should be done before allowing the test to be executed.

Each affected component (employee) should be spoken with and their buy in obtained. Any concerns that the employee may have should be discussed and open communication should be stressed.

At the decided date and time, the implementation of the test should begin. It is important that the person responsible for managing the tests drives the execution forward. This creates the perception of a proactive management team amongst employees.

Upon execution, the steps indicated within the test plan should be executed, verified and signed off as complete. Where a system had been taken off-line for test implementation, all required changes should be effected and verified before allowing the system to be taken back on-line. Where changes were effected on an on-line system, each change should be verified and unexpected results should be documented and brought to the attention of the appropriate role players who will determine what action should be taken to remedy the problem. The action taken should already be catered for in the contingency plan.

Once all changes have been effected and verified, and / or the system been brought back on-line, it is important that the system be monitored for steady state conditions. When the system is stable, the test parameters in question are monitored and recorded by the responsible role players. Once again, any abnormalities should be reported to appropriate role players as soon as possible.

If the system does not reach steady-state operation, the contingency plan should be consulted to determine the agreed upon way forward. In an extreme case, the test will be aborted and the changed parameters rolled back to the snapshot values.

8.4 Analysis of Results

During the execution of the tests, the results are constantly monitored and recorded. The risks are also closely monitored and the probability of occurrence is constantly recalculated. Where unexpected results or system instability occurs, the responsible role players will consult the contingency plan and determine the course of action. Upon completion of the tests, the results are processed and a report is generated signifying the total success, partial success or total failure of the test.

In the case of a successful test where the results have been unanimously accepted, the change will probably be finalized and the test terminated through the completion and storage of the relevant documentation as there is no reason for the test to be re-implemented. In the case where the test has failed and results unanimously rejected, the changed parameters will most probably be rolled back to the snap shot values and system steady-state re-enacted. A gray area exists where a test was partially successful. In such a case the responsible role players should decide on the action forward. They can decide to extend the duration of the test to gain more information, roll back to the snapshot values and return to the drawing board, or formalize parts of the test and rollback the rest if possible.

8.5 Correction and Re-Propagation of Optimization Functional Parameters

During testing information should be obtained that will verify the strength and accuracy of the solution. Where the test was not completely successful, the 'real-time' information will allow for correction and modification of optimization coefficients in the optimization algorithm. The re-execution of the algorithm will generate a new set of parameters that can be drafted into the test document. It is important to fully justify the expected effects of the new parameters to maintain stakeholder buy-in.

Once the parameters have been determined, the process of testing is defaulted to the step of determination of test objectives and scope.

8.6 Evolution of Optimization Functions

The team should be sensitive and open to the possibility of the deployed system definition model not accurately describing the system. The tests may bring to the fore certain unforeseen phenomena which will allow for the evolution of the system definition and optimization functions. In light of the new information, the models should be redetermined and verified, the optimization algorithms re-executed, and the optimal parametric coefficients redetermined. The effects of the modified parameters can be filtered into the test if the impact is not too great. However, if great impact is expected, the team should consider defaulting the test to its first step and formally re-engage the test with the new set of parameters.

8.7 Chapter Conclusion

Once a system has been analyzed and optimization criteria have been formulated into a set of possible solutions, each solution should be tested in turn to determine the one which provides the best fit (if there is only one solution in which there is sufficiently high confidence, only one solution needs to be tested). Prior to conducting the test, careful planning must be performed to minimize the impact on organizational operation as far as possible.

Tests should be executed in a controlled fashioned and the results should be continuously monitored. Any results that indicate increase in risk of failure, require consideration of reversion to contingency plans.

The analysis of results provide meaningful information as to the success or failure of the test and the accuracy of the optimization parameter and the model. From the results, the optimization parameters and models can be updated to more accurately model the system and take into consideration practical variations from the theoretical results.

After the modification of the parameters and / or model, the tests can be re-executed and the cycle continued.

If the tests were successful, the results can be cemented unless the team requires any further testing.

In the next chapter, this method will be applied to the case study of an engineering project house.

CHAPTER NINE: CASE STUDES

Chapter Outline

Chapter Overview

In this chapter the theory studied prior to this point will be applied in a case study on an Engineering Project House.

9.1 Chapter Introduction

In this chapter, a theoretical case study will be discussed whereby application of the above algorithm will be demonstrated. DRA Mineral Projects was used within this case study. All information contained in this case study was used with permission. The information was derived from the DRA Mineral Projects' website, the DRA Mineral Projects' Brochure, and an interview with one of DRA Mineral Projects' directors: Mr. Louwrens van der Merwe.

9.2 Case Study: Engineering Project House [67][68]

9.2.1 DRA Mineral Projects Background

DRA Mineral projects is a projects engineering company established in South Africa in 1984, and specializes in project management and process plant design. As of 2008, the organization employs just short of 700 employees (including mechanical, electrical, civil, instrumentation, structural and control engineers; as well as project, logistic and construction managers, administration, legal, financial and maintenance staff) and their success story was written on the combination of innovative approaches in the application of technology with engineering competence and strong project management principles.

The organization focuses on all aspects of engineering and project management including:

- The project life cycle including project feasibility studies, engineering analysis and design, component procurement and fabrication quality management, plant erection and construction, installation, automation and commissioning, and hand-over after client satisfaction;
- legal support, management of health, safety, environment and quality through the generation and enforcement of specifications and standards, and compliance to the legal requirements of the OHSA, ISO9001, ISO14001 and ISO18001 standards;
- waste management, energy management solutions, logistics support, and documentation management;
- client training, operations and post-implementation support;

- specialized winder applications, specialized electrical power flow and utilization analysis.

The organization's employees work closely with the client to establish specific needs, ensure total client satisfaction and innovatively generate practical and cost-effective solutions.

The organization tenders on EPCM (Engineer, Procure, Construct and Manage) type projects as well as fixed price (for example small- and large-scale Turnkey) projects. In an EPCM-type project, the client bears the majority of the risk[†], and DRA Mineral Projects is remunerated on an hourly rate for each employee that works on an EPCM project. Fixed price projects operate on a different basis in that DRA Mineral Projects will bear a significantly higher risk, but this generally implies possibly higher levels of remuneration in that DRA will be paid for the entire project, and not just man-hours spent. A brief discussion of the advantages and disadvantages of EPCM and fixed-price projects is offered in Table 9-1:

An EPCM type of project is favoured when the end deliverable is not completely quantifiable. The client bears the risk of changes together with associated costs as the project progresses. Advantages of EPCM projects:

Client Benefits	Project Organization Benefits
Client gets what he / she wants as they are paying for services, rather than only a finished product.	Lots of client input, so the needs of the client can be better provided for once identified. Also, unfamiliar areas of expertise in the project organization can be facilitated by the client.
Has a lot of input in the management and pace of the project.	Requires less expenses on management, and can allow for the development of better solutions under somewhat less pressure while indirectly creating an environment conducive to increasing employee knowledge and skill level at the project's expense, while still adding benefit and progress to the project.
Client involvement allows for client to have thorough knowledge of the progress of the plant	Organization bears less risk than a fixed-price project as the client bears the majority of the risk

† The client bears the majority of the risk, implying that the client enjoys potential savings, and incurs the costs of potential losses.

engineering, construction and commissioning.	for under- and over-sights (logistic mis-calculations, etc.), and project time drift. While professional accountability is still attributed personally and the organization could be held liable for gross negligence, any error that could be reasonably attributed to natural possible oversight and all consequential damages are still covered by the client.
The client bears the risk of failure of partially commissioned equipment and has to find a balance between costs or possible non-conformance to penalty contracts versus risk of equipment failure and consequential costs of the said non-conformance. To achieve targets, the client may request operations to begin production on partially completed plants.	Organization enjoys a more stable source of income and possibly bonuses that are more lucrative than the strictness of imposed penalties. It is important to realize that the lower risk also generally implies lower reward.

Basically, the risk-reward ratio is in favour of the client, but the low risk environment (from the organization's perspective is conducive to an experience development environment.

EPCM projects also offer disadvantages to both the client and the engineering organization (only a few are listed):

Client Disadvantages	**Project Organization Disadvantages**
Client bears the risk of oversights.	EPCM projects generally offer lower forms of reward as the accepted risk is lower.
There have been cited cases in industry where engineering organization's employees are perceived to work less efficiently for the perceived higher incentives. As the client is paying for services rendered, he / she is required to manage the project in such a way to minimize	Any deviance from the end result of the product study is defined as scope creep. Any occurrences of such should be well documented and managed very carefully so that relevant stakeholders can be presented with alternatives to determine if the playoff between scope clreem

the probability of slippage while still permitting sufficient time to effectively complete assigned tasks.	and financial gain is viable.
Corporate governance procedures could cause time inefficiencies for scarce engineering resources.	

Fixed Price Projects are favoured when the scope and end deliverables are clearly defined. The client knows exactly what he / she wants and the organization knows exactly what they are going to give him / her. The pros and cons offered include:

Client Benefits	Project Organization Benefits
Less client involvement and cost of management as the project organization facilitates the entire management of the contract and project.	The project can be delivered at a timeline mutually agreeable. The project team has to work consistently to meet the deliverable timeline as project viability is dependent thereon. The deliverable timeline in turn is dependent on the timing between expense and revenue stream. Slippage on the deliverables could mean cash negativity for longer periods of time (and the associated compounded interest) which affects the bottom line tremendously due to deferred revenue generation causing difficulties in mitigating the cash negativity.
Scope definition is clearer as the client knows exactly what they want.	Constantly changing client demands and scope creep could be curbed by the possible imposition of increased cost of project and time delays. The client is paying for an end deliverable and not a service. If the goal post changes, so does the time and cost required.
Client assumes less risk for implementation.	Innovative engineering could lead to higher

Also, client does not need to have expert knowledge on management of projects. Contractor bears risk of non-conformance to specification.	profitability but not remove the risk from the contactor. Successes experienced through innovative engineering could increase the reward, if despite the risk. The risk-reward ratio is more in favour of the organization.

The disadvantages of fixed price projects include the following:

Client Disadvantages	**Project Organization Disadvantages**
Client has less influence on finished product and incorrect scope specification can cause scope creep and delays. The allowance for modification of scope leads to cost incurred by the client in the management of scope creep.	Project team accepts higher risk and failure to achieve project goals results in strict penalties and losses. Engineering rework / oversights / undersights result in incurring unaccounted for expenses. Scope creep has a financial and a time implication.
Client may not always receive the best solution, but generally the 'fastest' solution. The client will generally receive the best mainstream solution available, but due to the generally imposed time limitations, cutting edge technology may not be provided.	Entrepreneurial minded people are required to successfully capitalize on this form of contract and these kind of people are not that frequently found.

A new type of contract which has emerged in the last two years is the agreed target price (ATP) project which is a mutation of the amalgamation of EPCM and LSTK projects. Literature needs yet to be fully developed on this topic, so its discussion is omitted.

In order to provide competitive services, the organization fast-tracks many projects through concurrent engineering which aims to incorporate the overlapping of processes in order to reduce the time-to-market through faster engineering solution design, development and delivery while still maintaining strict engineering principles, practices and standards. Unfortunately, concurrent engineering results in side-effects like increased risk due to uncertainties between interdependent processes, and a higher possibility for rework.

The successful implementation of organizational management and the efficient achievement of organizational objectives allows for the completion of projects on time and under budget which are often attached to lucrative bonuses. However, the existence of lucrative bonuses are often contractually coupled with the existence of strict penalties.

DRA Mineral Projects has tackled projects both locally and internationally, in various aspects of mining and mineral processing and in various price ranges – from a few million rands to its biggest 4.5 billion rand project in conjunction with Assmang mine on the BKM project. To this extent, DRA Mineral Projects has established itself as an international organization with head office South Africa and branches in Canada, Australia and China.

9.2.2 Organizational Structure

DRA Mineral Project has a very 'flat' organizational structure and focuses more on project optimization and assignment of people to their preferred tasks than it does on individual status, but still maintains emphasis on personal growth.

The organogram starts with a board of directors who provide vision and direction for employees. They are also responsible for the formulation of long, medium and short term strategies, goals and objectives. The directorate is also responsible for establishing ensuring commitment to the DRA culture: *"Have some fun. Do a good job. Do it on time and under budget. Make a little money*". To this extent, a trust-relationship is established in which employees are allowed to work flexible hours and are encouraged to explore and learn as much as possible.

Assisting the directorate, but still practicing in their personal capacities as engineers, are the discipline mentors. The mentors are those who have distinguished themselves as having expert technical knowledge and skills in certain disciplines, and are able to convey these to inquiring parties.

Beneath the directorate is a pool of projects and a pool of employees (including the mentors). Each project has its own set of constraints, required organization and project-specific construction. The employees in turn are able to fulfill various roles including engineering, logistics, project management, procurement, administration, financial accounting and maintenance. In general, each project will have at least one project manager, teams of discipline-specific engineers (comprising of the following disciplines, each with its own lead engineer: process; mechanical; civil and structural; electrical, instrumentation and control), a logistics engineer / manager (who typically works closely with, or is, the planner), an administrative team, a legal team, a financial team, and discipline-specific site and construction managers. The exact makeup of each complete project team varies depending on the size and monetary value of the project, the scope and novelty of the project, the anticipated risk and challenges that the project presents, and the client involvement and requirements.

By maintaining a flat organizational structure, it is possible to create and transparently manage the many-to-many project-to-employee relationship which exists.

9.2.3 Classification as a System

DRA Mineral Projects offers a service as opposed to products and due to the nature of the organization, human beings are DRA's biggest asset. DRA takes a noteworthily diplomatic stance in viewing each employee as being unique and important to the organization's successful operation.

For the sake of this research, DRA Mineral Projects will be defined as the system.

The employees and assets (offices and design equipment) are the components of the system.

The inputs will be the project specifications, information resources, time, energy, human and financial resources, and consumables (such as stationery, refreshments, etc.).

The outputs will be the finished feasibility study, design documentation, or commissioned and handed-over processing plant, depending on the nature of the project.

The set of processes will be defined as the union of the processes of engineering and managing each project, but will also include those necessary for operation such as financial, legal, administrative, maintenance, information technology and logistic support services offered internally†.

To facilitate the most logical assignment of equipment, each employee is provided with either a laptop or a desktop depending on the employee's role and needs. Each employee is also presented with office space and equipment, and supplied with appropriate stationery. There is thus a one-to-one relationship formed between employees and equipment.

† The latter services are exclusive of those offered within each project and are required for the successful operation of the organization.

9.2.4 The Optimization Process

The optimization process deployed within DRA could formally be classified as an abstract classical genetic algorithm problem which requires the use of experience, knowledge and an understanding of probabilities to guide the population survival selection process which is determined against a somewhat adaptive and dynamic fitness function.

The optimization process begins at a high up level where the directorate take strategic decisions on steering the organization along the path which provides the best profit to survival ratio. As part of this process, the market is probed to discover prospective project opportunities, the active phase in the life cycle of the current projects are analyzed, and the risk profile of the organization is determined by taking into consideration the risk profile of each project currently undertaken[†]. The output of this process provides strategic information:

- The organization's short, medium and long term strategy and vision;
- The knowledge of the organization's risk profile and tolerance and the contingency plans that need to be put in place to manage the risk;
- The projected organizational profits and budgets;
- The probability of survival and the extent to which negative entropy is achieved: depending on the organization's reserves, the organization's current survival position can be determined. The projected survival position can also be calculated by taking into consideration current system utilization and load, and the effect the new projects will place on reserve capacity. Should there be insufficient capacity to secure a favourable survival position, the organization could look at sourcing extra resources through growth or outsourcing of certain project-related tasks. The risk of each option is then carefully considered and an action plan is instantiated;
- The dynamic and adapted fitness function providing objectives against which the strength and accuracy of the optimized solution will be tested.

† When a new project presents itself, the new risk profile is determined and analyzed before the project is undertaken, provided that the new mutated risk profile is found fall within acceptable parameters.

If a preliminary systems analysis process indicates that organizational growth is required to sustain the current state of negative entropy and survival position, the market is surveyed for candidates that are capable of fulfilling the roles required. Candidates that exhibit acceptable levels of academic qualification are interviewed and sent to the organization's psychologist for psychological and psychometric testing and evaluation. (This forms part of the component ***analyze*** phase of the optimization algorithm through which each employee would have gone upon entering DRA's employ). The evaluation helps to determine the following information:

- Confirmation of academic and technical capability and skill set;
- Confirmation of managerial and communication capability and skill set;
- Level of compatibility exhibited by the prospective component with the organizational culture;
- Level team cohesion exhibited;
- Personality and behavioural profile including the strengths, weaknesses and areas that require development;
- Expectations, value system, motivators and probable position within the team;
- Intelligence quotient (IQ) and emotional quotient (EQ); and
- Risk tolerance and stress management capability.

Once the component analysis is complete, it is contrasted with the current DRA culture to determine the effect that the inclusion of the component will have on the system and vice-versa. Should the outcome of this process be favourable, the component is offered a position of employment and the standard procedures of remuneration negotiation proceed until both the organization and the component have found mutual grounds for agreement.

Once the component set has been defined, the survival position is again evaluated to determine the system's reserve capacity and ascertain that the system is not working too close to maximum capacity. Together with the determination of the survival position comes the resource assignment plan (man-plan) which attempts to construct project teams which are most likely to survive and effectively accomplish their objectives. The construction of the various project teams is once again run through an optimization call within the algorithm†. The pool of available resources are matched against the pool of unassigned project positions on a reiterative basis (as dictated by the optimization algorithm). The process of assignment calls for the use of a guided classical genetic algorithm technique and each iteration of the assignment of resources to project positions yields a solution that is tested against the fitness function. The effects of component-related variables such as team cohesion and introduced team dynamics, IQ and technical capabilities, etc. are all taken into consideration to find the components that effectively match the position in question. As biases within the assignment calculation are effects such as client affiliations and requests, risk tolerance, stress management, component load determination and component personal position. The process continues until the resource-allocation-plan which optimizes the fitness function is found. This is then taken back and contrasted against the objectives and the possible level to which the objectives will be achieved is determined. Where more information and experience is obtained after each successive optimization run, the fitness function can be adapted to more accurately model the organization's survival function.

Once the optimal assignment has been discovered, the solution is effected and carefully monitored. More meticulous sampling and monitoring is required within the system until steady-state operation is achieved. Once the system has reached equilibrium, the sampling intervals can be lengthened or, if the interpersonal relationships are strong enough to sustain it, the monitoring can be performed on an interrupt basis as opposed to continuous polling method.

Open and transparent communication is maintained between the directorate and all members of the project teams. This allows the directorate to constantly monitor the current position of each team against the theoretically projected position at the time of assignment. Both positive and negative deviation provide useful insight and allows experience to be gained and applied in guiding successive iterations of the optimization algorithm. Negative deviation together with open communication channels allow for the discovery of infringement of the project on the boundaries that define the risk profile, and the steps that will mitigate or eliminate the occurrence and effects of the risk can be instantiated early. Where unaccounted for risks and negative project outcomes

† To avoid introducing too many disturbances into the system, where current resource-to-project assignments exist, these are left unconsidered in the optimization process unless the current survival position dictates that it is absolutely necessary to consider reassignment of resources.

realize, the system reserve capacity can be deployed to react to the risk and restore favourable system equilibrium through equifinality.

Once the system exhibits equilibrium, the system's sensitivity to and tolerance of disturbances needs to be investigated. Possible scenarios are evaluated to determine the system's probability of survival given changes in various parameters such as economic and / or political climate, loss of key employees, possibility of project failure due to sabotage, etc. A measure of the system's resilience to these disturbances needs to be calculated to determine if the current optimal solution and systemic makeup allows the system to ride through lean times.

Where the projected optimal solution fails, the directorate may use the information from the possible resource mis-assignment to evolve the optimization function until one that most accurately models the system is found.

This optimization process is constantly deployed and actively manipulated in some stage of its implementation as it allows for recursive and reiterative function calls.

The entire process is manual and based on human judgment.

9.3 Simulation of Genetic Algorithm Optimization Function

9.3.1 Introduction

The simulation of the optimization functions is now presented. Due to lack of time and confidentiality of information, actual results could not be obtained. The following simulations were based on generated information.

DRA Mineral Projects was used as a model and the software was developed and customized for the engineering project-house industry. The value of using a project house as a model is found in projects having a limited life-span. This allows for modeling the projects as departments and teams as sub-departments (discipline-specific). The departments and sub-departments then become dynamic and require continual assignment and evaluation. Another benefit is that the resources with the biggest impact are human resources. Section 9.3.3 provides assumptions regarding other resources.

The software was developed in Microsoft Excel's Visual Basic for Applications (VBA). This software takes the definition of an organization (broken down into departments and sub-departments together with derived objectives) and allows the assignment to sub-departments from a resource pool. All viable combinations of resources are first determined. Thereafter parameters can then be matched, minimized or maximized to determine the 'score' of the resource against the requirement for each parameter. The scores are averaged among members of the combination to provide the combination's score for each parameter.

The combination's final fitness score is given by:

$$\mathrm{F}_C = \sum_i w_i \times f_i \qquad (9.1)$$

where f_i is the fitness score of the combination per parameter and w_i is the weight of each score.

Thereafter, the highest fitness score of each sub-department's combinations is elected as the 'winner' and assigned to the department.

A copy of the software is included with this dissertation. The software listing appears in Appendix A. The listing is well commented and should offer sufficient explanation.

9.3.2 Description of Simulation Software

The simulation 'package' was developed in MS Excel's VBA (Macros). Information to the algorithm is provided in Excel worksheets. Macros are then executed to perform the following tasks:

- Generate Objectives for the Organization: The organizational structure is manually assigned. This generation function only assigns random values to the objectives (genetic algorithm parameters).
  The function is called “Analyze Organization” and would typically be the manual process that involves analyzing and organization and developing a set of objectives.
- Generate a Resource Pool: This function is used to generate an entire resource pool with randomized data. Note: all current resources are deleted and recreated. The assignment of resources to disciplines is also random. The function is called “Analyze Component” and would typically be either a manual or automated process of determining the component's (or resource's) characteristic set.
- Determine Optimal Assignments of the Resource Pool to the Organization.

Figure 9-1 Indicates the 'Control Panel' where one can access these functions. The figure also displays various worksheet tabs:

- Departments: Defines the organizational structure and is an **input** to the simulation algorithm.
- Resources: Defines the resource pool's characteristic sets and is an **input** to the simulation algorithm.
- MatlabData: Contains a list of values randomized values based on the Gaussian distribution. These values are used by the randomization functions to 'select' values for the various characteristic parameters.
- Optimization Setup: For each organizational objective, defines the optimization function to be applied.
- Optimization Combinations: Provides all possible combinations per sub-department. Also

provides scores per combination. The optimal combination per sub-department is marked in bold green.

- Optimized Assignments: Displays the chosen assignments of resources to sub-departments and departments. Effectively provides an organizational hierarchy (horizontally oriented...).
- Assignment Summaries: Provides summaries pertaining to the assignments.
- Log Sheet: Provides a log of activities for debugging purposes.

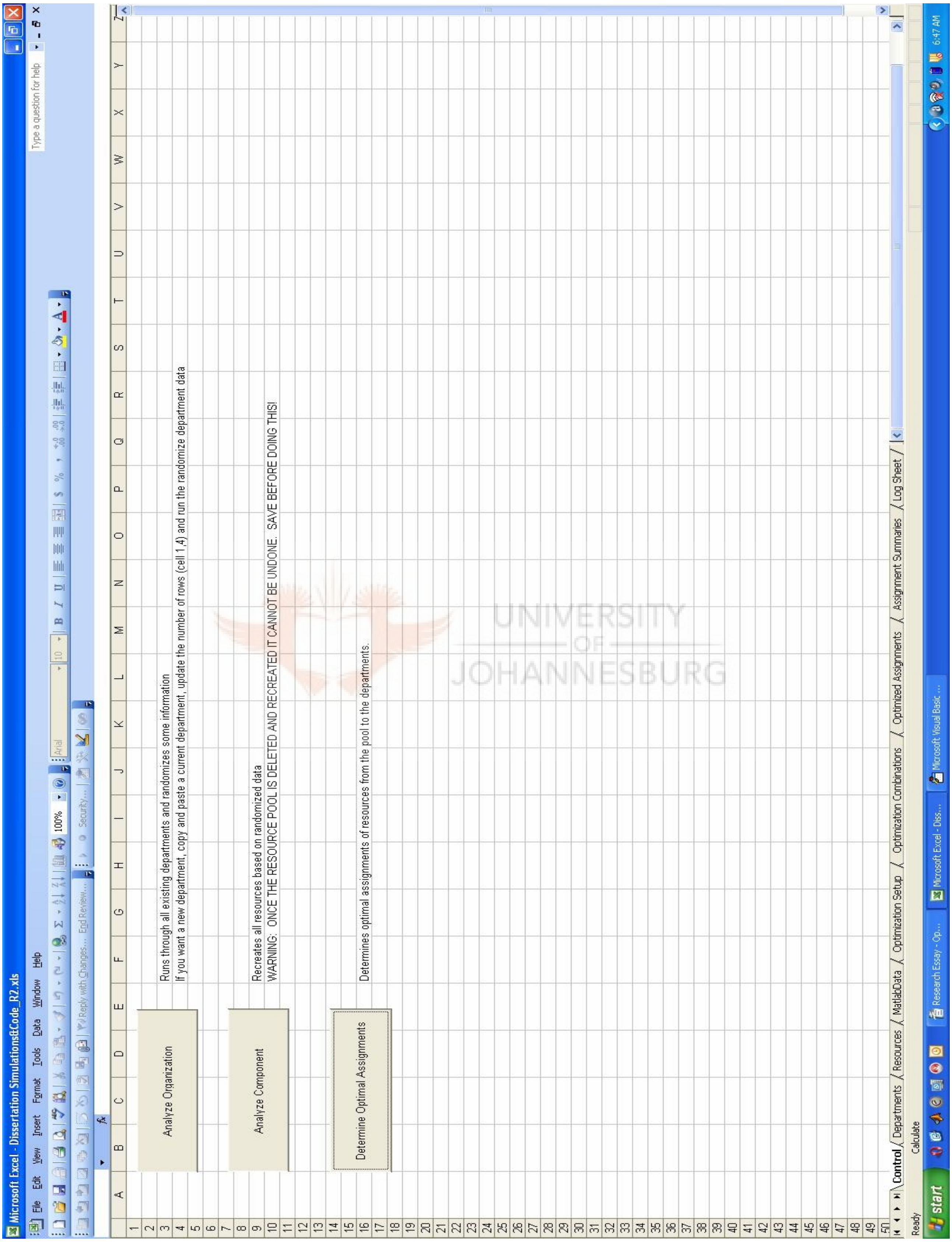


Figure 9-1: Simulation 'Control Pane'

9.3.3 Assumptions in Simulation

The following assumptions have been made in the simulations:

- Projects are modeled as organizational departments.
- Discipline-specific teams are modeled as departmental sub-departments.
- The most impacting component is the human resource. The characterization of the component leads to the most efficient operation of the component. This is possible due to the remainder of the assumptions.
- Technology, office space, furniture and equipment are organizational assets, but are not viewed in the light of organizational components for the sake of the simulation. They are viewed as enablers to resources, ie. They enable human resources to achieve their optimal characterization. This allows for simplification of the model and while implicitly filtering in the effect of these assets.
- Money is a motivator. Once again, the financial component is ignored for organizational optimization purposes (save the profitability analyses). Finances are one of the resource motivators for the purposes of the simulation. The rate / hour is factored into the optimization for reasons detailed in section 9.3.4.

9.3.4 Discussion of Fitness Parameters and Optimization Function

The following fitness parameters (characteristics) were taken into consideration to determine optimizations[†]:

- Personality Rating based on the DISC analysis. To make the simulation independent of differing analyses scoring methods, the results were scaled from 0 – 20 with 10 being the mean. This does not mean that 20 was the highest and 0 the lowest. The more important factor is the deviation from the mean. A rating of 10 in each of the D-I-S-C indices would indicate total balance. For example, a rating of D = 0 would indicate a totally non-dominating person, D = 10 would indicate a well balanced person (one who knows the place

† Please note that these parameters may have been adapted to suit the simulation algorithm and may not necessarily indicate the generally accepted practices.

of dominance and how to use it effectively), and D = 20 would indicate an excessively dominant person. Certain roles would require more dominance than others, and this rating should increase. The simulation assumes a mean DISC rating of 10 with a standard deviation of 2.

- Task Work Load vs Component Efficiency. Although each project has a given time-line, some projects require introduce higher pressure and workloads than others. For extremely high work loads, one would either increase the time span of the project (this is usually not acceptable) or provide more resources. For marginally higher work loads, one could place a more efficient resource in the place. This parameter attempts to match the component's efficiency rating to the expected work load. The simulation assumes a mean efficiency of 90 % with a standard deviation of 10 %.

- Task Complexity vs Component Ability. The simulation assumes Component Ability to be a function of IQ, experience, learning capabilities and problem solving ability. The higher the task complexity, the higher the required component ability. The simulation assumes a mean ability index of 120 with a standard deviation of 20.

- Team Cohesion vs Component Cohesion. The simulation assumes Component Cohesion to be a function of component values and EQ as these assist in determining a person's stance on acceptance, team work and conflict resolution. For extended project durations and difficult projects, a higher cohesion is required. The simulation assumes a mean cohesion index of 50 with a standard deviation of 20.

- Project Risk Factor vs Component Risk Tolerance. The simulation assumes a method of generation of risk profile. The component's risk tolerance should be matched to the project's risk factor. To see why this is the case: if the project risk factor is high and the component's risk tolerance is low a high amount of stress could demotivate the resource. On the other hand, if the project risk factor is low and the component's risk tolerance is high, a lack of 'adventure' may instill boredom and demotivate the component. In the author's opinion, it is better to match the component's risk tolerance with the project's risk factor. The simulation assumes a mean risk index of 50 with a standard deviation of 10.

- Rate / Hour. The expected rate / hour is indicative of what the company would be willing to pay for a given task. A person's rate is generally influenced by factors like ability, eduction, working experience, cohesion and value added to the organization. From a financial viewpoint, it would not be prudent to place a highly paid person in a job that requires a lower paid person as the increase in expenditure would be unmerited. Furthermore, if person's rate demands a certain characteristic composition, then possibly a lower paid individual may not perform to the same ability as a higher paid person may. The latter statement is admittedly riddled with assumption and error, and can quite easily be disproven in practice as many underpaid persons exhibit great performance when the opportunity arises. However, it is viable to assume that as a person's performance increase, so should his salary. The rate/hour is generated from an enumeration of best-guess averages and with a 20 % band around.

These parameters are each scored against a given optimization instruction and a percentage is obtained:

- Match: It is important to know the amount of deviation of the component's value from the required:

$$\text{paramFitness }\% = \left| 100 - 100 \times \left| \frac{required - component}{required} \right| \right| \tag{9.2}$$

- Maximize: The greater the component's value vs the required, the better the fit:

$$\text{paramFitness }\% = 100 + 100 \times \frac{component - required}{required} \tag{9.3}$$

- Minimize: The lesser the component's value vs the required, the better the fit:

$$\text{paramFitness }\% = \text{١٠٠} - \text{١٠٠} \times \frac{required - component}{required} \tag{9.4}$$

9.3.5 Description of Inputs to the Simulation

The following served as inputs to the simulations:

- Organization's analysis and definition as shown in Figure 9-2:

  The organizational definition is performed using a {Parameter Name, Parameter Value, Optimization Instruction to Apply} methodology. Names are to be strings, parameters are of type variant (but only numeric types are calculated – strings are ignored for optimization purposes) and the optimization instruction is string. The designation of the definition within the hierarchy is derived from the department number. This number is used to construct the hierarchy tree.

  Notice that the parameters used within the optimization are listed here as objectives to be met. An optimization instruction is also provided.

  The definition follows a top-down listing: the entire definition belongs solely to the organization.

- The component set's characteristic definitions (resource pool) as shown in Figure 9-3:

  Each resource in the pool has a unique identifier (resource number), a name, discipline and a number of analyzed parameters (characteristics). The discipline link the resource to a sub-department. The parameters are used as optimization indices.

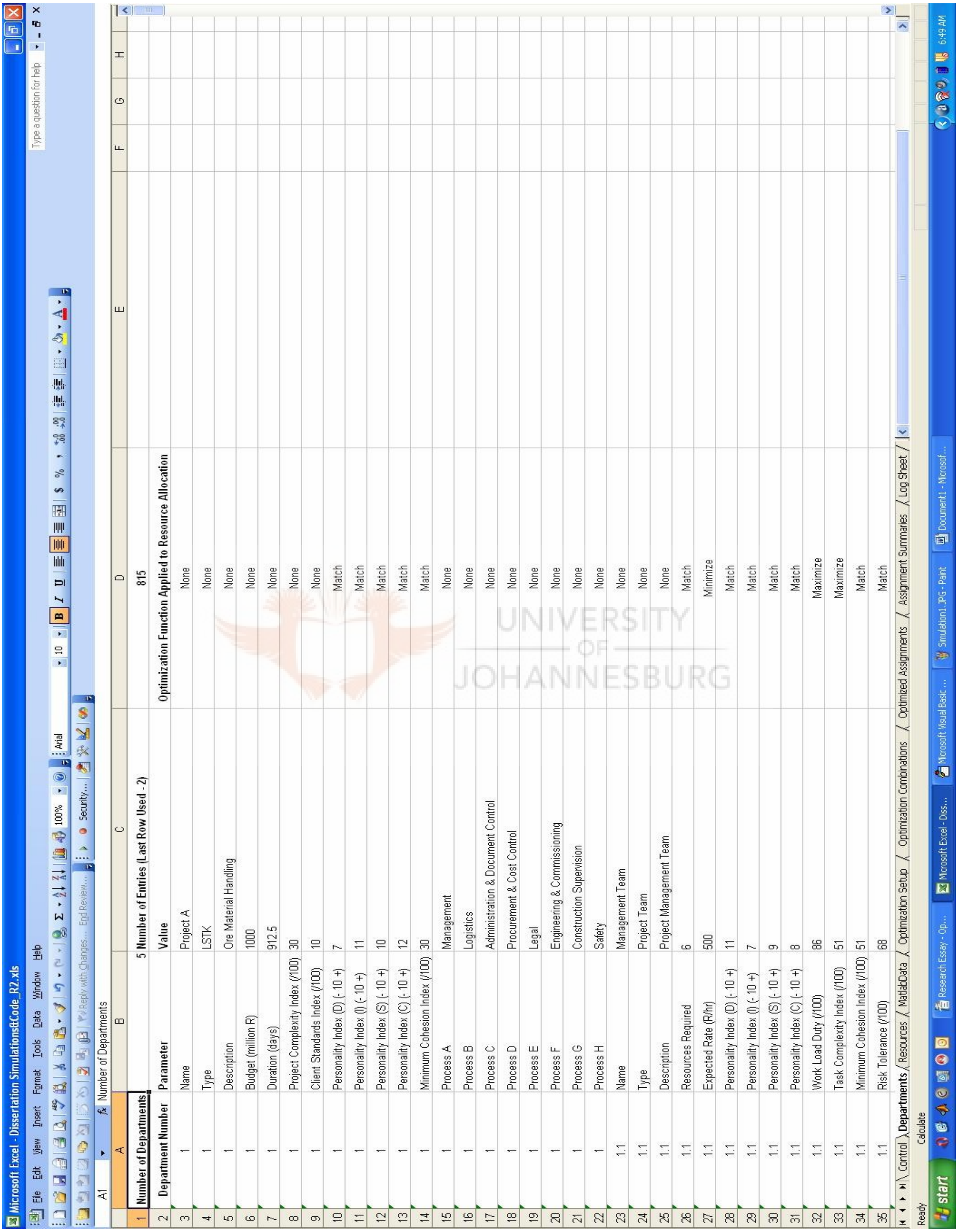
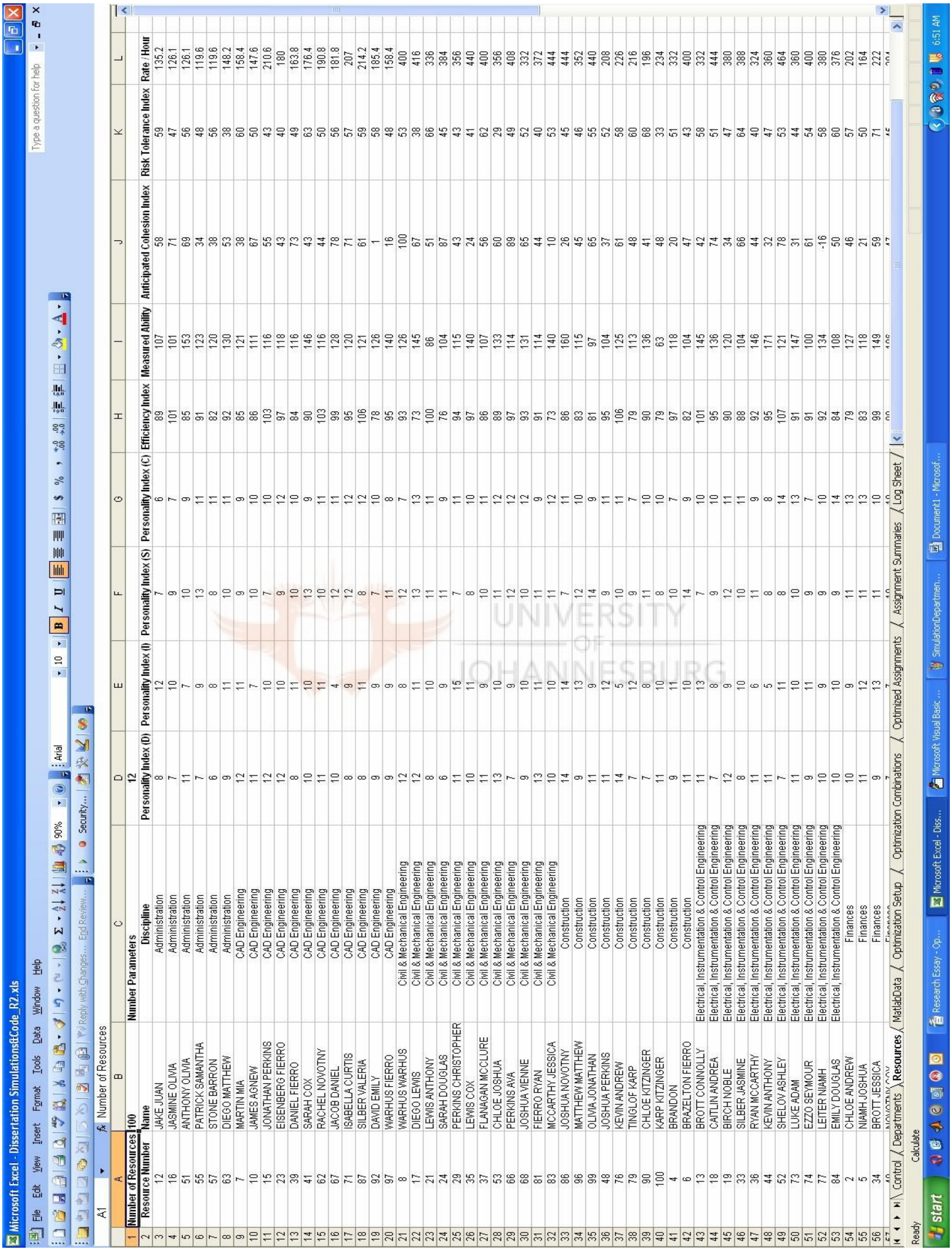


Figure 9-2: Organization's Analysis and Definition



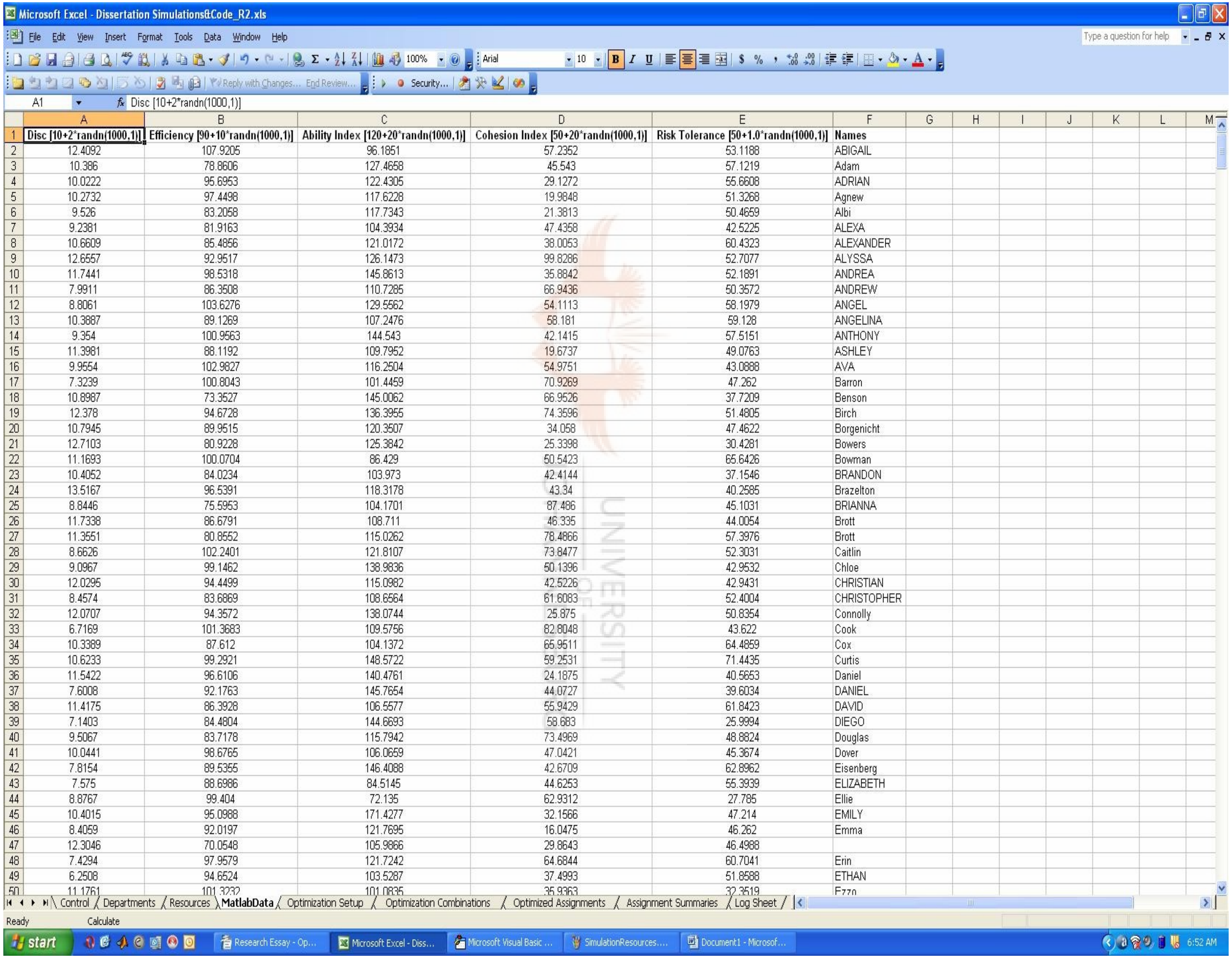
Number of Resources	100	Number Parameters	12								
Resource Number	Name	Discipline	Personality Index (D)	Personality Index (I)	Personality Index (S)	Personality Index (C)	Efficiency Index	Measured Ability	Anticipated Cohesion Index	Risk Tolerance Index	Rate / Hour
12	JAKE JUAN	Administration	8	12	7	6	89	107	58	59	135.2
16	JASMINE OLIVIA	Administration	7	10	9	7	101	101	71	47	126.1
51	ANTHONY OLIVIA	Administration	11	7	10	9	85	153	69	56	126.1
55	PATRICK SAMANTHA	Administration	7	9	13	11	91	123	34	48	119.6
57	STONE BARRON	Administration	6	8	8	11	82	120	38	56	119.6
63	DIEGO MATTHEW	Administration	9	11	10	11	92	130	53	38	148.2
7	MARTIN MIA	CAD Engineering	12	11	9	9	85	121	38	60	158.4
10	JAMES AGNEW	CAD Engineering	11	7	10	10	86	111	67	50	147.6
15	JONATHAN PERKINS	CAD Engineering	12	10	7	10	103	116	55	43	210.6
23	EISENBERG FIERRO	CAD Engineering	12	10	9	12	97	118	43	40	180
39	DANIEL FIERRO	CAD Engineering	8	11	10	10	84	116	73	49	163.8
41	SARAH COX	CAD Engineering	10	10	13	9	90	146	43	63	176.4
62	RACHEL NOVOTNY	CAD Engineering	11	11	10	11	103	116	44	50	190.8
67	JACOB DANIEL	CAD Engineering	10	4	12	11	99	128	78	56	181.8
71	ISABELLA CURTIS	CAD Engineering	8	9	12	12	95	120	71	57	207
87	SILBER VALERIA	CAD Engineering	8	11	8	12	106	121	61	59	214.2
92	DAVID EMILY	CAD Engineering	9	9	7	10	78	126	1	58	185.4
97	WARHUS FIERRO	CAD Engineering	9	9	11	8	95	140	16	48	158.4
8	WARHUS WARHUS	Civil & Mechanical Engineering	12	8	12	7	93	126	100	53	400
17	DIEGO LEWIS	Civil & Mechanical Engineering	12	11	13	13	73	145	67	38	416
21	LEWIS ANTHONY	Civil & Mechanical Engineering	8	10	11	11	100	86	51	66	336
24	SARAH DOUGLAS	Civil & Mechanical Engineering	6	9	11	9	76	104	87	45	384
29	PERKINS CHRISTOPHER	Civil & Mechanical Engineering	11	15	7	11	94	115	43	43	356
35	LEWIS COX	Civil & Mechanical Engineering	10	11	8	10	97	140	24	41	440
37	FLANAGAN MCCLURE	Civil & Mechanical Engineering	11	9	10	11	86	107	56	62	400
53	CHLOE JOSHUA	Civil & Mechanical Engineering	13	10	11	12	89	133	60	29	356
66	PERKINS AVA	Civil & Mechanical Engineering	7	9	12	12	97	114	89	49	408
68	JOSHUA VIENNE	Civil & Mechanical Engineering	9	10	10	12	93	131	65	52	332
81	FIERRO RYAN	Civil & Mechanical Engineering	13	11	11	9	91	114	44	40	372
83	MCCARTHY JESSICA	Civil & Mechanical Engineering	10	10	11	12	73	140	10	53	444
86	JOSHUA NOVOTNY	Construction	14	14	7	11	86	160	26	45	444
96	MATTHEW MATTHEW	Construction	9	13	12	10	83	115	45	46	352
99	OLIVIA JONATHAN	Construction	11	9	14	9	81	97	65	55	440
48	JOSHUA PERKINS	Construction	11	12	9	11	95	104	37	52	208
76	KEVIN ANDREW	Construction	14	5	10	11	106	125	61	58	226
79	TINGLOF KARP	Construction	7	12	9	7	79	113	48	60	216
90	CHLOE KITZINGER	Construction	7	8	11	10	90	136	41	68	196
100	KARP KITZINGER	Construction	11	10	8	10	79	63	48	33	234
4	BRANDON	Construction	9	11	10	7	97	118	20	51	332
6	BRAZELTON FIERRO	Construction	11	10	14	9	82	104	47	43	400
13	BROTT CONNOLLY	Electrical, Instrumentation & Control Engineering	11	13	7	10	101	145	42	58	332
18	CAITLIN ANDREA	Electrical, Instrumentation & Control Engineering	7	8	9	10	95	136	74	51	444
19	BIRCH NOBLE	Electrical, Instrumentation & Control Engineering	12	9	12	11	90	120	34	47	380
33	SILBER JASMINE	Electrical, Instrumentation & Control Engineering	8	10	10	11	88	104	66	64	388
36	RYAN MCCARTHY	Electrical, Instrumentation & Control Engineering	11	6	11	9	92	146	44	40	324
44	KEVIN ANTHONY	Electrical, Instrumentation & Control Engineering	11	5	8	8	95	171	32	47	360
52	SHELOV ASHLEY	Electrical, Instrumentation & Control Engineering	7	11	8	14	107	121	78	53	464
73	LUKE ADAM	Electrical, Instrumentation & Control Engineering	11	10	10	13	91	147	31	44	360
74	EZZO SEYMOUR	Electrical, Instrumentation & Control Engineering	9	11	9	7	91	100	61	54	400
77	LEITER NIAMH	Electrical, Instrumentation & Control Engineering	10	9	9	10	92	134	-16	58	380
84	EMILY DOUGLAS	Electrical, Instrumentation & Control Engineering	10	10	9	14	84	108	50	60	376
2	CHLOE ANDREW	Finances	10	9	11	13	79	127	46	57	202
5	NIAMH JOSHUA	Finances	11	12	11	13	83	118	21	50	164
34	BROTT JESSICA	Finances	9	13	11	10	99	149	59	71	222

Figure 9-3: Component set's characteristics. (Resource pool)

9.3.6 Generation of Simulation Parameters

The software allows for generation of parameters for simulation purposes. As has been stated, the organizational structure is constructed manually, but the parameter values can be assigned either manually or randomly. The resource pool can either be created manually or generated automatically.

To generate 'realistic' parameters, Matlab's ***randn*** function was used to elicit random values based on the Gaussian (Normal) distribution. Figure 9-4 shows this classification. The names list is used to generate names for the resources and was constructed from various listings on Google.



	A	B	C	D	E	F
1	Disc [10+2*randn(1000,1)]	Efficiency [90+10*randn(1000,1)]	Ability Index [120+20*randn(1000,1)]	Cohesion Index [50+20*randn(1000,1)]	Risk Tolerance [50+1.0*randn(1000,1)]	Names
2	12.4092	107.9205	96.1851	57.2352	53.1188	ABIGAIL
3	10.386	78.8606	127.4658	45.543	57.1219	Adam
4	10.0222	95.6953	122.4305	29.1272	55.6608	ADRIAN
5	10.2732	97.4498	117.6228	19.9848	51.3268	Agnew
6	9.526	83.2058	117.7343	21.3813	50.4659	Albi
7	9.2381	81.9163	104.3934	47.4358	42.5225	ALEXA
8	10.6609	85.4856	121.0172	38.0053	60.4323	ALEXANDER
9	12.6557	92.9517	126.1473	99.8286	52.7077	ALYSSA
10	11.7441	98.5318	145.8613	35.8842	52.1891	ANDREA
11	7.9911	86.3508	110.7285	66.9436	50.3572	ANDREW
12	8.8061	103.6276	129.5562	54.1113	58.1979	ANGEL
13	10.3887	89.1269	107.2476	58.181	59.128	ANGELINA
14	9.354	100.9563	144.543	42.1415	57.5151	ANTHONY
15	11.3981	88.1192	109.7952	19.6737	49.0763	ASHLEY
16	9.9554	102.9827	116.2504	54.9751	43.0888	AVA
17	7.3239	100.8043	101.4459	70.9269	47.262	Barron
18	10.8987	73.3527	145.0062	66.9526	37.7209	Benson
19	12.378	94.6728	136.3955	74.3596	51.4805	Birch
20	10.7945	89.9515	120.3507	34.058	47.4622	Borgenicht
21	12.7103	80.9228	125.3842	25.3398	30.4281	Bowers
22	11.1693	100.0704	86.429	50.5423	65.6426	Bowman
23	10.4052	84.0234	103.973	42.4144	37.1546	BRANDON
24	13.5167	96.5391	118.3178	43.34	40.2585	Brazelton
25	8.8446	75.5953	104.1701	87.486	45.1031	BRIANNA
26	11.7338	86.6791	108.711	46.335	44.0054	Brott
27	11.3551	80.8552	115.0262	78.4866	57.3976	Brott
28	8.6626	102.2401	121.8107	73.8477	52.3031	Caitlin
29	9.0967	99.1462	138.9836	50.1396	42.9532	Chloe
30	12.0295	94.4499	115.0982	42.5226	42.9431	CHRISTIAN
31	8.4574	83.6869	108.6564	61.6083	52.4004	CHRISTOPHER
32	12.0707	94.3572	138.0744	25.875	50.8354	Connolly
33	6.7169	101.3683	109.5756	82.8048	43.622	Cook
34	10.3389	87.612	104.1372	65.9511	64.4859	Cox
35	10.6233	99.2921	148.5722	59.2531	71.4435	Curtis
36	11.5422	96.6106	140.4761	24.1875	40.5653	Daniel
37	7.6008	92.1763	145.7654	44.0727	39.6034	DANIEL
38	11.4175	86.3928	106.5577	55.9429	61.8423	DAVID
39	7.1403	84.4804	144.6693	58.683	25.9994	DIEGO
40	9.5067	83.7178	115.7942	73.4969	48.8824	Douglas
41	10.0441	98.6765	106.0659	47.0421	45.3674	Dover
42	7.8154	89.5355	146.4088	42.6709	62.8962	Eisenberg
43	7.575	88.6986	84.5145	44.6253	55.3939	ELIZABETH
44	8.8767	99.404	72.135	62.9312	27.785	Ellie
45	10.4015	95.0988	171.4277	32.1566	47.214	EMILY
46	8.4059	92.0197	121.7695	16.0475	46.262	Emma
47	12.3046	70.0548	105.9866	29.8643	46.4988	
48	7.4294	97.9579	121.7242	64.6844	60.7041	Erin
49	6.2508	94.6524	103.5287	37.4993	51.8588	ETHAN
50	11.1761	101.3232	101.0835	35.9363	32.3519	Ezzo

*Figure 9-4: Random data derived from Matlab's **randn function***

The following descriptions provide information about the generated data:

- DISC Rating: Mean = 10, Std. Dev. = 2; [10 + 2 * randn (1000, 1)]

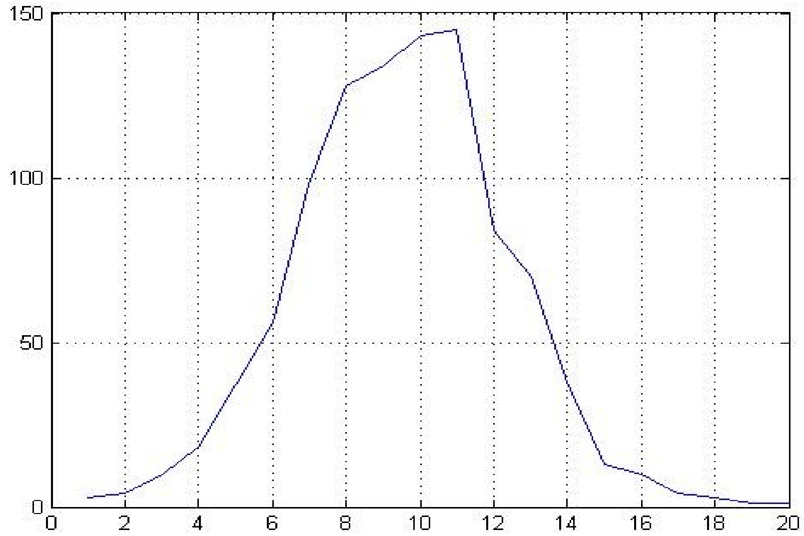


Figure 9-5: DISC Profile Distribution

- Efficiency Rating: Mean = 90, Std. Dev. = 10; [90 + 10 * randn(1000,1)]

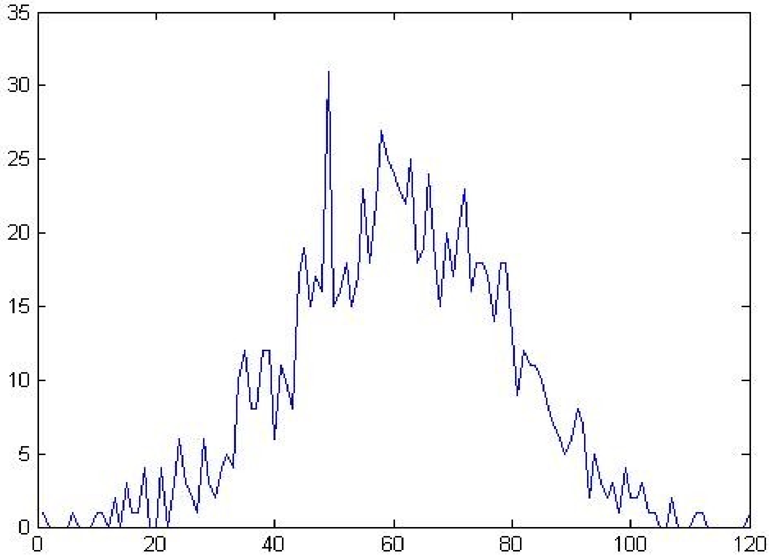


Figure 9-6: Efficiency Profile Distribution

- Ability Index: Mean = 120, Std. Dev. = 20; [120 + 20 * randn(1000,1)]

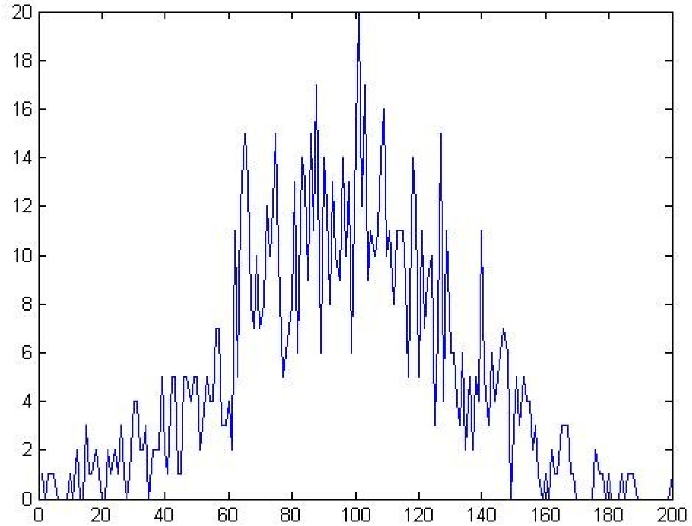


Figure 9-7: Ability Profile Distribution

- Cohesion Index: Mean = 50, Std. Dev. = 20; [50 + 20 * randn(1000, 1)]

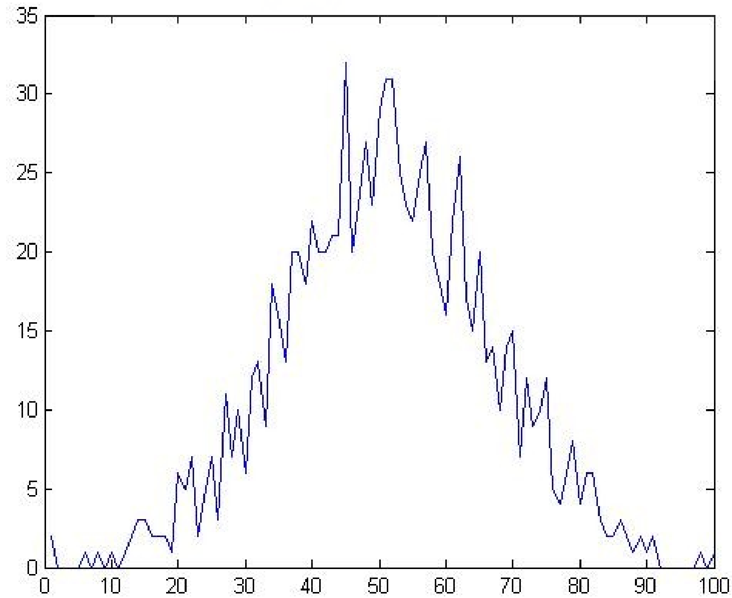


Figure 9-8: Cohesion Profile Distribution

- Risk Tolerance: Mean = 50, Std. Dev. = 10; [50 + 10 * randn(1000, 1)]

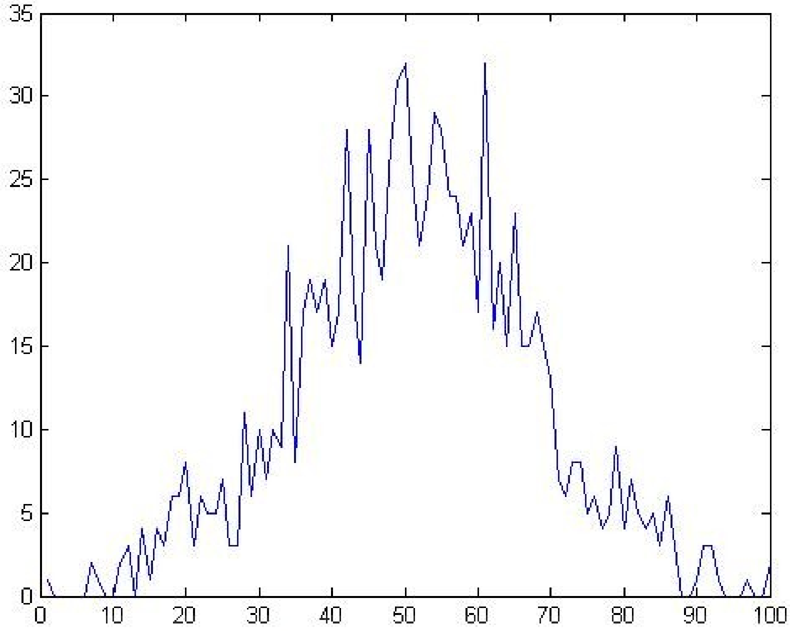


Figure 9-9: Risk Profile Distribution

9.3.7 Execution of Simulation

Once the simulated inputs have been setup (and random sets generated where required), the simulation can be executed. (The 'Control Panel') can be used for all these tasks.

The simulation executes the following steps:

1. Clears previous results.
2. Analyzes organization's structure and creates a software structural definition of the organization.
3. Analyzes the resource pool and creates a software structural definition of the resource pool.
4. Calls the recursive and re-iterative optimization function detailed in section 7.4. The function call passes the organization and resource pool to the function. For each department within the organization the function calls itself to optimize the department. To optimize the department, the function first calls itself to optimize each sub-department within the department.
5. Each sub-department and the resource pool is passed to an 'Optimal Assignment' function.
6. The sub-department's discipline is determined and the resource pool is filtered to yield only resources from the same discipline.
7. If k is the number of resources required by the sub-department and n is the number of resources in the filtered resource pool, then all possible solutions becomes a problem of selecting k out of n elements. The number of possible solutions is given from the combinations† formula in combinatorics:

$$n\_C\_k = \frac{n!}{k!(n-k)!} \tag{9.5}$$

8. Once these n_C_k possibilities are generated, each possible solution is passed to a fitness test function. Within the fitness test function, each parameter (characteristic) of each

† It is important to note that I haven't used the permutation formula for the simple reason: Assignment of resources ABC is the same as BCA which is the same as CAB, etc. This means that the order is unimportant and we want unique resource assignment each time. Solving all permutation using n_P_k is also possible, but would greatly increase execution time and would also provide many results with exactly the same score as duplicate possible solutions would exist.

resource is scored against the sub-department's resource requirements. The resource scores are then averaged per possible solution and the fitness score is stored. Once the solution's average score per parameter is obtained, equation (9.1) is used to provide the solution's final score.

9. When each possible solution set has been scored, the highest score is selected as the winner and these resources are assigned to the sub-department.

10. Once the assignment has taken place, the functions return to the recursive optimization algorithm and the next sub-department is optimized.

11. When all sub-departments have been optimized, call is returned to the department and the next department is optimized in like manner until all departments within the organization have been optimized.

9.3.8 Discussion of Simulation Outputs

The simulation outputs are provided in Figures 9-10 and 9-11.

Figure 9-10 details the Optimization Combination and each combination's fitness score. The chosen combination per sub-department is highlighted in green and made bold (not shown in the figure).

Figure 9-11 details the assignment of resources to sub-departments and provides a horizontally aligned hierarchy.

The following is important to note:

- The assignments are based on the best match of resources to sub-department given the parameteric fitness requirements. This means that after the highest score is obtained, the first resource solution in the filtered pool which matches the score is assigned. This could result in the over-assignment of resources depending on scenarios. Section 9.3.10 details work-arounds for this.
- If k exceeds n while evaluating equation (9.5), the optimization algorithm is not performed as it is not possible to choose the elements from the resource pool (there are not enough elements therein). The assignments will indicate [0] in at the relevant sub-department.
- Where no conflict of assignment exists, the optimal solution has been found. The next step forward would be to apply the results to the organization (in the case of the simulation, it is a virtual organization) and measure performance of organizational objectives (profitability, sustained growth, component motivation, etc). The performance can be used to evolve the fitness functions or the optimization parameters.

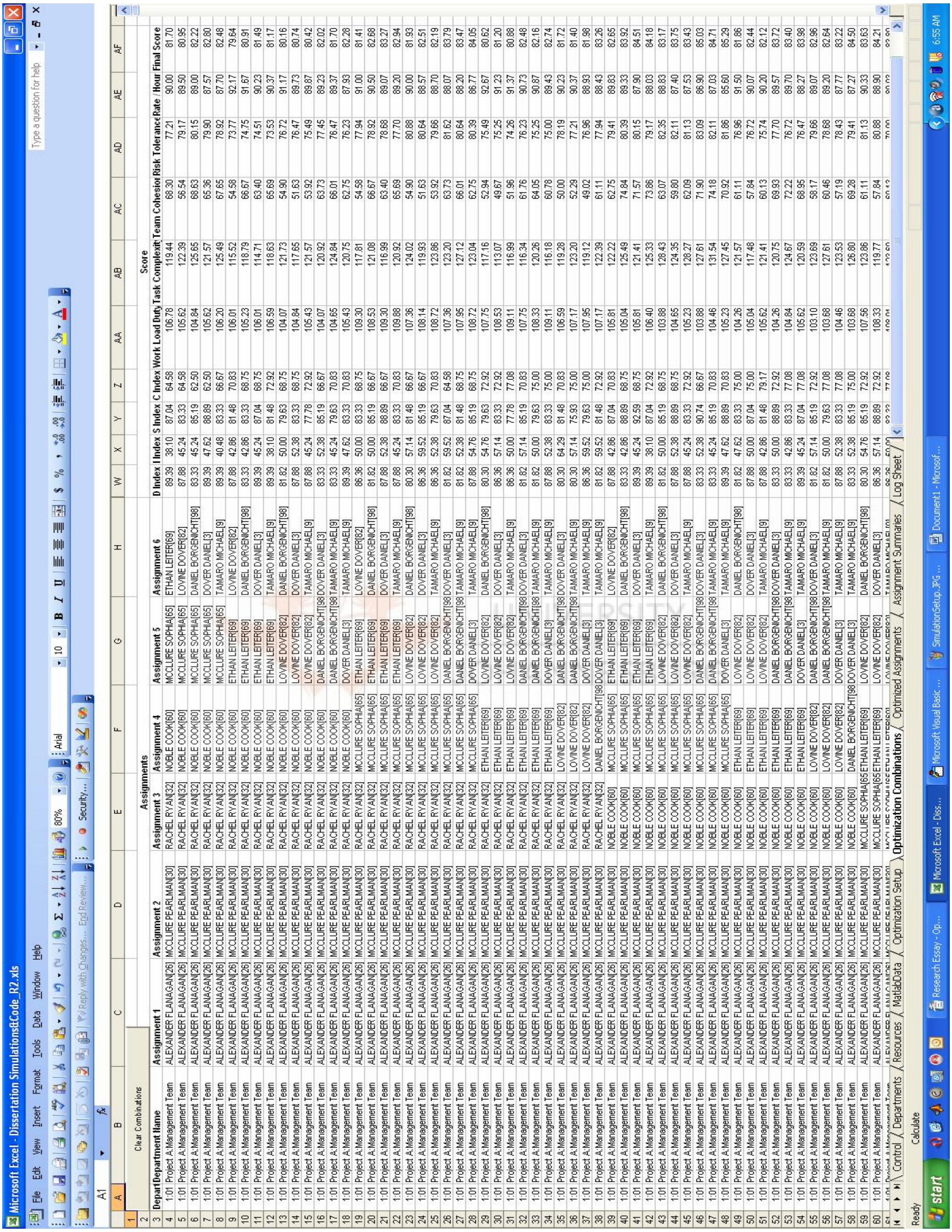


Figure 9-10: Possible Assignment Combinations and Fitness Scores

Figure 9-12 provides useful summary information about assignments. Resources with a 0 count have not been assigned. If resources are assigned to more than 1 sub-department (project team) they are over-assigned, which may or may not be correct based on the project demands. If the organization requires more resources than that which is in the resource pool, resources will be over-assigned.

	Department	Sub Department	Resource 1	Resource 2	Resource 3	Resource 4	Resource 5	Resource 6	Resource 7
2	Project A								
3		Management Team	ALEXANDER FLANAGAN [26]	MCCLURE SOPHIA [65]	ETHAN LEITER [69]	DANIEL BORGENICHT [98]	DOVER DANIEL [3]	TAMARO MICHAEL [9]	
4		Logistics Team	LEWIS NOVOTNY [61]	EISENBERG REISS [64]	KEVIN PEARLMAN [1]				
5		Administration Team	JAKE JUAN [12]	ANTHONY OLIVIA [51]	DIEGO MATTHEW [63]				
6		Finances Team	CHLOE ANDREW [2]	NIAMH JOSHUA [5]	BROTT JESSICA [34]	COX ISABELLA [72]	JOSEPH JONATHAN [75]		
7		Legal Team	JUAN MICHAEL [28]	EMILY BRAZELTON [43]	DIEGO ANDREA [50]	ANDREW JACOB [80]	LUKE JAMIE [88]		
8		Process Engineering Team	LEWIS MALMSTROM [11]	BOWMAN ANDREA [27]	NATHAN FIERRO [78]				
9		Civil & Mechanical Engineering Team	PERKINS CHRISTOPHER [29]	LEWIS COX [35]					
10		Electrical, Instrumentation & Control Engineering Team	BROTT CONNOLLY [13]	CAITLIN ANDREA [18]	RYAN MCCARTHY [36]	KEVIN ANTHONY [44]	EZZO SEYMOUR [74]		
11		CAD Engineering Team	JONATHAN PERKINS [15]	EISENBERG FIERRO [23]	SARAH COX [41]	RACHEL NOVOTNY [62]	WARHUS FIERRO [97]		
12		Construction Supervision	MATTHEW MATTHEW [96]	OLIVIA JONATHAN [99]	KEVIN ANDREW [76]	CHLOE KITZINGER [90]	BRANDON [4]	BRAZELTON FIERRO [6]	
13		Safety Team	MALMSTROM ABIGAIL [93]	JOSEPH JESSICA [91]					
14	Project B								
15		Management Team	MCCLURE SOPHIA [65]	DANIEL BORGENICHT [98]	TAMARO MICHAEL [9]				
16		Logistics Team	LEWIS NOVOTNY [61]	EISENBERG REISS [64]	NATALIE STAFFORD [70]				
17		Administration Team	JAKE JUAN [12]	ANTHONY OLIVIA [51]	PATRICK SAMANTHA [55]	DIEGO MATTHEW [63]			
18		Finances Team	BROTT JESSICA [34]	NOVOTNY COX [40]	KEVIN OLIVIA [56]	COX ISABELLA [72]	BRANDON CAITLIN [85]		
19		Legal Team	EMMA ELIZABETH [14]	JUAN MICHAEL [28]	EMILY BRAZELTON [43]	DIEGO ANDREA [50]	ANDREW JACOB [80]	LUKE JAMIE [88]	
20		Process Engineering Team	LEWIS MALMSTROM [11]	BOWMAN ANDREA [27]	BOWERS COOK [31]	NATHAN FIERRO [78]			
21		Civil & Mechanical Engineering Team	WARHUS WARHUS [8]	LEWIS COX [35]	CHLOE JOSHUA [53]	FIERRO RYAN [81]			
22		Electrical, Instrumentation & Control Engineering Team	CAITLIN ANDREA [18]	SHELOV ASHLEY [52]	LUKE ADAM [73]				
23		CAD Engineering Team	SARAH COX [41]						
24		Construction Supervision Team	KEVIN ANDREW [76]						
25		Safety Team	MALMSTROM ABIGAIL [93]	ELIZABETH PATRICK [95]	GUILIANO WOLF [45]	JOSHUA ISABELLA [89]	MATTHEW ANDREA [94]		
26	Project C								
27		Management Team	ETHAN LEITER [69]	DANIEL BORGENICHT [98]	TAMARO MICHAEL [9]				
28		Logistics Team	LANSKY [25]	LEWIS NOVOTNY [61]	EISENBERG REISS [64]	NATALIE STAFFORD [70]	KEVIN PEARLMAN [1]		
29		Administration Team	JASMINE OLIVIA [16]	ANTHONY OLIVIA [51]	PATRICK SAMANTHA [55]	STONE BARRON [57]	DIEGO MATTHEW [63]		
30		Finances Team	CHLOE ANDREW [2]	BROTT JESSICA [34]	JOSEPH JONATHAN [75]				
31		Legal Team	JUAN MICHAEL [28]	DIEGO ANDREA [50]	LUKE JAMIE [88]				
32		Process Engineering Team	LEWIS MALMSTROM [11]						
33		Civil & Mechanical Engineering Team	WARHUS WARHUS [8]	LEWIS COX [35]	PERKINS AVA [66]	FIERRO RYAN [81]			
34		Electrical, Instrumentation & Control Engineering Team	CAITLIN ANDREA [18]	BIRCH NOBLE [19]	RYAN MCCARTHY [36]	LUKE ADAM [73]	EMILY DOUGLAS [84]		
35		CAD Engineering Team	SARAH COX [41]	SILBER VALERIA [87]					
36		Construction Supervision	JOSHUA NOVOTNY [86]	MATTHEW MATTHEW [96]	OLIVIA JONATHAN [99]	JOSHUA PERKINS [48]	KEVIN ANDREW [76]	BRANDON [4]	
37		Safety Team	MALMSTROM ABIGAIL [93]	ELIZABETH PATRICK [95]	JOSE REISS [42]				
38	Project D								
39		Management Team	NOBLE COOK [60]	MCCLURE SOPHIA [65]	ETHAN LEITER [69]	TAMARO MICHAEL [9]			
40		Logistics Team	LANSKY [25]	DOUGLAS [46]	LEWIS NOVOTNY [61]	EISENBERG REISS [64]	NATALIE STAFFORD [70]	KEVIN PEARLMAN [1]	
41		Administration Team	JASMINE OLIVIA [16]	ANTHONY OLIVIA [51]	PATRICK SAMANTHA [55]	STONE BARRON [57]	DIEGO MATTHEW [63]		
42		Finances Team	CHLOE ANDREW [2]	BROTT JESSICA [34]	NOVOTNY COX [40]	KEVIN OLIVIA [56]	COX ISABELLA [72]	JOSEPH JONATHAN [75]	
43		Legal Team	JUAN MICHAEL [28]	EMILY BRAZELTON [43]	DIEGO ANDREA [50]	ANDREW JACOB [80]	LUKE JAMIE [88]		
44		Process Engineering Team	LEWIS MALMSTROM [11]	NATALIE BOWMAN [22]	BOWMAN ANDREA [27]	BORGENICHT ALEXA [49]	RYAN GUILIANO [54]	NATHAN FIERRO [78]	
45		Civil & Mechanical Engineering Team	SARAH DOUGLAS [24]	PERKINS CHRISTOPHER [29]	LEWIS COX [35]	CHLOE JOSHUA [53]	JOSHUA VIENNE [68]	FIERRO RYAN [81]	
46		Electrical, Instrumentation & Control Engineering Team	BROTT CONNOLLY [13]	RYAN MCCARTHY [36]	KEVIN ANTHONY [44]	LUKE ADAM [73]	LEITER NIAMH [77]		
47		CAD Engineering Team	JACOB DANIEL [67]	ISABELLA CURTIS [71]					
48		Construction Supervision	CHLOE KITZINGER [90]	KARP KITZINGER [100]	BRAZELTON FIERRO [6]				
49		Safety Team	MALMSTROM ABIGAIL [93]	ELIZABETH PATRICK [95]	JOSHUA ISABELLA [89]	MATTHEW ANDREA [94]			
50	Project E								

Figure 9-11: Final Assignment of Resources to Sub-Departments

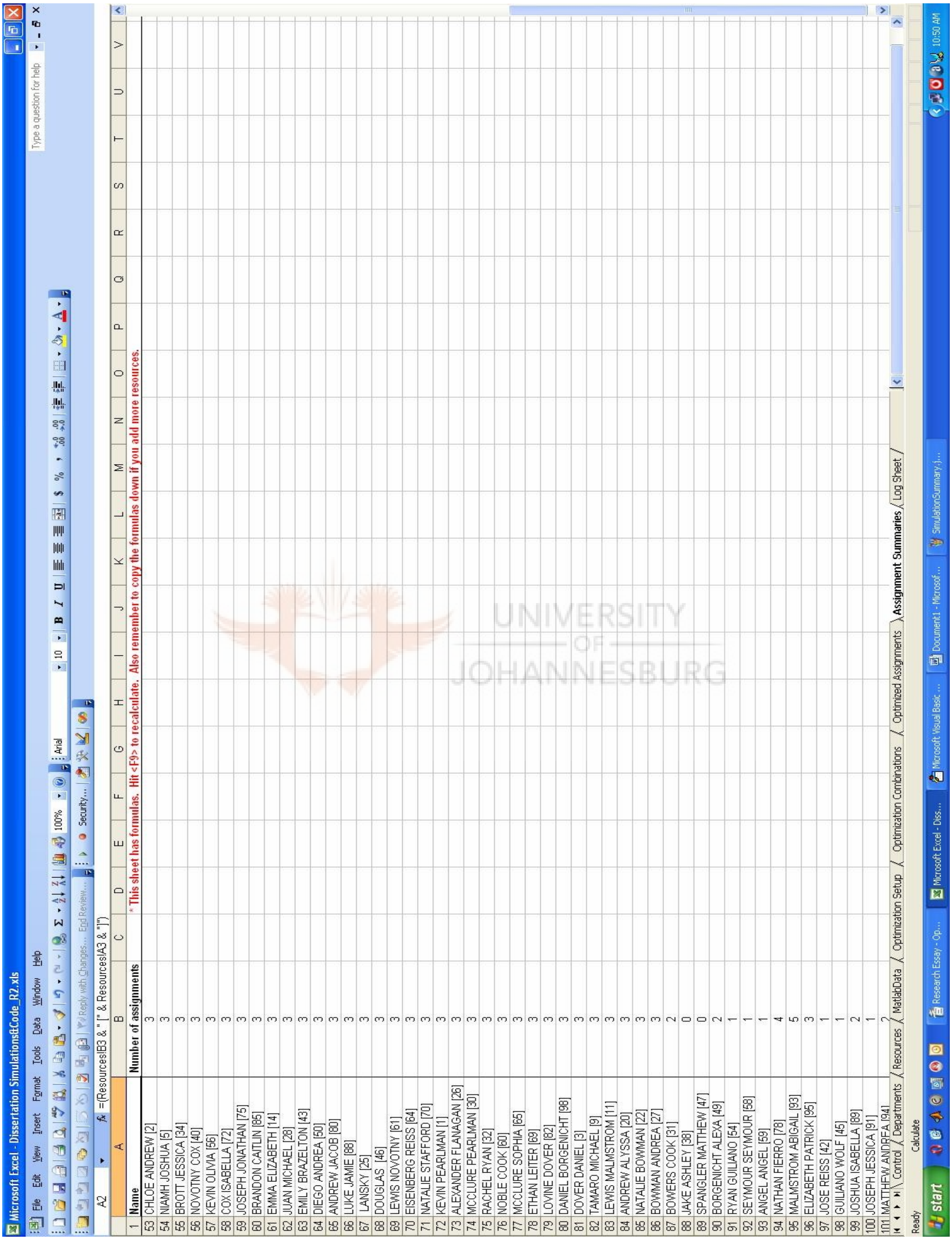


Figure 9-12: Assignment Summaries

9.3.9 Discussion of VBA Restrictions

For future development, the author does not recommend using VBA for the following reasons:

- The combinatorial algorithm was a recursive algorithm which offered great difficulty as VBA does not natively support complex data structures outside of UDTs. Attempts to use collections demanded the instantiation of object oriented directives which would deviate substantially from the then current programming style. To circumvent this problem, I used arrays and performed the extra accounting of manipulating the arrays' indices to achieve the required results.
- VBA does not allow UDT types (structs) to reference themselves (for example in a linked list or a recursive definition). To see where this is required: Assume organization S has Department S_1 with Sub-Department S_{11} and Sub-Sub-Department S_{111}. The structures of S_1, S_{11} and S_{111} are all the same if well-defined, but the parameters differ. To see that this is the case, if viewing (recurring) on the level of the Department, S_1 looks like the organization, S_{11} looks like the department and S_{111} looks like the Sub-Department. If viewing (recurring) on the level of the Sub-Department, S_{11} looks like the organization and S_{111} looks like the Department. A recursive definition should allow for a reference to the same data type while holding the hierarchical structure in memory. To circumvent this problem, I created UDT's with different names but the same structure.
- VBA does not allow passing of late-bound types to functions. This means that when declaring a function, if any of the parameters that is to be passed to the function is a UDT it must be declared at compile-time and cannot be mutated during run-time. This posed a big problem with the recursive nature of the optimization algorithm defined in section 7. The algorithm should take a type Variant, determine the data Type and the execute a function based on the given data Type. (For example, one should be able to pass an organization, a department, a sub-department, etc. to the recursive optimization function and the function should be able to change its behaviour based on the type of the input). To circumvent this problem, I split the optimization function into its iterative components and strong-typed the input parameters.

9.3.10 Simulation Conclusion and Recommendations for Improvement

The simulation software was implemented to prove the concepts defined within this dissertation, particularly those stated in Chapter 7. The results and assignments bear testimony to the success of the concept. An organization with 5 departments (each with its own sub-departments) and a resource pool of 100 employees was generated and passed through the optimization algorithm. All possible assignments of resources to sub-departments were generated and scored against the fitness function. The optimal solution was assigned to the sub-department.

The software is by no means in its final form and the following improvements suggest avenues for future work:

- Convert the software to a more flexible software environment like C or the .Net environment.
- Consider using object oriented programming principles. This may slow down performance but will allow for easier manipulation of the software.
- Allow dynamic linked resource – sub-department parameter fitness checking against the user's fitness function.
- To overcome over-allocated resources the following actions could take place:
    - Manual assignment of over-allocated resources. Chapter 7 comments about detuning a sub-department to achieve optimization within the organization. This may need to be considered if work loads are particularly high. Detuned assignments may require optimally tuned assignment to mentor inexperienced resources which ultimately allows for organizational growth.
    - To solve the problem automatically, one could perform a number of tasks:
        - As each optimal solution set is assigned to a sub-department, the resources can be removed from the available resource pool. This may lead to starvation of resources for departments being analyzed later. To mitigate this effect, one could implement a priority rating and optimize the departments with the highest priority first, but this may still lead to starvation of resources on lower priority ratings; this would then

cause a them to elevate in priority as the deadline approaches and may case the assignment criteria to become unstable and begin with oscillatory assignment behaviour.

- One could also isolate all sub-departments that require the same resource on an organization-wide basis and determine the optimized assignments. This would mimic the manual behaviour above, but would become extremely programmatically intensive.
- If time is not as critical, the organization could look outside to gain resources to complement its resource pool. This allows for guided growth of the organization.

9.4 Chapter Conclusion

In this chapter, a case study was presented where an organization implicitly uses the methodologies of systems theory and total system control and optimization to determine the most efficient and effective system parameters. A snap shot of the as-is status of DRA was provided.

DRA Mineral Projects is an international organization which was founded in South Africa in 1984 and has written a success story in which the execution of effective engineering management principles have allowed for the achievement of organizational goals and objectives, and many happy clients. The workforce that is just short of seven hundred strong places high responsibility and trust in the capabilities of the DRA directorate. Through the last 24 years of DRA's existence, it has seen many changes and weathered many storms, and has exhibited high levels of negative entropy. Given the organization's ability to adapt to its surroundings and tolerate disturbances in the environment and within the system, the optimal systemic parameters allow for the achievement of efficient steady-state operation and a high probability of survival.

The process of optimizing DRA Mineral Projects as an organization is one which requires careful planning, experience, expert knowledge and total commitment on the part of the directorate and the success of the organization bears witness to this achievement.

The structures of DRA was used as a model for generation of a software that allows the simulation of assignment of resources to project houses. The results of a genetic-algorithm-based simulation was then presented. The algorithms were run on generated data to prove the methodology of automated assignment of resources.

For future work, actual DRA (or other) data needs to be gathered, fed into the model and then compared with the human-based and logical assignments. The model might need to be evolved to achieve a more accurate depiction of the system. Thereafter, the assignments can be enacted, and the fit of the model can be determined.

CHAPTER TEN: CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

Chapter Outline

Chapter Overview

This chapter brings this research to its conclusion. A summary is provided of the information within this text and recommendations for future work in this field are also discussed.

10.1 Conclusion

Within the global environment exists the organizational space in which all organizations exist and interact. When the global environment is in equilibrium, the nature of organizational space is to provide nourishment to each organization it contains, thus allowing for the sometimes slack operation of the organization. However, disturbances introduce dynamic variations within the global climate of the environment and organizational space, thus placing an ever increasing pressure on organizations to optimize their operations in order to survive and preserve life. The organizational optimization requires a more efficient utilization of resources (which leads to the minimization of the probability of depletion of environmental resources) and energy to produce outputs of a consistently high quality and minimize the production of waste.

By articulating the hybridization of the disciplines of engineering and management, one is left with the view that the successful engineering manager is one who has been equipped to comprehend an organization in its totality: from the human, financial, administrative and communication aspects to the technical, production, development, logistic and maintenance aspects. It is this comprehension of the system which allows for the systemic optimization to be a natural byproduct of an engineering manager's education; for it is in seeing the forest together with every tree therein that one appreciates the complexity of attempting to fully optimize a system's operation.

This said, the field of General Systems Theory allows an organization to be perceived as a system: each system comprises of a set of sub-systems which in turn comprise of a set of sub-...-sub-systems. By perceiving each sub-...-system to be a system within the environment of its parent, one is able to generically define any of these systems as being one which takes a set of inputs and transforms them into a set of outputs through a set of processes. The set of components are those elements of which the system comprises, and each component is fitted with a set of characteristics. Inputs include all resources that go into any of the processes, such as raw materials, energy, time knowledge, and information. The output set is any of the finished products from the processes, such as a finished design, a report, the payment of wages, a commissioned processing plant, an iron, etc. and the waste products which are purged back into the environment. The component set includes the accumulation of all entities, both physical and abstract that belong to the system.

These could range from humans to finances to knowledge to historical data. Each of the components can be fully described by determining the unique parameters of its characteristic set.

In viewing the organization as an open system, one identifies the close relationship between the system and its environment. One also needs to consider the inter- and intra- system relationships and interferences which occur by event or nature. An organization can be classified as a system through the definition of a few characteristics: the importation of energy; throughput; outputs; the cyclic occurrence of systemic events; negative entropy; information and feedback; systemic steady state operation and dynamic homeostasis; differentiation; integration and coordination; and equifinality.

One of the systemic components exhibits non-linear and sometimes non-causal behaviour which creates complexities within the model of the system, and thus merits special discussion. The human component is one which is characterized by a number of factors. This research postulates that human behaviour results from the effects of the following factors: physiological makeup, personality profile, intelligence quotient, emotional profile, motivators and the value system. However, due to the non-linear behaviour of humans, it is difficult to predict the behaviour to a given stimulus at any given time as any one of the factors listed above could vary. One could at best attribute a probability to the behaviour that the human would exhibit in response to any given stimuli. In the management of human beings, it is important to take into consideration the operating environment, as factors that fall outside the preferred operational ranges could possibly induce unmerited behaviour, depending on the value system.

Various mathematical techniques exist in system modeling and optimization. These include, but are not limited to, the fields of linear and non-linear programming, genetic algorithms, statistics and stochastics, and applications from set theory which allow for 'batch' processing.

The global environment is not an infinite source of raw materials. Nor can it contain an infinite amount of waste materials. In response to systemic interactions, the environment is self-modulating and thus forces systems to adapt and optimize in order to survive. The case of optimization is a somewhat complex process as it requires the accurate modeling of the system prior to selection of appropriate optimization techniques.

In order to optimize a system, one needs to define the optimizing or fitness function against which the optimized solution will be measured. The fitness function can be constructed by evaluating the organizational objectives and measurables. Systemic optimization requires an iterative and recursive approach, and a pseudo-algorithm was provided which should allow for the holistic system and sub-...-system optimization with each level being optimized according to its own optimization function.

Once a suitable solution is found, careful planning and evaluation should be effected before the solution is realized. As part of the evaluation, the effects on production, change management, risk of implementation, risk mitigation plans and parameter monitoring plans need to be put in place. Before parameterizing the system with the new solution, a snapshot of the as-is state of the system should be taken for backup purposes – this will allow for a rollback to original system steady-state operation should the solution present itself as non-optimal. After effecting the system-wide parameterization, the chosen sampling points should be carefully monitored and the system performance and progress constantly evaluated until the system reaches steady-state operation. Thereafter, the system's performance is monitored on a long term basis until verification of optimal system performance is obtained. The newly parameterized system should be contrasted with the snapshot that was taken to ascertain the achievement of positive progress in the optimization process. Thereafter an optimized system can be handed over.

Finally, this research provided in a case study a snap-shot of the as-is status of DRA Mineral Projects: an internationally acclaimed project engineering and management organization that was founded in South Africa in 1984. Due to the nature of operation, DRA offers services and solutions as opposed to products, and as such, humans are its greatest assets. The perception of DRA as a system is inherent and the system optimization is performed in a recursive and reiterative manner. The DRA Mineral Projects success story bears witness to the application of general systems theory and total systems control and optimization philosophies in practice. A second case study was presented where the statutes of assignments of resources at DRA Mineral Projects was used to develop software that allowed a genetic-algorithmic modeling of these assignments. Simulations were run and the simulations were discussed. Due to the sensitivity of information and time restrictions, the algorithm was not run on actual data.

An academic seeks to remain a scholar even after the successful completion of his studies. The successful scholar is not one who worships his teacher's theory, but one who questions it. As inquiring, innovative and resourceful engineering managers, it is necessary that the knowledge and skills that were imparted through experience and academic training be utilized to positively influence the environment in which they interact. It is true that in an organizational environment, the risks may be higher, the system may be more complex and responsibility will be more personal, but the aspiring engineering manager will achieve success through the careful and calculated application of the principles and skills that were bestowed upon him or her.

If the world as we know it holds organizational space as one of its facets, then the global system is at the mercy of the operations of each organization and the effective operation of organizational space demands the efficient operation of every system within that space thus allowing for the formation of symbiotic inter-system relationships and the mutual survival of all systems within the space.

10.2 Recommendations for Future Work

A prospective extension of this work would be the execution of a number of case studies using the principles and theory detailed in this research. The formal application of the optimization pseudo-algorithm will allow for the practical verification of success, and the further formalization of structuring of organizational modeling and optimization together with the development of the mathematics and science behind it can be considered.

The software should also be extended as detailed in Chapter 9.3.10:

- Convert the software to a more flexible software environment like C or the .Net environment.
- Consider using object oriented programming principles. This may slow down performance but will allow for easier manipulation of the software.
- Allow dynamic linked resource – sub-department parameter fitness checking against the user's fitness function.
- Overcome the challenge of over-allocated resources.
- Provide graphical summary information.

This dissertation provided a theoretical approach to the existential proof of the recursive and reiterative optimization algorithm. The practicalities hereof need to be determined: An organization needs to be analyzed and the results fed into the algorithm. The optimized assignments should then be enacted within the organization and the models elaborated upon. During the practical approach, the test procedures of Chapter 8 should be borne in mind.

This dissertation opens ideas for further research in the following fields:

- The development of a statistical (particularly stochastic) will help with the determination of probability of optimization success with time.
- Only optimized assignments were considered in the case study as the resources of a department / sub-department should be optimized to allow for an optimal workforce. It would be educative to establish a methodology for evaluating processes and determine a

model for human based work flows and processes. Perhaps a time-based analysis would offer a viable initial study.

APPENDICES

Chapter Outline

- Appendix A: Software Code Listing
  Source: The Author

Chapter Overview

A list of attached appendices providing supplementary information.

Appendix A: Software Code Listing

Module 1: General Type Declarations and Helper Functions

```
' Public Declarations

Option Explicit


' Stores the value of how many resources are being displayed +3 to know where to write fitness scores

Public Const OptCombScoreColOffset = 23


' Enumerations of best-guess average salaries.

Public Enum AverageSalaries

    Administration = 130

    CAD = 180

    Civil_Mech = 400

    Construction = 200

    E_C_I = 400

    Finances = 200

    Legal = 220

    Logistics = 210

    Management = 500

    Process = 400

    safety = 150

End Enum


' Enumeration of fitness weights.

Public Enum FitnessWeights

    D_Weight = 12

    I_Weight = 12

    S_Weight = 12

    C_Weight = 12

    WorkEfficiency_Weight = 12
```

```
    TaskComplexit_Weight = 12
    TeamCohesion_Weight = 12
    RiskTolerance_Weight = 12
    RateHour_Weight = 4
    Final_Weight = 100
End Enum


' UDT containing fitness scores
Public Type FitnessScores
    D_Score As Single
    I_Score As Single
    S_Score As Single
    C_Score As Single
    WorkEfficiency_Score As Single
    TaskComplexit_Score As Single
    TeamCohesion_Score As Single
    RiskTolerance_Score As Single
    RateHour_Score As Single
    Final_Score As Single
End Type


' UDT containing resource information
Public Type Resource
    ResourceID As Integer
    ResourceName As String
    Discipline As String
    D_Index As Integer
    I_Index As Integer
    S_Index As Integer
    C_Index As Integer
    Efficiency_Index As Integer
    Measured_ability As Integer
```

```
    Cohesion_Index As Integer
    Risk_Index As Integer
    RatePerHour As Integer
End Type


' UDT containing parameter information
Public Type Parameter
    Name As String
    Value As Variant
    OptimizeFunc As String
End Type


' UDT containing resource combinations for 2D array passing
Public Type ResourceCombinations
    resourceComb() As Resource
End Type


' UDT containing process information
Public Type Process
    ProcessID As String
    Name As String
End Type


' UDT containing subdepartment definition
Public Type SubDepartment
    Processes() As Process
    Resources() As Resource
    Parameters() As Parameter

    ProcessesSize As Integer
    ResourcesSize As Integer
    ParametersSize As Integer
```

```
End Type


' UDT containing department definition
Public Type Department
    Processes() As Process
    subDepartments() As SubDepartment
    Resources() As Resource
    Parameters() As Parameter


    ProcessesSize As Integer
    subDepartmentsSize As Integer
    ResourcesSize As Integer
    ParametersSize As Integer
End Type


' UDT containing organization definition
Public Type Organization
    Departments() As Department
    ResourcePool() As Resource
    DepartmentsSize As Integer
    ResourcePoolSize As Integer
End Type


' global definitions
Public Org As Organization
Public tmpDept As Department
Public tmpRes As Resource
Public log As Worksheet
Public logResourceComb As Worksheet


Public Function IsNothing(variable As Variant) As Boolean
    ''''''''''''''''''''''''''''''''''''''''''''''
```

```
    ' Helper function determines if a variable is set to
    ' an instance of something.
    ''''''''''''''''''''''''''''''''''''''''''''
    On Error Resume Next
    IsNothing = (variable Is Nothing)
    Err.Clear
    On Error GoTo 0
End Function 'IsNothing

Public Function startsWith(mainString As String, searchString As String) As Boolean
    ''''''''''''''''''''''''''''''''''''''''''''
    ' Helper function to determine if a string starts
    ' with a certain series of characters
    ''''''''''''''''''''''''''''''''''''''''''''

    If Left(mainString, Len(searchString)) = searchString Then
        startsWith = True
    Else
        startsWith = False
    End If
End Function

Public Sub wLog(msg As String, Optional ByVal msg2 As String, Optional ByVal msg3 As String, Optional ByVal msg4 As String, Optional ByVal msg5 As String, Optional ByVal msg6 As String)
    ''''''''''''''''''''''''''''''''''''''''''''
    ' Helper function to write to the log and take
    ' care of accounting.
    ''''''''''''''''''''''''''''''''''''''''''''

    ' Set log reference
    If IsNothing(log) Then Set log = Worksheets("Log Sheet")
```

```
    log.Cells(1, 2) = log.Cells(1, 2) + 1
    log.Cells(log.Cells(1, 2), 1) = Now
    log.Cells(log.Cells(1, 2), 2) = msg
    If msg2 <> "" Then log.Cells(log.Cells(1, 2), 3) = msg2
    If msg3 <> "" Then log.Cells(log.Cells(1, 2), 4) = msg3
    If msg4 <> "" Then log.Cells(log.Cells(1, 2), 5) = msg4
    If msg5 <> "" Then log.Cells(log.Cells(1, 2), 6) = msg5
    If msg6 <> "" Then log.Cells(log.Cells(1, 2), 7) = msg6
    If ActiveSheet.Name = log.Name Then
        log.Cells(log.Cells(1, 2), 1).Select
    End If
End Sub

Public Sub wLogResourceCombination(ByRef singleComb() As Resource)
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Helper function to write combinations and take
    ' care of accounting.
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' General Purpose Counters
    Dim i As Integer

    ' Set Resource Log Reference
    If IsNothing(logResourceComb) Then Set logResourceComb = Worksheets("Optimization Combinations")

    logResourceComb.Cells(1, 2) = logResourceComb.Cells(1, 2) + 1
    logResourceComb.Cells(logResourceComb.Cells(1, 2), 1) = Worksheets("Control").currOptDeptNr & ":" &
Worksheets("Control").currOptSubDeptNr
    logResourceComb.Cells(logResourceComb.Cells(1, 2), 2) = Worksheets("Control").currOptDeptName & ":" &
Worksheets("Control").currOptSubDeptName

    For i = LBound(singleComb) To UBound(singleComb)
        logResourceComb.Cells(logResourceComb.Cells(1, 2), 3 + (i - 1)) = singleComb(i).ResourceName & "[" & singleComb(i).ResourceID & "]"
    Next i
```

```
    If ActiveSheet.Name = logResourceComb.Name Then
        logResourceComb.Cells(logResourceComb.Cells(1, 2), 1).Select
    End If
    DoEvents

End Sub

Public Sub wLogCombinationFitness(ByRef fitnessScore As FitnessScores, ByVal currVal As Integer, ByVal totalVal As Integer)
    ''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Helper function to match fitness scores to
    ' combinations and take care of accounting.
    ''''''''''''''''''''''''''''''''''''''''''''''''''

    ' Column Offset
    Dim colOffset As Integer
    ' Temporary Current Row
    Dim tmpCurrRow As Integer

    ' Start of Score Information
    colOffset = OptCombScoreColOffset

    ' Read Current Row
    tmpCurrRow = logResourceComb.Cells(1, 2)

    ' Set Resource Log Reference
    If IsNothing(logResourceComb) Then Set logResourceComb = Worksheets("Optimization Combinations")

    ' Record values on sheet
    logResourceComb.Cells(tmpCurrRow - totalVal + currVal, colOffset) = Round(fitnessScore.D_Score, 2)
    logResourceComb.Cells(tmpCurrRow - totalVal + currVal, colOffset + 1) = Round(fitnessScore.I_Score, 2)
    logResourceComb.Cells(tmpCurrRow - totalVal + currVal, colOffset + 2) = Round(fitnessScore.S_Score, 2)
    logResourceComb.Cells(tmpCurrRow - totalVal + currVal, colOffset + 3) = Round(fitnessScore.C_Score, 2)
```

```
    logResourceComb.Cells(tmpCurrRow - totalVal + currVal, colOffset + 4) = Round(fitnessScore.WorkEfficiency_Score, 2)
    logResourceComb.Cells(tmpCurrRow - totalVal + currVal, colOffset + 5) = Round(fitnessScore.TaskComplexit_Score, 2)
    logResourceComb.Cells(tmpCurrRow - totalVal + currVal, colOffset + 6) = Round(fitnessScore.TeamCohesion_Score, 2)
    logResourceComb.Cells(tmpCurrRow - totalVal + currVal, colOffset + 7) = Round(fitnessScore.RiskTolerance_Score, 2)
    logResourceComb.Cells(tmpCurrRow - totalVal + currVal, colOffset + 8) = Round(fitnessScore.RateHour_Score, 2)
    logResourceComb.Cells(tmpCurrRow - totalVal + currVal, colOffset + 9) = Round(fitnessScore.Final_Score, 2)

    ' Move sheet if it is active
    If ActiveSheet.Name = logResourceComb.Name Then
        logResourceComb.Cells(tmpCurrRow - totalVal + currVal, 1).Select
    End If
    DoEvents
End Sub
Public Function Factorial(ByVal num As Integer) As Double
    ''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Helper function determine the factorial (!)
    ''''''''''''''''''''''''''''''''''''''''''''''''''

    ' General Purpose Counter
    Dim i As Integer

    Factorial = 1
    For i = 2 To num
        Factorial = Factorial * i
    Next i
End Function

Public Function Ceiling(ByVal num As Single) As Long
    ''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Helper function to determine the ceiling (upper integer)
    ''''''''''''''''''''''''''''''''''''''''''''''''''
```

```
    Ceiling = -Int(-num)

End Function
```

Module2: Optimization Assignment Functions

```
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' This module contains optimization code
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''

Public Sub genCombs(ByRef dataIn() As Resource, ByVal nrChoices As Integer, ByRef singleComb() As Resource, ByRef globalComb As ResourceCombinations, ByRef resourcePos As Long, ByVal depth As Long, ByVal margin As Long)
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Recursive function to generate n_C_k combinations
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''

    Dim i As Long

    ' If correct number of elements have been selected, store them
    If (depth > nrChoices) Then
        resourceCombinationAdd singleComb, globalComb, resourcePos
        wLogResourceCombination singleComb
        Exit Sub
    End If

    ' If there are enough elements to be selected
    If ((UBound(dataIn) - LBound(dataIn) + 1) - margin) < (nrChoices - depth) Then Exit Sub

    ' Keep recurring through pack and eliminate right most elements
    For i = margin To (UBound(dataIn) - LBound(dataIn) + 1)
        singleComb(depth) = dataIn(i)
        genCombs dataIn, nrChoices, singleComb, globalComb, resourcePos, depth + 1, i + 1
    Next i
End Sub

Public Sub resourceCombinationAdd(ByRef singleComb() As Resource, ByRef globalComb As ResourceCombinations, ByRef resourcePos As Long)
```

```
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Helper function add possible combinations to the array
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''

    ' General Purpose Counters
    Dim i As Integer

    ' Once the combination is complete, add it to the resource list
    For i = LBound(globalComb.resourceComb, 2) To UBound(globalComb.resourceComb, 2)
        globalComb.resourceComb(resourcePos, i) = singleComb(i)
    Next i
    resourcePos = resourcePos + 1
End Sub

Public Sub testCombFitness(ByRef ParamsIn() As Parameter, ByRef globalComb As ResourceCombinations, ByRef fitscore() As FitnessScores)
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Determines a given combination's fitness score
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''

    ' General Purpose Counters
    Dim i, j, k As Integer
    ' Temporarily Parameter
    Dim tmpParam As Parameter

    ' For each combination
    For i = LBound(globalComb.resourceComb, 1) To UBound(globalComb.resourceComb, 1)
    ' D-Rating
        ' Extract relevant parameter
        For j = LBound(ParamsIn) To UBound(ParamsIn)
            If startsWith(ParamsIn(j).Name, "Personality Index (D)") Then
                tmpParam = ParamsIn(j)
                Exit For
```

```
        End If
    Next j

    'Run through each resource in the combination
    For j = LBound(globalComb.resourceComb, 2) To UBound(globalComb.resourceComb, 2)
        fitscore(i).D_Score = fitscore(i).D_Score + testParamFitness(tmpParam, globalComb.resourceComb(i, j).D_Index)
    Next j
    fitscore(i).D_Score = fitscore(i).D_Score / (UBound(globalComb.resourceComb, 2) - LBound(globalComb.resourceComb, 2) + 1)

' I-Rating
    ' Extract relevant parameter
    For j = LBound(ParamsIn) To UBound(ParamsIn)
        If startsWith(ParamsIn(j).Name, "Personality Index (I)") Then
            tmpParam = ParamsIn(j)
            Exit For
        End If
    Next j

    For j = LBound(globalComb.resourceComb, 2) To UBound(globalComb.resourceComb, 2)
        fitscore(i).I_Score = fitscore(i).I_Score + testParamFitness(tmpParam, globalComb.resourceComb(i, j).I_Index)
    Next j
    fitscore(i).I_Score = fitscore(i).I_Score / (UBound(globalComb.resourceComb, 2) - LBound(globalComb.resourceComb, 2) + 1)

' S-Rating
    ' Extract relevant parameter
    For j = LBound(ParamsIn) To UBound(ParamsIn)
        If startsWith(ParamsIn(j).Name, "Personality Index (S)") Then
            tmpParam = ParamsIn(j)
            Exit For
        End If
    Next j
```

```
        For j = LBound(globalComb.resourceComb, 2) To UBound(globalComb.resourceComb, 2)
            fitscore(i).S_Score = fitscore(i).S_Score + testParamFitness(tmpParam, globalComb.resourceComb(i, j).S_Index)
        Next j
        fitscore(i).S_Score = fitscore(i).S_Score / (UBound(globalComb.resourceComb, 2) - LBound(globalComb.resourceComb, 2) + 1)

    ' C-Rating
        ' Extract relevant parameter
        For j = LBound(ParamsIn) To UBound(ParamsIn)
            If startsWith(ParamsIn(j).Name, "Personality Index (C)") Then
                tmpParam = ParamsIn(j)
                Exit For
            End If
        Next j

        For j = LBound(globalComb.resourceComb, 2) To UBound(globalComb.resourceComb, 2)
            fitscore(i).C_Score = fitscore(i).C_Score + testParamFitness(tmpParam, globalComb.resourceComb(i, j).C_Index)
        Next j
        fitscore(i).C_Score = fitscore(i).C_Score / (UBound(globalComb.resourceComb, 2) - LBound(globalComb.resourceComb, 2) + 1)

    ' Work Efficiency Rating
        ' Extract relevant parameter
        For j = LBound(ParamsIn) To UBound(ParamsIn)
            If startsWith(ParamsIn(j).Name, "Work Load Duty") Then
                tmpParam = ParamsIn(j)
                Exit For
            End If
        Next j

        For j = LBound(globalComb.resourceComb, 2) To UBound(globalComb.resourceComb, 2)
            fitscore(i).WorkEfficiency_Score = fitscore(i).WorkEfficiency_Score + testParamFitness(tmpParam, globalComb.resourceComb(i,
j).Efficiency_Index)
        Next j
```

```
        fitscore(i).WorkEfficiency_Score = fitscore(i).WorkEfficiency_Score / (UBound(globalComb.resourceComb, 2) -
LBound(globalComb.resourceComb, 2) + 1)

    ' Task Complexity Rating
        ' Extract relevant parameter
        For j = LBound(ParamsIn) To UBound(ParamsIn)
            If startsWith(ParamsIn(j).Name, "Task Complexity Index") Then
                tmpParam = ParamsIn(j)
                Exit For
            End If
        Next j

        ' Temporary Function:
        tmpParam.Value = 2 * tmpParam.Value

        For j = LBound(globalComb.resourceComb, 2) To UBound(globalComb.resourceComb, 2)
            fitscore(i).TaskComplexit_Score = fitscore(i).TaskComplexit_Score + testParamFitness(tmpParam, globalComb.resourceComb(i,
j).Measured_ability)
        Next j
        fitscore(i).TaskComplexit_Score = fitscore(i).TaskComplexit_Score / (UBound(globalComb.resourceComb, 2) -
LBound(globalComb.resourceComb, 2) + 1)

    ' Team Cohesion Rating
        ' Extract relevant parameter
        For j = LBound(ParamsIn) To UBound(ParamsIn)
            If startsWith(ParamsIn(j).Name, "Minimum Cohesion Index") Then
                tmpParam = ParamsIn(j)
                Exit For
            End If
        Next j

        For j = LBound(globalComb.resourceComb, 2) To UBound(globalComb.resourceComb, 2)
            fitscore(i).TeamCohesion_Score = fitscore(i).TeamCohesion_Score + testParamFitness(tmpParam, globalComb.resourceComb(i,
```

```
j).Cohesion_Index)
        Next j
        fitscore(i).TeamCohesion_Score = fitscore(i).TeamCohesion_Score / (UBound(globalComb.resourceComb, 2) -
LBound(globalComb.resourceComb, 2) + 1)

    ' Risk Tolerance Rating
        ' Extract relevant parameter
        For j = LBound(ParamsIn) To UBound(ParamsIn)
            If startsWith(ParamsIn(j).Name, "Risk Tolerance") Then
                tmpParam = ParamsIn(j)
                Exit For
            End If
        Next j

        For j = LBound(globalComb.resourceComb, 2) To UBound(globalComb.resourceComb, 2)
            fitscore(i).RiskTolerance_Score = fitscore(i).RiskTolerance_Score + testParamFitness(tmpParam, globalComb.resourceComb(i,
j).Risk_Index)
        Next j
        fitscore(i).RiskTolerance_Score = fitscore(i).RiskTolerance_Score / (UBound(globalComb.resourceComb, 2) -
LBound(globalComb.resourceComb, 2) + 1)

    ' RateHour Rating
        ' Extract relevant parameter
        For j = LBound(ParamsIn) To UBound(ParamsIn)
            If startsWith(ParamsIn(j).Name, "Expected Rate") Then
                tmpParam = ParamsIn(j)
                Exit For
            End If
        Next j

        For j = LBound(globalComb.resourceComb, 2) To UBound(globalComb.resourceComb, 2)
            fitscore(i).RateHour_Score = fitscore(i).RateHour_Score + testParamFitness(tmpParam, globalComb.resourceComb(i, j).RatePerHour)
        Next j
```

```
        fitscore(i).RateHour_Score = fitscore(i).RateHour_Score / (UBound(globalComb.resourceComb, 2) - LBound(globalComb.resourceComb, 2) +
1)


    ' Final Score
        With fitscore(i)
            .Final_Score = (.D_Score * FitnessWeights.D_Weight + _
                        .I_Score * FitnessWeights.I_Weight + _
                        .S_Score * FitnessWeights.S_Weight + _
                        .C_Score * FitnessWeights.C_Weight + _
                        .WorkEfficiency_Score * FitnessWeights.WorkEfficiency_Weight + _
                        .TaskComplexit_Score * FitnessWeights.TaskComplexit_Weight + _
                        .TeamCohesion_Score * FitnessWeights.TeamCohesion_Weight + _
                        .RiskTolerance_Score * FitnessWeights.RiskTolerance_Weight + _
                        .RateHour_Score * FitnessWeights.RateHour_Weight) _
                        / 100

        End With

    'Write Scores on Combinations Sheet
        wLogCombinationFitness fitscore(i), i, UBound(fitscore) - LBound(fitscore) + 1
    Next i
End Sub


Public Function testParamFitness(ByRef paramIn As Parameter, ByVal resourceIndexIn As Single) As Single
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Determines a given parameter's fitness score
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''


    If paramIn.OptimizeFunc = "Match" Then
        testParamFitness = Abs(100 - 100 * Abs(paramIn.Value - resourceIndexIn) / paramIn.Value)
    ElseIf paramIn.OptimizeFunc = "Maximize" Then
        testParamFitness = 100 + 100 * (resourceIndexIn - paramIn.Value) / paramIn.Value
```

```
    ElseIf paramIn.OptimizeFunc = "Minimize" Then
        testParamFitness = 100 - 100 * (paramIn.Value - resourceIndexIn) / paramIn.Value
    Else
        testParamFitness = 0
    End If
End Function


Public Function mostFitCombination(ByRef fitscore() As FitnessScores) As Long
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Assigns the most fit combination solution
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''

    ' General Purpose Counters
    Dim i As Long
    ' Maximum Score
    Dim maxFitScore As Single

    maxFitScore = maxScore(fitscore)

    For i = LBound(fitscore) To UBound(fitscore)
        If fitscore(i).Final_Score = maxFitScore Then
            mostFitCombination = i
            Worksheets("Optimization Combinations").Rows(Worksheets("Optimization Combinations").Cells(1, 2) - (UBound(fitscore) - LBound(fitscore) + 1) + i & ":" & Worksheets("Optimization Combinations").Cells(1, 2) - (UBound(fitscore) - LBound(fitscore) + 1) + i).Font.Color = vbGreen
            Worksheets("Optimization Combinations").Rows(Worksheets("Optimization Combinations").Cells(1, 2) - (UBound(fitscore) - LBound(fitscore) + 1) + i & ":" & Worksheets("Optimization Combinations").Cells(1, 2) - (UBound(fitscore) - LBound(fitscore) + 1) + i).Font.Bold = True
            Exit Function
        End If
    Next i
End Function
```

```
Public Function maxScore(ByRef fitscore() As FitnessScores) As Single
    ''''''''''''''''''''''''''''''''''''''''''''''
    ' Helper function to determine the score of the most
    ' fit combination
    '''''''''''''''''''''''''''''''''''''''''''''

    ' General Purpose Counters
    Dim i As Integer

    maxScore = fitscore(1).Final_Score

    For i = LBound(fitscore) + 1 To UBound(fitscore)
        If fitscore(i).Final_Score > maxScore Then maxScore = fitscore(i).Final_Score
    Next i
End Function
```

Sheet1: Organization Definition

```
Option Explicit


Public Sub Analyze_Organization()
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' This function mimics the effort of analyzing an organization and
    ' provides values to some of the parameters that exist within the
    ' given structure.  The structure of the organization is not affected
    ' in any way.  Only simulation values are modified to play around
    ' with the simulations.
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''


    ' General Purpose Counters
    Dim i, j, k As Integer
    ' Reference to worksheet
    Dim sht As Worksheet


    ' Generate new seed
    Math.Randomize


    Set sht = Worksheets("Departments")
    sht.Activate


    For i = 3 To sht.Cells(1, 4) + 2
        If ActiveSheet.Name = sht.Name Then sht.Cells(i, 1).Select
        DoEvents
        If startsWith(sht.Cells(i, 2), "Personality") Then
            sht.Cells(i, 3) = Round(Worksheets("MatlabData").Cells(Round(1000 * Math.Rnd()) Mod 1000 + 2, 1))
        ElseIf startsWith(sht.Cells(i, 2), "Work Load") Then
            sht.Cells(i, 3) = Round(Worksheets("MatlabData").Cells(Round(1000 * Math.Rnd()) Mod 1000 + 2, 2))
        ElseIf startsWith(sht.Cells(i, 2), "Task Complexity") Then
```

```
        sht.Cells(i, 3) = Round(Worksheets("MatlabData").Cells(Round(1000 * Math.Rnd()) Mod 1000 + 2, 3) / 2)

      ElseIf startsWith(sht.Cells(i, 2), "Minimum Cohesion") Then

        sht.Cells(i, 3) = Round(Worksheets("MatlabData").Cells(Round(1000 * Math.Rnd()) Mod 1000 + 2, 4))

      ElseIf startsWith(sht.Cells(i, 2), "Risk Tolerance") Then

        sht.Cells(i, 3) = Round(Worksheets("MatlabData").Cells(Round(1000 * Math.Rnd()) Mod 1000 + 2, 5))

      ElseIf startsWith(sht.Cells(i, 2), "Resources Required") Then

        sht.Cells(i, 3) = Round(1000 * Math.Rnd() Mod 6) + 1

      End If

   Next i


   sht.Cells(3, 1).Select

End Sub

Public Sub createOrganization()

   ''''''''''''''''''''''''''''''''''''''''''''''''''''''

   ' Provides the means of creating a software

   ' representation of the organization based on the

   ' provided definition

   ''''''''''''''''''''''''''''''''''''''''''''''''''''''


   wLog "Starting with Organization's Definition"


   wLog "-->", "Populating Organization's Departments..."

   populateDepartments Module1.Org

   wLog "-->", "Found " & Org.DepartmentsSize & " Departments"


   wLog "-->", "Populating populate Organization's Human Resources..."

   populateResourcePool Module1.Org

   wLog "-->", "Found " & Org.ResourcePoolSize & " Resources"


   wLog "Organization's Definition is Complete."


End Sub
```

```
Private Sub populateDepartments(ByRef Org As Organization)
    ''''''''''''''''''''''''''''''''''''''''''''''''
    ' Performs actual population of departments and
    ' sub departments from the structures
    ''''''''''''''''''''''''''''''''''''''''''''''''

    ' Pointer to worksheet
    Dim sht As Worksheet
    ' General purpose counters
    Dim i, j, k As Integer
    ' current & nr of Departments / Sub Departments
    Dim currDept, currSubDept, nrDept, nrSubDept As Integer
    ' number of entries
    Dim nrEntries As Integer

    ' set pointer to correct sheet
    Set sht = Worksheets("Departments")

    ' Create an empty department and subdepartment
    ReDim Org.Departments(1 To 1)
    ReDim Org.Departments(1).Parameters(1 To 1)
    ReDim Org.Departments(1).Processes(1 To 1)
    ReDim Org.Departments(1).Resources(1 To 1)
    ReDim Org.Departments(1).subDepartments(1 To 1)
    Org.Departments(1).ParametersSize = 1
    Org.Departments(1).ProcessesSize = 1
    Org.Departments(1).subDepartmentsSize = 1

    ReDim Org.Departments(1).subDepartments(1).Parameters(1 To 1)
    ReDim Org.Departments(1).subDepartments(1).Processes(1 To 1)
    ReDim Org.Departments(1).subDepartments(1).Resources(1 To 1)
```

```
Org.Departments(1).subDepartments(1).ParametersSize = 1

Org.Departments(1).subDepartments(1).ProcessesSize = 1


' Get the number of records / entries

nrEntries = sht.Cells(1, 4) + 2

'nrDept = Int(Left(sht.Cells(nrEntries, 1), InStr(1, sht.Cells(nrEntries, 1), ".")))


' start with nothing

currDept = 0

currSubDept = 0


For i = 3 To nrEntries

    If ActiveSheet.Name = sht.Name Then

        sht.Cells(i, 1).Select

        DoEvents

    End If


    ' determine departmnet / subdepartment

    If InStr(1, sht.Cells(i, 1), ".") > 0 Then

        currDept = Int(Left(sht.Cells(i, 1), InStr(1, sht.Cells(i, 1), ".")))

        currSubDept = Int(Right(sht.Cells(i, 1), Len(sht.Cells(i, 1)) - InStr(1, sht.Cells(i, 1), ".")))

    Else

        currDept = Int(sht.Cells(i, 1))

        currSubDept = 0

    End If

    ' Allocate memory for department if necessary

    'If currDept = 1 And IsNothing(Org.Departments) Then ReDim Org.Departments(1 To currDept)

    If currDept > UBound(Org.Departments) Then

        ReDim Preserve Org.Departments(1 To currDept)

        ReDim Preserve Org.Departments(currDept).Parameters(1 To 1)

        ReDim Preserve Org.Departments(currDept).Processes(1 To 1)

        ReDim Preserve Org.Departments(currDept).Resources(1 To 1)
```

```
        ReDim Preserve Org.Departments(currDept).subDepartments(1 To 1)
        Org.Departments(currDept).ParametersSize = 1
        Org.Departments(currDept).ProcessesSize = 1
        Org.Departments(currDept).subDepartmentsSize = 1

        ReDim Preserve Org.Departments(currDept).subDepartments(1).Parameters(1 To 1)
        ReDim Preserve Org.Departments(currDept).subDepartments(1).Processes(1 To 1)
        ReDim Preserve Org.Departments(currDept).subDepartments(1).Resources(1 To 1)
        Org.Departments(currDept).subDepartments(1).ParametersSize = 1
        Org.Departments(currDept).subDepartments(1).ProcessesSize = 1
    End If

    'If currSubDept = 1 And IsNothing(Org.Departments.subDepartments) Then ReDim Org.Departments(currDept).subDepartments(1 To
currSubDept)
    If currSubDept > 0 And currSubDept > UBound(Org.Departments(currDept).subDepartments) Then
        Org.Departments(currDept).subDepartmentsSize = currSubDept
        ReDim Preserve Org.Departments(currDept).subDepartments(1 To currSubDept)
        ReDim Preserve Org.Departments(currDept).subDepartments(currSubDept).Parameters(1 To 1)
        ReDim Preserve Org.Departments(currDept).subDepartments(currSubDept).Processes(1 To 1)
        ReDim Preserve Org.Departments(currDept).subDepartments(currSubDept).Resources(1 To 1)
        Org.Departments(currDept).subDepartments(currSubDept).ParametersSize = 1
        Org.Departments(currDept).subDepartments(currSubDept).ProcessesSize = 1
    End If

    ' Assign memory for parameters:
    If currSubDept = 0 Then
        ' If this is the main department
        If startsWith(sht.Cells(i, 2), "Process") Then
        ' check if it is a process
            ' if this one is taken, we need to make space...
            If Org.Departments(currDept).Processes(Org.Departments(currDept).ProcessesSize).ProcessID <> "" Then
                Org.Departments(currDept).ProcessesSize = Org.Departments(currDept).ProcessesSize + 1
```

```
            ReDim Preserve Org.Departments(currDept).Processes(1 To Org.Departments(currDept).ProcessesSize)
          End If
          Org.Departments(currDept).Processes(Org.Departments(currDept).ProcessesSize).ProcessID = sht.Cells(i, 2)
          Org.Departments(currDept).Processes(Org.Departments(currDept).ProcessesSize).Name = sht.Cells(i, 3)
        Else
        ' now it must be a parameter
          ' if this one is taken, we need to make space...
          If Org.Departments(currDept).Parameters(Org.Departments(currDept).ParametersSize).Name <> "" Then
            Org.Departments(currDept).ParametersSize = Org.Departments(currDept).ParametersSize + 1
            ReDim Preserve Org.Departments(currDept).Parameters(1 To Org.Departments(currDept).ParametersSize)
          End If
          Org.Departments(currDept).Parameters(Org.Departments(currDept).ParametersSize).Name = sht.Cells(i, 2)
          Org.Departments(currDept).Parameters(Org.Departments(currDept).ParametersSize).Value = sht.Cells(i, 3)
          Org.Departments(currDept).Parameters(Org.Departments(currDept).ParametersSize).OptimizeFunc = sht.Cells(i, 4)
        End If
      Else
        ' If this is the subdepartment
        If startsWith(sht.Cells(i, 2), "Process") Then
        ' check if it is a process
          ' if this one is taken, we need to make space...
          If
Org.Departments(currDept).subDepartments(currSubDept).Processes(Org.Departments(currDept).subDepartments(currSubDept).ProcessesSize).Proc
essID <> "" Then
            Org.Departments(currDept).subDepartments(currSubDept).ProcessesSize =
Org.Departments(currDept).subDepartments(currSubDept).ProcessesSize + 1
            ReDim Preserve Org.Departments(currDept).subDepartments(currSubDept).Processes(1 To
Org.Departments(currDept).subDepartments(currSubDept).ProcessesSize)
          End If
          Org.Departments(currDept).subDepartments(currSubDept).Processes(Org.Departments(currDept).subDepartments(currSubDept).Processes
Size).ProcessID = sht.Cells(i, 2)
          Org.Departments(currDept).subDepartments(currSubDept).Processes(Org.Departments(currDept).subDepartments(currSubDept).Processes
Size).Name = sht.Cells(i, 3)
        Else
        ' now it must be a parameter
```

```
        ' if this one is taken, we need to make space...
        If
Org.Departments(currDept).subDepartments(currSubDept).Parameters(Org.Departments(currDept).subDepartments(currSubDept).ParametersSize).N
ame <> "" Then
            Org.Departments(currDept).subDepartments(currSubDept).ParametersSize =
Org.Departments(currDept).subDepartments(currSubDept).ParametersSize + 1
            ReDim Preserve Org.Departments(currDept).subDepartments(currSubDept).Parameters(1 To
Org.Departments(currDept).subDepartments(currSubDept).ParametersSize)
        End If
        Org.Departments(currDept).subDepartments(currSubDept).Parameters(Org.Departments(currDept).subDepartments(currSubDept).Paramet
ersSize).Name = sht.Cells(i, 2)
        Org.Departments(currDept).subDepartments(currSubDept).Parameters(Org.Departments(currDept).subDepartments(currSubDept).Paramet
ersSize).Value = sht.Cells(i, 3)
        Org.Departments(currDept).subDepartments(currSubDept).Parameters(Org.Departments(currDept).subDepartments(currSubDept).Paramet
ersSize).OptimizeFunc = sht.Cells(i, 4)
      End If
    End If
  Next i
  ' Finally set all department size:
  Org.DepartmentsSize = UBound(Org.Departments)
  DoEvents
End Sub

Private Sub populateResourcePool(ByRef Org As Organization)
  ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
  ' Generates a software representation of the resource
  ' pool
  ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
  ' Pointer to worksheet
  Dim sht As Worksheet
  ' General purpose counters
  Dim i, j, k As Integer
  ' number of Resources
  Dim nrResources As Integer
```

```
    ' Set pointer to correct sheet
    Set sht = Worksheets("Resources")

    ' Get number of resources
    nrResources = sht.Cells(1, 2)

    ' Allocate memory for resources in pool
    ReDim Org.ResourcePool(1 To nrResources)

    ' For each resource, populate the information
    For i = 1 To nrResources
        Org.ResourcePool(i).ResourceID = sht.Cells(i + 2, 1)
        Org.ResourcePool(i).ResourceName = sht.Cells(i + 2, 2)
        Org.ResourcePool(i).Discipline = sht.Cells(i + 2, 3)
        Org.ResourcePool(i).D_Index = sht.Cells(i + 2, 4)
        Org.ResourcePool(i).I_Index = sht.Cells(i + 2, 5)
        Org.ResourcePool(i).S_Index = sht.Cells(i + 2, 6)
        Org.ResourcePool(i).C_Index = sht.Cells(i + 2, 7)
        Org.ResourcePool(i).Efficiency_Index = sht.Cells(i + 2, 8)
        Org.ResourcePool(i).Measured_ability = sht.Cells(i + 2, 9)
        Org.ResourcePool(i).Cohesion_Index = sht.Cells(i + 2, 10)
        Org.ResourcePool(i).Risk_Index = sht.Cells(i + 2, 11)
        Org.ResourcePool(i).RatePerHour = sht.Cells(i + 2, 12)
    Next i
    ' set organization resource size
    Org.ResourcePoolSize = UBound(Org.ResourcePool)
    DoEvents
End Sub
```

Sheet2: Resource Pool

```
Option Explicit


Public Sub Analyze_Component()
    ''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Mimics the manual analysis of human components
    ' phase.  Calls a resource generator to simulate
    ' results
    ''''''''''''''''''''''''''''''''''''''''''''''''''
    Call generateResources
End Sub


Private Sub generateResources()
    ''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Randomly generates a resource pool based on the
    ' simulation's requirements.
    ''''''''''''''''''''''''''''''''''''''''''''''''''
Dim nrResources, nrParams, rowCntr, discCntr, effCntr, abilityCntr, coCntr, rtCntr, i, j As Integer
Dim Departments(1 To 15) As String


    Worksheets("Resources").Activate


    ' Generate New Random Seed
    Math.Randomize


    ' initialize counters
    rowCntr = 3
    discCntr = 2
    effCntr = 2
    abilityCntr = 2
    coCntr = 2
```

```
rtCntr = 2

' Define Departments
Departments(1) = "Management"
Departments(2) = "Logistics"
Departments(3) = "Administration"
Departments(4) = "Finances"
Departments(5) = "Legal"
Departments(6) = "Process Engineering"
Departments(7) = "Civil & Mechanical Engineering"
Departments(8) = "Electrical, Instrumentation & Control Engineering"
Departments(9) = "CAD Engineering"
Departments(10) = "Process Engineering"
Departments(11) = "Civil & Mechanical Engineering"
Departments(12) = "Electrical, Instrumentation & Control Engineering"
Departments(13) = "CAD Engineering"
Departments(14) = "Construction"
Departments(15) = "Safety"

' Determine number resources & params
nrResources = Worksheets("Resources").Cells(1, 2)
nrParams = Worksheets("Resources").Cells(1, 4)

' Generate each resource
For i = 1 To nrResources
  ' Select Current Row
  If ActiveSheet.Name = Worksheets("Resources").Name Then Worksheets("resources").Cells(rowCntr, 1).Select
  DoEvents

  ' Generate Parameters per Resource
  For j = 1 To nrParams
    If Worksheets("Resources").Cells(2, j) = "Resource Number" Then
```

```
            Worksheets("Resources").Cells(rowCntr, j) = i
        ElseIf Worksheets("Resources").Cells(2, j) = "Name" Then
            Worksheets("Resources").Cells(rowCntr, j) = UCase(Worksheets("MatlabData").Cells((Round(1000 * Math.Rnd()) Mod 127) + 2, 6) & " " & Worksheets("MatlabData").Cells((Round(1000 * Math.Rnd()) Mod 127) + 2, 6))
        ElseIf Worksheets("Resources").Cells(2, j) = "Discipline" Then
            Worksheets("Resources").Cells(rowCntr, j) = Departments((Round(Math.Rnd() * 1000) Mod UBound(Departments)) + 1)
        ElseIf Left(Worksheets("Resources").Cells(2, j), Len("Personality")) = "Personality" Then
            Worksheets("resources").Cells(rowCntr, j) = Round(Worksheets("MatlabData").Cells(discCntr, 1))
            discCntr = discCntr + 1
        ElseIf Worksheets("Resources").Cells(2, j) = "Efficiency Index" Then
            Worksheets("resources").Cells(rowCntr, j) = Round(Worksheets("MatlabData").Cells(effCntr, 2))
            effCntr = effCntr + 1
        ElseIf Worksheets("Resources").Cells(2, j) = "Measured ability" Then
            Worksheets("resources").Cells(rowCntr, j) = Round(Worksheets("MatlabData").Cells(abilityCntr, 3))
            abilityCntr = abilityCntr + 1
        ElseIf Worksheets("Resources").Cells(2, j) = "Anticipated Cohesion Index" Then
            Worksheets("resources").Cells(rowCntr, j) = Round(Worksheets("MatlabData").Cells(coCntr, 4))
            coCntr = coCntr + 1
        ElseIf Worksheets("Resources").Cells(2, j) = "Risk Tolerance Index" Then
            Worksheets("resources").Cells(rowCntr, j) = Round(Worksheets("MatlabData").Cells(rtCntr, 5))
            rtCntr = rtCntr + 1
        ElseIf Worksheets("Resources").Cells(2, j) = "Rate / Hour" Then
            Select Case Worksheets("Resources").Cells(rowCntr, 3)
                Case "Administration"
                    Worksheets("Resources").Cells(rowCntr, j) = AverageSalaries.Administration + (-1) ^ (Round(Math.Rnd() * 1000)) * AverageSalaries.Administration * (Round(Math.Rnd() * 1000) Mod 20) / 100
                Case "CAD Engineering"
                    Worksheets("Resources").Cells(rowCntr, j) = AverageSalaries.CAD + (-1) ^ (Round(Math.Rnd() * 1000)) * AverageSalaries.CAD * (Round(Math.Rnd() * 1000) Mod 20) / 100
                Case "Civil & Mechanical Engineering"
                    Worksheets("Resources").Cells(rowCntr, j) = AverageSalaries.Civil_Mech + (-1) ^ (Round(Math.Rnd() * 1000)) * AverageSalaries.Civil_Mech * (Round(Math.Rnd() * 1000) Mod 20) / 100
                Case "Construction"
```

```
                    Worksheets("Resources").Cells(rowCntr, j) = AverageSalaries.Construction + (-1) ^ (Round(Math.Rnd() * 1000)) *
AverageSalaries.Construction * (Round(Math.Rnd() * 1000) Mod 20) / 100

                Case "Electrical, Instrumentation & Control Engineering"

                    Worksheets("Resources").Cells(rowCntr, j) = AverageSalaries.E_C_I + (-1) ^ (Round(Math.Rnd() * 1000)) * AverageSalaries.E_C_I
* (Round(Math.Rnd() * 1000) Mod 20) / 100

                Case "Finances"

                    Worksheets("Resources").Cells(rowCntr, j) = AverageSalaries.Finances + (-1) ^ (Round(Math.Rnd() * 1000)) *
AverageSalaries.Finances * (Round(Math.Rnd() * 1000) Mod 20) / 100

                Case "Legal"

                    Worksheets("Resources").Cells(rowCntr, j) = AverageSalaries.Legal + (-1) ^ (Round(Math.Rnd() * 1000)) * AverageSalaries.Legal *
(Round(Math.Rnd() * 1000) Mod 20) / 100

                Case "Logistics"

                    Worksheets("Resources").Cells(rowCntr, j) = AverageSalaries.Logistics + (-1) ^ (Round(Math.Rnd() * 1000)) *
AverageSalaries.Logistics * (Round(Math.Rnd() * 1000) Mod 20) / 100

                Case "Management"

                    Worksheets("Resources").Cells(rowCntr, j) = AverageSalaries.Management + (-1) ^ (Round(Math.Rnd() * 1000)) *
AverageSalaries.Management * (Round(Math.Rnd() * 1000) Mod 20) / 100

                Case "Process Engineering"

                    Worksheets("Resources").Cells(rowCntr, j) = AverageSalaries.Process + (-1) ^ (Round(Math.Rnd() * 1000)) *
AverageSalaries.Process * (Round(Math.Rnd() * 1000) Mod 20) / 100

                Case "Safety"

                    Worksheets("Resources").Cells(rowCntr, j) = AverageSalaries.safety + (-1) ^ (Round(Math.Rnd() * 1000)) * AverageSalaries.safety *
(Round(Math.Rnd() * 1000) Mod 20) / 100

                Case Else

                    Worksheets("Resources").Cells(rowCntr, j) = 0

            End Select

        End If

    Next j

    ' jump to the next row

    rowCntr = rowCntr + 1

  Next i


  ' Sort by discipline, then by resource ID

  Rows("3:" & Worksheets("Resources").Cells(1, 2) + 2).Select
```

```
    Selection.sort Key1:=Range("C3"), Order1:=xlAscending, Key2:=Range("A3") _
        , Order2:=xlAscending, Key3:=Range("B3"), Order3:=xlAscending, Header:= _
        xlGuess, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom, _
        DataOption1:=xlSortNormal, DataOption2:=xlSortNormal, DataOption3:= _
        xlSortNormal

End Sub
```

Sheet3: Matlab Data

```
' Do nothing.  This is just a storage sheet.
```

Sheet4: Control Panel and Recursive Optimization Calls

```
Option Explicit

Public currOptDeptName, currOptSubDeptName As String

Public currOptDeptNr, currOptSubDeptNr As Integer


Public Sub cmdOptimalSolution_Click()

    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''

    ' Determines the optimal solution based on the given rules

    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''



    ' Flush any current configurations.

    Worksheets("Optimization Combinations").Activate

    Worksheets("Optimization Combinations").cmdClearCombinations_Click


    ' Step 1: Create Organization Strucutre

    ' Step 2: Assign Resources to Department

    ' Step 3: Determine Optimal Solution Set

    Worksheets("Departments").createOrganization

    wLog "Starting With Optimization of Organization"

    OptimizeOrg Module1.Org

    DisplayOptimizedOrg Module1.Org

End Sub


Public Sub OptimizeOrg(ByRef O1 As Organization)

    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''

    ' Optimze Organization forms part of the pseudo-recursive

    ' function and calls the optimizer to optimize each department

    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''



    ' General Purpose Counter

    Dim i, j, k As Integer
```

```
    For i = LBound(O1.Departments) To UBound(O1.Departments)

        ' set the name of the current department

        For j = LBound(O1.Departments(i).Parameters) To UBound(O1.Departments(i).Parameters)

            If O1.Departments(i).Parameters(j).Name = "Name" Then

                currOptDeptName = O1.Departments(i).Parameters(j).Value

                currOptDeptNr = i

                Exit For

            End If

        Next j

        wLog "", "Optimizing Department: " & currOptDeptName

        ' optimize department

        OptimizeDep O1.Departments(i), O1.ResourcePool


        wLog "", "Done Optimizing Deparment: " & currOptDeptName

    Next i

End Sub


Public Sub OptimizeDep(ByRef D1 As Department, ByRef Resources() As Resource)

    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''

    ' Optimze Organization forms part of the pseudo-recursive

    ' function and calls the optimizer to optimize each sub-department

    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''


    ' General purpose counter

    Dim i, j, k As Integer


    For i = LBound(D1.subDepartments) To UBound(D1.subDepartments)

        ' Check that there are optimization parameters in the set

        If D1.subDepartments(i).ParametersSize > 0 Then

            ' set the name of the current sub-department

            For j = LBound(D1.subDepartments(i).Parameters) To UBound(D1.subDepartments(i).Parameters)
```

```
            If D1.subDepartments(i).Parameters(j).Name = "Name" Then
               currOptSubDeptName = D1.subDepartments(i).Parameters(j).Value
               currOptSubDeptNr = i
               Exit For
            End If
         Next j
         wLog "", "", "Optimizing SubDepartment: " & currOptSubDeptName
         OptimizeSubDep D1.subDepartments(i), Resources
         wLog "", "", "Done Optimizing SubDepartment: " & currOptSubDeptName
      End If
   Next i
End Sub

Public Sub OptimizeSubDep(ByRef SD1 As SubDepartment, ByRef Resources() As Resource)
   '''''''''''''''''''''''''''''''''''''''''''''''''''''
   ' Optimze Organization forms part of the pseudo-recursive
   ' function and calls the optimizer analyze and optimize
   ' all assignments
   '''''''''''''''''''''''''''''''''''''''''''''''''''''

   ' General purpose counter
   Dim i, j, k As Integer
   Dim tmpresources() As Resource
   Dim tmpparams() As Parameter

   ReDim tmpresources(1 To 1) As Resource
   ReDim tmpparams(1 To 1) As Parameter


   ''' ISOLATE RELEVANT RESOURCES:
   wLog "", "", "", "Isolating Matching Resources"
   ' Look for the name parameter:
```

```
    For i = LBound(SD1.Parameters) To UBound(SD1.Parameters)
        ' Check for parameter called "Name" for a match
        If SD1.Parameters(i).Name = "Name" Then
            ' create resource list:
            For j = LBound(Resources) To UBound(Resources)
                If startsWith(CStr(SD1.Parameters(i).Value), Resources(j).Discipline) Then
                    If tmpresources(UBound(tmpresources)).Discipline <> "" Then
                        ReDim Preserve tmpresources(1 To UBound(tmpresources) + 1)
                    End If
                    tmpresources(UBound(tmpresources)) = Resources(j)
                End If
            Next j
            Exit For
        End If
    Next i

    ''' ISOLATE NUMERIC PARAMETERS
    wLog "", "", "", "Isolating Numeric Parameters"
    For i = LBound(SD1.Parameters) To UBound(SD1.Parameters)
        If IsNumeric(SD1.Parameters(i).Value) Then
            If tmpparams(UBound(tmpparams)).Name <> "" Then
                ReDim Preserve tmpparams(1 To UBound(tmpparams) + 1)
            End If
            tmpparams(UBound(tmpparams)) = SD1.Parameters(i)
        End If
    Next i

    wLog "", "", "", "Calling Optimal Assigment"
    OptimalAssignment tmpparams, tmpresources, SD1.Resources

End Sub
```

```
Public Sub OptimalAssignment(ByRef ParamsIn() As Parameter, ByRef ResourcesIn() As Resource, ByRef ResourcesOut() As Resource)
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    'Optimized Assignments:
    '   1.  Generate Possible Combinations
    '   2.  Test Combinations Against Fitness Function
    '   3.  Determine Most Fit Function
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''

    ' General Purpose Counters
    Dim i, j, k As Integer
    ' Number of resources required
    Dim nrResourcesReq As Integer
    ' Combinatoric Resources
    Dim combResource As ResourceCombinations
    Dim tmpSingleComb() As Resource
    ' Number of unique combinations
    Dim nrCombs As Long
    Dim tmpResourceLoc As Long
    ' Keep Track of Fitness Scores
    Dim fitscore() As FitnessScores
    Dim mostFitIndex As Long

    ' Determine how many resources are required
    For i = LBound(ParamsIn) To UBound(ParamsIn)
        If startsWith(ParamsIn(i).Name, "Resources Required") Then
            nrResourcesReq = Ceiling(ParamsIn(i).Value)
            Exit For
        End If
    Next i

    ' 1.    Generate Possible Combinations:
     nrCombs = CLng(Factorial(UBound(ResourcesIn) - LBound(ResourcesIn) + 1) / (Factorial(nrResourcesReq) * Factorial(UBound(ResourcesIn) -
```

```
LBound(ResourcesIn) + 1 - nrResourcesReq)))

    wLog "", "", "", "", "Generating Possible Combinations: " & (UBound(ResourcesIn) - LBound(ResourcesIn) + 1) & "_C_" & nrResourcesReq & "
= " & nrCombs


    ' Allocate memory

    If nrCombs = 0 Then nrCombs = 1

    ReDim combResource.resourceComb(1 To nrCombs, 1 To nrResourcesReq)

    tmpResourceLoc = 1

    ReDim tmpSingleComb(1 To nrResourcesReq)

    'GenCombinations ResourcesIn, nrResourcesReq

    genCombs ResourcesIn, nrResourcesReq, tmpSingleComb, combResource, tmpResourceLoc, 1, 1


    ' 2.    Test Combination against a fitness function

    wLog "", "", "", "", "Testing Combinations Against Fitness Function"

    ReDim fitscore(1 To nrCombs)

    testCombFitness ParamsIn, combResource, fitscore


    ' 3.    Determine Most Fit Function

    wLog "", "", "", "", "Assigning Most Fit Function"

    mostFitIndex = mostFitCombination(fitscore)

    ReDim ResourcesOut(LBound(combResource.resourceComb, 2) To UBound(combResource.resourceComb, 2))

    For i = LBound(ResourcesOut) To UBound(ResourcesOut)

        ResourcesOut(i) = combResource.resourceComb(mostFitIndex, (i))

    Next i

End Sub


Public Sub DisplayOptimizedOrg(ByRef tmpOrg As Organization)

    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''

    ' Graphically constructs the hierarchy of the optimized organization

    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''


    ' General Purpose Counters
```

```
Dim i, j, k As Integer
Dim rowCntr As Integer
' Link to worksheet
Dim sht As Worksheet

Set sht = Worksheets("Optimized Assignments")

sht.Activate
sht.Rows("2:65000").Select
Selection.Delete

sht.Cells(2, 1).Select

rowCntr = 1
' Run through each department
For i = LBound(tmpOrg.Departments) To UBound(tmpOrg.Departments)
    rowCntr = rowCntr + 1
    sht.Cells(rowCntr, 1).Select
    DoEvents
    ' get name
    For j = LBound(tmpOrg.Departments(i).Parameters) To UBound(tmpOrg.Departments(i).Parameters)
        If tmpOrg.Departments(i).Parameters(j).Name = "Name" Then
            sht.Cells(rowCntr, 1) = tmpOrg.Departments(i).Parameters(j).Value
            Exit For
        End If
    Next j
    ' Run through each Subdepartment
    For j = LBound(tmpOrg.Departments(i).subDepartments) To UBound(tmpOrg.Departments(i).subDepartments)
        rowCntr = rowCntr + 1
        sht.Cells(rowCntr, 1).Select
        DoEvents
        ' get name
```

```
        For k = LBound(tmpOrg.Departments(i).subDepartments(j).Parameters) To UBound(tmpOrg.Departments(i).subDepartments(j).Parameters)
          If tmpOrg.Departments(i).subDepartments(j).Parameters(k).Name = "Name" Then
            sht.Cells(rowCntr, 2) = tmpOrg.Departments(i).subDepartments(j).Parameters(k).Value
            Exit For
          End If
        Next k
        ' run through each resource
        For k = LBound(tmpOrg.Departments(i).subDepartments(j).Resources) To UBound(tmpOrg.Departments(i).subDepartments(j).Resources)
                    sht.Cells(rowCntr, 2 + k) = tmpOrg.Departments(i).subDepartments(j).Resources(k).ResourceName & " [" & tmpOrg.Departments(i).subDepartments(j).Resources(k).ResourceID & "]"
        Next k
      Next j
    Next i
End Sub

Private Sub cmdRandomDepartment_Click()
    ''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Forces the user to confirm choice before excuting
    ' destructive function
    ''''''''''''''''''''''''''''''''''''''''''''''''''
    Dim ans As Integer

    ans = MsgBox("Are you sure you want to Run this?  Warning:  Data will be overwritten!", vbYesNo)
    If ans = 6 Then Worksheets("Departments").Analyze_Organization
End Sub

Private Sub cmdRandomResourcePool_Click()
    ''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Forces the user to confirm choice before excuting
    ' destructive function
    ''''''''''''''''''''''''''''''''''''''''''''''''''
    Dim ans As Integer
```

```
    ans = MsgBox("Are you sure you want to Run this?  Warning:  ALL RESOURCES WILL BE DELETED AND RECREATED", vbYesNo)

    If ans = 6 Then Worksheets("Resources").Analyze_Component

End Sub
```

Sheet5: Log Sheet

```
Private Sub cmdClearLog_Click()

    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''

    ' Clears the log sheet

    '''''''''''''''''''''''''''''''''''''''''''''''''''''''''''


    If Worksheets("Log Sheet").Cells(1, 2) > 2 Then

        Rows("2:" & Worksheets("Log Sheet").Cells(1, 2)).Select

        Selection.Delete

        Worksheets("Log Sheet").Cells(1, 2) = 2

        Worksheets("Log Sheet").Cells(2, 1).Select

    End If

End Sub
```

Sheet6: Optimization Combinations

```
Public Sub cmdClearCombinations_Click()

    ''''''''''''''''''''''''''''''''''''''''''''''

    ' Clears old combinations sheet

    '''''''''''''''''''''''''''''''''''''''''''''

    If Worksheets("Optimization Combinations").Cells(1, 2) > 3 Then

        Rows("4:" & Worksheets("Optimization Combinations").Cells(1, 2)).Select

        Selection.Delete

        Worksheets("Optimization Combinations").Cells(1, 2) = 3

        Worksheets("Optimization Combinations").Cells(4, 1).Select

    End If

End Sub
```

Sheet7: Optimized Assignments

```
' Do nothing.  This is just a storage sheet.
```

Sheet8: Optimization Setup

```
' Do nothing.  This is just a storage sheet.
```

Sheet9: Assignment Summaries

```
' Do nothing.  This is just a storage sheet.
```

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