A web-based decision support system for the allocation of audit resources

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It all starts here ™

Abstract

Internal auditing is a crucial business process, as it ensures that an organization's operations run effectively and that the organization's business documents are creditable. However, as auditing is an intensive process, the resources available are usually insufficient to conduct complete audits. It is therefore necessary to allocate audit resources in such a way that the overall risk to the organization is minimised. Furthermore, because large organizations can have a large number of departments that are separated geographically, it can be difficult to obtain input from all of the applicable role-players, such as auditors that have working knowledge of the departments and whose input can help reduce the risk faced by the organization. In this study a web-based decision support system is proposed that utilises various techniques, such as the Analytic Hierarchy Process (AHP) and the Method of Lagrange Multipliers, in order to determine audit resource allocations. The study also introduces a consensus technique that was specifically developed for use with the AHP. These techniques were implemented in a web-based system that produced repeatable, reliable results during testing. The system was also demonstrated to an industry representative that has experience with audits, who found the system to be highly usable and very versatile. The study makes several contributions to the fields of Auditing and Risk Management, and in a broader respect to the field of Information Security, as it proposes improvements to an existing audit method that is used to safeguard an organization's crucial business information. The study follows a positivistic design and create approach, which includes a literature study, the development of a new web-based system, and the testing of said system.

Keywords

Decision Support Systems, Internal Auditing, Resource Allocation, Consensus, Analytic Hierarchy Process, Method of Lagrange Multipliers

Opsomming

Interne ouditering is ŉ kritiese besigheidsproses, aangesien dit verseker dat ŉ organisasie effektief bedryf word en dat die organisasie se besigheidsdokumente geloofwaardig is. Aangesien ouditering ŉ hoogs intensiewe proses is, is die beskikbare hulpbronne gewoonlik onvoldoende om volledige ouditte te doen. Dit is daarom nodig om oudit hulpbronne só toe te ken dat die algehele risiko vir die organisasie geminimeer word. Verder, aangesien groot organisasies ŉ groot hoeveelheid departemente kan hê wat geografies geskei is, kan dit moeilik wees om insette te kry vanaf al die betrokke rolspelers, soos die ouditeurs wat werkende kennis het van die departemente en wie se invoer die risiko vir die organisasie kan verminder. In hierdie studie word ŉ webgebaseerde besluitsteunstelsel voorgestel wat ŉ verskeidenheid tegnieke, soos die Analitiese Hiërargiese Proses (AHP) en die Metode van Lagrange Vermenigvuldigers, gebruik om oudit hulpbron toekennings te bepaal. Die studie stel ook ŉ konsensus tegniek voor wat spesifiek vir gebruik saam met die AHP ontwikkel is. Hierdie tegnieke was in ŉ webgebaseerde stelsel geïmplementeer wat herhaalbare, betroubare resultate tydens toetsing opgelewer het. Die stelsel was ook aan ŉ industrieverteenwoordiger, was ervaring met ouditte het, gedemonstreer en dié het gevind dat die stelsel baie bruikbaar en aanpasbaar is. Die studie maak verskeie bydraes binne die veld van Ouditering en Risiko Bestuur, en in ŉ breër sin binne die veld van Inligting Sekuriteit, aangesien dit verbeteringe voorstel om ŉ bestaande ouditering metode, wat gebruik word om ŉ organisasie se kritiese besigheidsinligting te beskerm, te verbeter. Die studie volg ŉ positivistiese ontwerp en skep benadering, wat ŉ literatuurstudie, die ontwikkeling van ŉ nuwe webgebaseerde stelsel, en die toetsing van voorafgenoemde stelsel insluit.

Sleutelwoorde

Besluitsteunstelsels, Interne Ouditering, Hulpbrontoekenning, Konsensus, Analitiese Hiërargie Proses, Metode van Lagrange Vermenigvuldigers

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Chapter 1 : INTRODUCTION AND PROBLEM STATEMENT

1.1 INTRODUCTION

The first chapter focuses on providing an introduction to the study, as well as a brief overview. The chapter starts with a discussion of the problem statement, followed by the study's research aims and objectives. The various research methodologies that have been used are then discussed briefly, followed by an overview of the specific research method used in this study. The chapter then concludes by providing an overview of the structure of the study by briefly describing each of the remaining chapters.

1.2 PROBLEM STATEMENT

One of the most important functions that any business has to perform is that of auditing as it lends credence to business documents (Gray & Manson, 2000) and helps to prevent fraud and mismanagement (Patton *et al.*, 1983). Unfortunately auditing requires a substantial amount of time and effort which in turn translates to increased business expenditure. As such, most companies only audit processes and business functions that include a high risk of fraud, or where a close eye on business transactions are crucial to the success of the business. Because the risk of fraud or mismanagement increases when a process is not audited regularly, the available audit resources need to be managed in a way that will minimise the organization's overall risk. There is also a significant difference of opinion regarding risk factors that are relevant to the auditing process (Van Buuren *et al.*, 2014), which leads to the conclusion that a flexible method to calculate audit risk is needed. This study proposes a Decision Support System (DSS) to help determine the areas of greatest risk by utilising a combination of the Analytical Hierarchy Process (AHP) and other mathematical techniques.

A number of studies focused on resource allocation and specifically audit resource allocation, such as those done by Pathak & Baldwin (2008) and Fukukawa *et al.* (2011), but no studies were found that address the problem of allocating audit resources within a distributed environment, such as a multinational or international company, nor were there any found that allow for the participation of multiple role-players. As these types of organizations tend to have increasingly complex business operations, objective inputs from multiple role-players tend to improve the audit process, as problem areas are better identified when a greater number of role-players are given the opportunity to provide their input. This is where this study aims to make a novel contribution, in that it proposes a method that can be used to calculate audit resource allocations within such an environment, i.e. where the participation of multiple role-players in the audit planning process improves its efficacy.

As for the system proposed for this study, a DSS type system was selected because it allows for a flexible method to solve a problem that is mostly unstructured, such as those that management typically has to deal with (Sprague, 1980). In addition, it utilises data analysis and data processing techniques to produce a solution that will aid the auditors in determining the most suitable course of action. A DSS is therefore considered well-suited to handle this problem.

The AHP as primary solution, is proposed because it is a suitable algorithm for evaluating audit risk and because it has a sound mathematical foundation (Patton *et al.*, 1983). This technique, which in this study uses risk factors as comparison criteria, and the Method of Lagrange Multipliers as optimization method, provide for a logical method to allocate audit resources and have the added advantage of producing answers that are easily justifiable. The literature has also shown that the technique is well suited for use in resource allocation (Krüger & Hattingh, 2006). Additionally, it allows for the flexibility needed when dealing with varying risk evaluation philosophies. While an audit system utilising the AHP has already been proposed (Lin *et al.*, 1984), the system lacks the customisability, flexibility and distributed nature that is required by modern companies, specifically those that conduct business on an international level and therefore have a team of auditors that function in a regionally independent manner, whilst still being accountable to a head office. The proposed system would, in order to account for this deficiency, be web-based to allow for access to a central, standardised system that will enable the auditors to reach a consensus regarding the allocation of audit resources, regardless of their physical location, in an automated manner that does not require the auditors to physically meet and discuss the various options. This will enable the auditors to assess the various divisions being audited via a standardised method, which will actively promote the organisation's goals and allow for a transparent method for assigning audit resources. Furthermore, by utilizing the primary risk factors that have been identified by the Institute of Internal Auditors (The Institute of Internal Auditors, 2015) as evaluation criteria for the allocation of audit resources, the available resources are naturally allocated in a much more effective way.

It should however be mentioned that, as the solution will always incorporate part of the problem, and the solution will never be perfect, merely "good enough" resource allocation is an inherently "wicked" problem, according to the properties of wicked problems as first described by Rittel & Webber (1973). The ideal solution to allocating audit resources would, after all, be to increase the auditing budget so that the entire organization can be audited on a continuous basis. However, because increasing the auditing budget to such a degree is not a feasible solution, parts of the organization will have to face a greater risk of fraud and mismanagement in order to minimise the overall risk to the company. In doing this, these parts become metaphorical sacrifices for the greater good of the company, and the method used to select the sacrificial parts will necessarily determine the solution, and as such form part of solution itself. This means that, should the audit resources be allocated based on an evaluation using a specific set of risk factors, those risk factors determine the solution and are therefore part of the solution. This means that it will always be possible to state the solution obtained using this method in terms of the risk factors used – use of different risk factors may, after all, produce an alternate solution that is just as valid. The aim of this study is therefore not to provide for a method to solve the problem of allocating audit resources in a distributed environment, but merely to provide for a method of allocating audit resources in a better, more efficient way.

In summary, the aim of this study is to develop a web-based DSS that will aid in the allocation of audit resources within an organization that has multiple, geographically separate divisions. The proposed system will allow for the aforementioned resources to not only be assigned in a standardised way, but will allow for the distinct role-players, such as auditors and managers, to provide their input regardless of geographical boundaries. In addition, these inputs will be tested for consistency and finally be mathematically processed such that the inputs ultimately used for resource allocation will be comparable to the consensus among the role-players.

1.3 RESEARCH AIMS AND OBJECTIVES

The primary goal of this study is to develop a web-based DSS that utilises a number of mathematical techniques, including the AHP, which aids in calculating how audit resources should be assigned to various audit units, such as company departments. In support of this primary objective, a number of secondary goals need to be addressed as well:

- As the system is aimed towards auditing, it is necessary to understand how the audit process works and where the system will fit in. The goal is therefore ***to gain a functional understanding of how auditing works in general***, so that the system can be designed properly.
- The system developed during the course of this study will require a number of mathematical techniques and models in order to function. These models and techniques include, among others, the AHP, consensus heuristics, nonlinear programming models and a model used to calculate audit resource allocation from an AHP result. The goal in this regard is ***to gain a clear understanding of how these models work and how they, along with the techniques, can be used in an implemented system.***
- The proposed system for this study is a DSS. In order to ensure that a DSS is produced, rather than a generic web-based application, a working knowledge of DSS should be obtained. The next goal is therefore ***to properly describe DSS and its***

characteristics, and explain how a system can be evaluated in order to determine if it is indeed a DSS.

- The final of the secondary goals is to evaluate the system that was developed during the course of the study. This evaluation should address the crucial aspects of the system, namely that the system is indeed a DSS, that its results correlate to what is mathematically expected, and that the produced system is in fact usable. The goal here is therefore ***to describe a testing procedure, follow the testing procedure, and finally produce an evaluation of the system that addresses all of the aspects crucial to its viability.***

1.4 METHODS OF INVESTIGATION

In the interests of clarity, a brief discussion of the various possible research paradigms that can be followed will now be given, followed by a description of the overall method used for this study. The following descriptions are based primarily on the work done by Oates (2006). The paradigms that will be discussed are positivism, interpretive research and critical social research.

1.4.1 POSITIVISM

Positivism is, simply put, a research paradigm that maintains that all scientific study should be made based on observable and repeatable facts. Positivism also maintains that the universe is not dependent upon the existence of an observer; therefore, the impact the observer has on the object of study should either be fully accounted for or eliminated completely. Positivism is furthermore based on empirical observation of facts, i.e. that which can be observed with the senses (Angers, 2013). Subsequently, positivism tends to lead to the development of laws and theories that aim to describe the universe in an almost summarised manner. The necessity for the development of these laws comes from the need for scientific facts to be both 'trans-situational' and 'trans-temporal', i.e. that they are valid everywhere in the universe, rather than just the "here and now" (Prendergast, 1979).

Because of the structured nature of positivism, it is generally regarded as the paradigm most associated with scientific study. The research strategies most associated with this paradigm are, among others, strategies such as experimentation and design and create. The data collection methods in both of these cases can vary between various types of observation and simulation, but the final data obtained is almost always analysed in a mathematical, statistical manner.

1.4.2 Interpretive Research

Interpretive research stands in stark contrast to positivism in that interpretive research is used to identify and explore the interrelated factors within a research domain that cannot be described using positivistic approaches. Interpretive research is therefore often associated with fields such as anthropology, sociology and psychology, as these fields focus on exploring the subjective and often ambiguous facts surrounding human actions and understanding. It also differs from positivism in that, where positivism's aim is to obtain a set of laws that can describe the universe, interpretive research is more ideographic in nature, i.e. it is often more concerned with the aspects of a single entity than of the possibly non-existent aspects of the group within which the entity is found (Creswell *et al.*, 2012). Interpretive research also tends to focus on more subjective subjects, such as human perception. In this, interpretive research can be used to describe any number of subjective "realities" and the results of interpretive research are therefore often not universally applicable, or only applicable in some select cases. Interpretive research also generally produces more than one valid explanation for the results of the study, and the outcome of a particular study therefore tends to itself be subjective.

As interpretive research tends to be more subjective in nature, there is virtually no research strategy that cannot be used in interpretive research. There are, however, two main research strategies that are almost exclusively associated with interpretive research, namely the evaluation of case studies and ethnography (Oates, 2006). As they are both highly unstructured in nature, neither of these methods have any clear forms of data that can be extracted, as the specific data obtained would necessarily depend upon the specifics of the research strategy being followed. In general though, the types of data typically collected include documents, observations, interview reports and focus group reports. These types of data, being qualitative in nature, can seldom be analysed mathematically and are therefore typically analysed using methods such as hermeneutics, content analysis, conversation analysis, discourse analysis and narrative analysis.

1.4.3 Critical Social Research

Critical Social (CS) research is generally less well known than interpretive research and positivism. This follows from the nature of CS research, namely that it brings about a change within a social environment and then observes the impact of such a change. Because of the social nature of the research paradigm, CS research is very similar to interpretive research, with the main distinction being that where interpretive research aims to describe and explain various interrelated factors with regards to an entity, CS research observes an environment, and then affects change within that environment to observe the impact of the change. CS research is therefore also highly subjective in both its methods and conclusion, as a change that might be considered positive by one individual might be considered negative by another.

CS research has almost no limit to the number of research strategies, data collection and data analysis techniques that it can implement. The only requirement for CS research is that the methods used can either be used to evaluate the group being researched or affect change within that group. As such, any technique from observation, to case studies, to action research can be used to collect data for CS research. The types of data and data analysis used in CS research are equally varied, as both quantitative and qualitative data can be used to describe how an environment has changed.

1.4.4 Research Method Used for This Study

With the specifics of the research paradigms and methodologies established, the research method that is followed during the course of this study will now be described. The study is positivistic in nature and will follow a design and create research strategy. This strategy, according to Oates (2006), involves the development of new IT products, such as applications. The research strategy, in this instance, is focused on the development of an IT application based upon a proven model, and the evaluation of said developed system. The aim of this particular type of design and create strategy used in this study is to illustrate how, or prove that, a particular model can be implemented as an IT product and that the produced product is useful as an implementation of that model. The specific method of study is as follows:

1. Obtain functional, background information on auditing.
2. Identify relevant mathematical techniques to use in the study.
3. Determine the exact nature of DSS so that evaluation criteria can be developed.
4. Develop a web-based DSS that addresses the research problem.
5. Use simulations to determine the accuracy of the system's results.
6. Evaluate the system using the results obtained from the simulations, as well as the evaluation criteria obtained in step 3.

For the development of the web-based DSS, the ASP.NET framework was selected. The reasons for selecting this particular framework are mostly subjective in nature, as the researcher is most comfortable with the C# coding language, which can almost exclusively be used with ASP.NET. The second, less subjective reason is that, as the DSS that is developed is aimed at management level individuals and auditors that have to maintain a certain degree of confidentiality, the DSS will have to be capable of incorporating certain security features, such as limited access. As ASP.NET uses server-side processing, it is better suited to designing secure systems than, for example HTML. PHP would have been a viable alternative, but was not selected based upon the researcher's lack of familiarity with the language.

1.5 Structure of Study

In this section an overview along with a short description of each of the various chapters in this study are given. The study has 6 chapters in total including the introduction and conclusion chapters.

1.5.1 Chapter 2: Auditing Principles and Related Concepts

Chapter 2 is a primarily literature based chapter that focuses on the various relevant aspects of auditing, such as internal auditing, the principles of risk management, audit planning, and the allocation of audit resources, along with some of the strategies associated with the allocation of audit resources. The purpose of this chapter is merely to provide a working knowledge of auditing, and not to provide an in-depth discussion of the various complexities and attributes of auditing.

1.5.2 Chapter 3: Management Science Techniques Used in this Study

Chapter 3 focuses on the various mathematical techniques and models used in this study, such as multi-criteria and multi-objective techniques, consensus techniques, nonlinear optimization and resource allocation models. The purpose of this chapter is to describe the techniques and models used, but not the theoretical mathematical principles that were used to develop them. The focus is therefore on the application of the techniques and models, rather than the theoretical mathematical principles that support them.

1.5.3 Chapter 4: Development of the Decision Support System

In chapter 4 the DSS that was developed for the study is described. The chapter starts with a description of DSS in general, with specific reference to the definition of a DSS, its characteristics, and a framework describing DSS in general. The chapter also aims to clarify the distinction between DSS and expert systems.

Following this more theoretical section, the chapter moves on to discussing a consensus heuristic that was developed for this study, along with a brief mention of why it was needed. The AHP is then discussed using an example, after which the system itself is described, along with an example illustrating how the mathematical techniques described in chapter 3 are applied.

1.5.4 Chapter 5: Results and Discussion

The focus of chapter 5 is on the evaluation of the DSS described in chapter 4, along with a discussion of the results of the aforementioned evaluations. The chapter starts with an evaluation of the system according to the characteristics of a DSS as described in chapter 4, followed by a description of the procedure followed when testing the DSS using simulated data. The data obtained from these simulations are then discussed, after which the simulations are altered to illustrate how the system can be used to perform "what-if" analyses. The chapter then provides a summary of the comments received from an external evaluator that has experience with industrial audits, and concludes with a list of the contributions the study has made.

1.5.5 Chapter 6: Conclusion

The final chapter focuses on the overall results of the study, with specific reference to how the research aims were met and how the problems experienced during the study were addressed. The chapter concludes with a brief mention of future work that can be done based on this study.

1.6 Chapter Summary

In this chapter the basic concepts of the study are explained. The chapter provides an introduction to the purpose of the study, moved on to discuss it aims and objectives and described the research methodology that is followed. The chapter then concludes with a brief overview of the remainder of the study.

Chapter 2 : Literature Review – Auditing Principles and Related Concepts

2.1 Introduction

This study involves the development of a decision support system to aid in the allocation of audit resources. This chapter focuses on discussing the primary aspects of auditing that are relevant to this study.

To that end, the chapter begins with a short overview on auditing, with particular attention given to internal auditing. The discussion then moves on to risk management and how the audit process contributes to risk management. In this section the concepts of audit planning, the audit cycle, risk management and the selection of audit units are discussed.

The final section of this chapter focuses on resource allocation. This discussion focuses on a description of the overall concept, how resource allocation is typically done and how it applies to auditing. The section then concludes with a brief overview of the literature with regards to resource allocation

2.2 Auditing: Basic Principles

The core premise of this study is that the resource allocation component of audit planning can be optimised using various mathematical techniques, specifically the Analytic Hierarchy Process (AHP) and the Method of Lagrange Multipliers. Unfortunately, this statement makes little sense to someone without at least some background in auditing. In order to remedy this, this section focuses on some of the basic principles of auditing.

The overview in this section focuses on the two concepts of auditing that are crucial to this study, namely internal auditing and risk management. The section on auditing focuses on the more fundamental aspects of internal auditing, such as a description of what internal auditing is, and how it usually progresses (section 2.2.2.1). This discussion of internal auditing is done as the system developed in this study is aimed at improving processes associated with internal auditing, rather than auditing in general.

The second concept to be discussed is that of risk management. Risk management, much like auditing itself, has a substantial number of studies, models and techniques associated with it. In fact, auditing within an organization merely forms part of risk management and as such an in depth discussion of risk management lies outside the scope of this study. The focus therefore is on concepts such as audit planning and risk assessment, rather than the various methods and strategies that can be used to control identified risks, such as mitigation or transference (Schwalbe, 2014).

2.2.1 Internal Auditing

The first subject of discussion is that of internal auditing. The IIA (Institute of Internal Auditors) defines internal auditing as such:

"Internal auditing is an independent, objective assurance and consulting activity designed to add value and improve an organization's operations. It helps an organization accomplish its objectives by bringing a systematic, disciplined approach to evaluate and improve the effectiveness of risk management, control, and governance processes."

(The Institute of Internal Auditors, 2015)

Internal auditing is therefore, quite simply, a form of auditing aimed at achieving two primary goals, namely to improve the operational efficiency of an organization and to minimise the potential losses that an organization may face (Patton *et al.*, 1983). This process of minimization might include the reduction or elimination of fraud, mismanagement and bookkeeping errors, to name but a few. As this study's focus is mainly internal auditing, the goal of auditing, for the purposes of this study at least, will be assumed to be the minimisation of organizational losses. In the interest of further clarifying what is meant with internal auditing, the differences between the tasks of internal and external auditors are shown in Table 2.1.

TABLE 2.1: RESPONSIBILITIES OF INTERNAL AND EXTERNAL AUDITORS (SAWYER & SUMNERS, 1988)

Internal auditor	External auditor
An organizational employee.	An independent contractor
Serves the needs of the organization.	Serves third parties who need reliable financial information
Reviews all operations and controls in an organization for efficiency, economy, and effectiveness.	Reviews principal balance sheet and income statement accounts. Reviews operations and internal controls to determine scope of examination and reliability of financial data.
Is directly concerned with the prevention of fraud in any form or extent in any activity audited.	Is incidentally concerned with the prevention and detection of fraud in general, but is directly concerned when financial statements may be materially affected.
Is independent of the activities audited, but is ready to respond to the needs and desires	Is independent of management and the board of directors both in fact and in mental

of all elements of management.	attitude.
Reviews activities continually.	Reviews records supporting financial statements periodically – usually once a year.

This short description of auditing does beg a bit of expansion, however. The process of internal auditing, much like any other management process within an organization, requires certain resources to function. These resources, which may include money and manpower, are necessarily limited. After all, the purpose of a company is to maximise profits and auditing is expensive. A further complication to auditing is the fact that no process within any company is devoid of human interaction. This results in the all too familiar situation whereby the "human aspects" at play in a company (politics, ambition, greed, etc.) influences the actions of both employees and auditors. A manager might have troubles at home that result in a preoccupation that negatively, albeit temporarily, impacts the performance of his department. An auditor might choose to overlook small errors so that he can focus on bigger problems. Both of these scenarios, along with any number that a person can conceive of, illustrate one very important point, namely optimal auditing depends on the proper management of resources. As the primary idea behind auditing is to minimise losses, it follows that there is a direct relationship between the management of resources and the management of risks within an organization.

2.2.2 Risk Management

As mentioned in section 2.2.1, risk management is directly tied to the minimisation of company losses. However, as a company's risk management procedures may include such steps as insurance and various other techniques, it becomes abundantly clear that not all risks within a company can be managed through auditing. Auditing a department will, after all, not reduce the risk of its infrastructure being damaged by a lightning strike. It should therefore be emphasised that risk management, within the scope of this study, relates to risks such as fraud and mismanagement, namely risks that can be mitigated or eliminated entirely through audit procedures.

The DSS developed in this study is aimed specifically at aiding risk management. The system analyses certain risk factors and, based upon those risk factors, provides a recommendation that, if implemented, should reduce or eliminate the impact of certain risks. It indirectly manages the risk by allocating an appropriate amount of resources to the mitigation of that risk. The system itself, along with the details of its operation, is discussed in chapter 5.

Three aspects of the audit process, as it relates to risk management, are discussed. These three aspects are audit planning, risk assessment and the selection of audit units.

2.2.2.1 Audit Planning

Audit planning, as the name implies, involves the analysis of certain risk factors and the collection of specific types of information, that are then used to develop an audit plan (Kaplan & Reckers, 1989). Any organization that performs internal auditing should, based upon its size and the complexities of its operations, develop an appropriate internal audit plan (Institute of Internal Auditors, 2015). The audit plan also details the assignment of the audit staff, as well as the scheduling of any personnel involved in the auditing process (Lee & Jeong, 1995). The audit plan is therefore a comprehensive plan that details the following:

- information that should be collected and reviewed during the audit;
- the process that will be followed during the audit;
- the assignment of the audit staff; and
- the scheduling of the audit staff.

The audit plan should, furthermore, be based on an assessment of which risk the organization faces, and how it exposes the organization to losses of liabilities. This continuous assessment of risk should be the primary focus of the audit planning process, but the organization's strategic plan may be used in planning internal audits as well. By incorporating elements of the organization's strategic plan, its overall attitude towards risk will be incorporated naturally into its audit processes (Institute of Internal Auditors, 2015).

Furthermore, the entire audit process consists of the following seven steps (Sawyer & Sumners, 1988):

1. the preliminary survey;
2. the audit program;
3. field work;
4. development of deficiency findings;
5. preparation of working papers;
6. reporting the audit; and
7. reviews.

Based upon the above information, it can be inferred that internal auditing follows a systematic, cyclic process, due to the repetitive nature inherent in long-term internal audit procedures. The cycle is illustrated in Figure 2.1.

As Figure 2.1 shows, the audit cycle starts with a pre-audit phase. The purpose of this phase is to collect the information necessary to perform the audit. The information collected is generally used to address the scope of the audit. Once the pre-audit phase is completed, the audit planning phase begins.

During the audit planning phase, the audit plan is developed. As mentioned above, this plan outlines the entire audit, from procedures and guidelines to personnel scheduling. After the audit plan has been finalised, the actual audit can begin. Upon the completion of the audit process and presentation of the results to management, the audit cycle can start anew and the entire process then starts from the beginning.

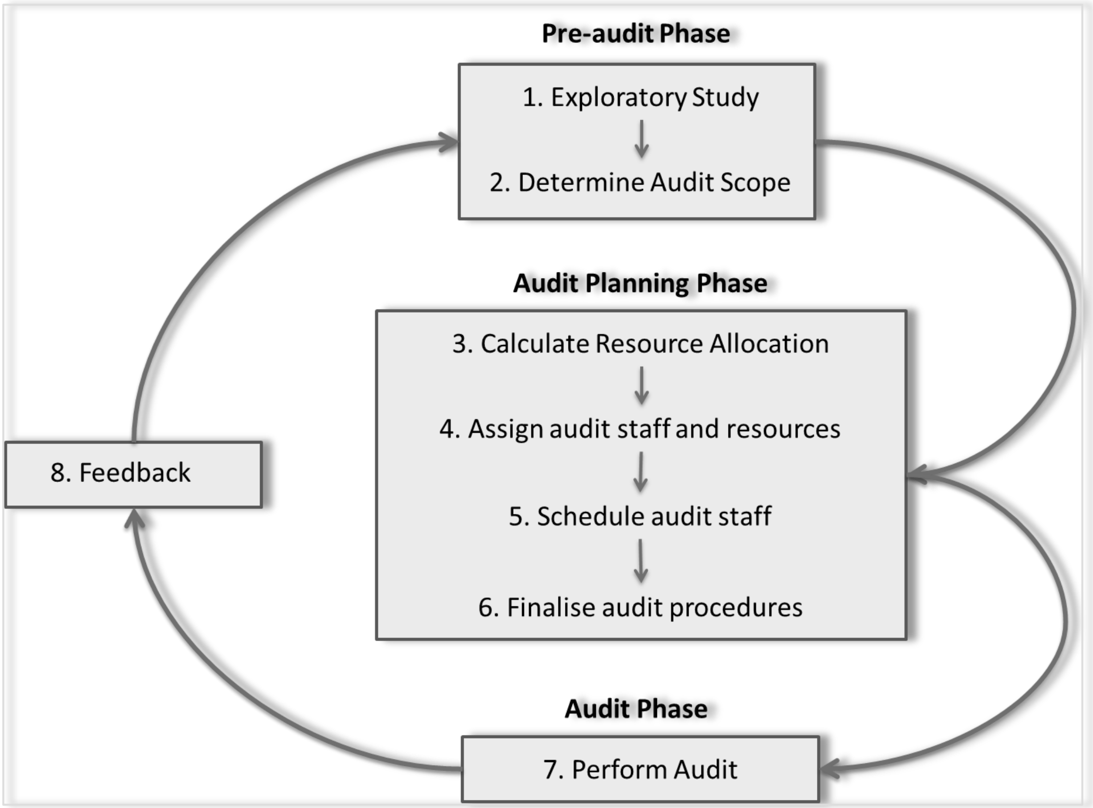


FIGURE 2.1: INTERNAL AUDIT CYCLE

The numbered items in Figure 2.1 comprise of the following.

1. **Exploratory study:** The aim of the exploratory study is to determine what types of information is needed to develop the audit plan. This involves the selection of various risk factors to be analysed, a strategic evaluation based on the organization's strategic plan and a roster of available personnel, to name but a few.
2. **Determine audit scope:** Once the exploratory study has been completed, the information obtained can be used to determine the exact scope of the audit process. The specific audit units are also confirmed in this step.
3. **Calculate resource allocation:** The optimisation of this step is the focus of this study. The aim here is to distribute the available audit resources between the various audit units.
4. **Assign audit staff and resources:** Once the overall allocation of resources has been completed, the specific resources and personnel still need to be assigned. In this

step, the various risk factors, overall resource allocations and personnel backgrounds are used to assign personnel to specific audit units. If the organization utilises an "on-site" training program, personnel undergoing training will also receive assignments in this step. Other relevant resources, such as money, office supplies and hardware, are also distributed in this step.

5. **Schedule audit staff:** Now that the audit personnel have been assigned to their various audit units, their work schedules need to be developed in order to maximise efficiency. Unlike the process followed in step 4, which assigned personnel to audit units, this step involves the scheduling of the assigned personnel based upon the circumstances of the audit unit and the skills of the auditors. If, for example, interviews are necessary, they should ideally be scheduled so that the best interviewer performs the interviews at a time when the interviews will cause the minimum amount of disruption to the unit's activities. As the audit plan needs to be approved by senior management, this step may substitute actual schedules for scheduling procedures, depending on various time constraints.
6. **Finalise audit procedures:** As soon as the audit personnel have received their various assignments and schedules, the overall and specific procedures and guidelines for the audit can be finalised. In this step the audit staff makes any relevant changes, finalises the plan and delivers it to senior management for approval. If senior management requests any changes, these changes are incorporated and returned for approval. Once the audit plan has been approved, the actual audit can begin.
7. **Perform the audit:** As the audit plan has now been completed, the time has come to perform the actual audit. Ideally, the audit will progress according to the audit plan, with minimal deviations.
8. **Feedback:** Upon completion of the audit, the internal auditing division needs to report back to senior management. This feedback may include reports on the various audit units, financial statements, etc. This feedback step also provides some of the information needed for the next exploratory study and allows senior management to comment on the scope of the following audit cycle.

Over the years a number of studies have focused on improving the audit planning process. These studies have primarily focused on the scheduling of audit personnel, and a few examples of these studies are mentioned in Table 2.2. As personnel scheduling is clearly relevant to audit planning, several examples of studies that focus on personnel scheduling in general are also mentioned.

TABLE 2.2: AUDIT PLANNING AND PERSONNEL SCHEDULING STUDIES

Title	Description	Reference
Application of production scheduling methods to external and internal audit scheduling	This study aims to solve some of the audit planning questions by developing a large activity network that is produced using an analysis of a complex, real world auditing environment. The specific audit planning problems are then solved by combining the activity network with an integer programming model.	(Dodin & Chan, 1991)
Audit scheduling with overlapping activities and sequence-dependent setup costs	The complexities that arise as a result of setup costs and overlapping audit activities are discussed. The proposed solution also uses an activity network and an integer programming model.	(Dodin & Elimam, 1997)
Project scheduling under resource and mode identity constraints: model, complexity, methods and application	In this study a mode-constraint solution is proposed to solve the time-resource-cost trade-off problem that is inherent to staff scheduling and, by extension, audit staff scheduling.	(Salewski *et al.*, 1997)
Tabu search in audit scheduling	The problem of assigning multiple auditors of varying abilities to various audit units is addressed. The proposed solution is a heuristic procedure that develops an initial schedule and then improves upon that schedule using a heuristic process.	(Dodin *et al.*, 1998)
Personnel scheduling: a literature review	While this paper does not describe any new techniques, it does discuss several of the studies concerned with personnel scheduling that have been published since 2004. The paper also contains a classification scheme that was used to classify the various studies that were mentioned in the paper.	(Van den Bergh *et al.*, 2013)

Personnel scheduling: Models and complexity	This paper discusses some of the various mathematical models used in solving personnel scheduling problems. Complexity issues of each of the various models.	(Brucker *et al.*, 2011)
Staff scheduling at the United States Postal Service	The study proposes an integer linear program aimed at determining the optimal personnel schedules by taking the various regulations and legal requirements into account. The proposed method can be used to optimally schedule full- and part-time employees in order to reduce overall costs.	(Bard *et al.*, 2003)
A genetic algorithm for scheduling staff of mixed skills under multi-criteria	In this study an algorithm is proposed that utilises a multi-criteria optimization model to schedule personnel with various skills. The study also aims to reduce the overall surplus of available personnel, thereby optimizing the size of the company's staff.	(Cai & Li, 2000)
A multi-agent-based approach for personnel scheduling in assembly centres	In this paper a multi-agent approach is discussed that aims to schedule personnel such that the employees working in a multi-product assembly centre are scheduled according to their skills and their preferences, thereby improving both workforce efficacy and employee satisfaction.	(Sabar *et al.*, 2009)

The part of the audit planning process that this study focuses on is specifically the allocation of overall audit resources. The aim of this study is to develop a system that will help the audit department of an organization to optimise the resource allocation process. The proposed method, instead of using an arbitrary ranking system or a simple heuristic, allocates the resources to each of the audit units based upon the various risks, as well as their perceived importance that have been identified with regard to each of the audit units. This serves to both minimise the overall loss to the company and to improve the efficacy of the audit personnel assignments. The identification of the risks associated with each audit unit is however not such a trivial matter. In the next section, the assessment of the risks, and specifically the risk factors that are relevant to internal auditing, are discussed.

2.2.2.2 Risk Assessment

Assessing, and in fact identifying, the risks associated with each of the audit units is one of the most crucial parts of developing an audit plan. It should however be stressed that the focus of this study is on negative risks, i.e. those risks that may cause harm to the company should the risk develop into an incident (Schwalbe, 2014).

Several of the more common risk factors were identified by Patton *et al.* (1983). These risk factors correlate to those published as examples by the IIA (Hill, 2012) and in the Statements on Auditing Standards (American Institute of Certified Public Accountants, 2002). These risk factors, 19 in total, are as follows:

Quality of an internal control system

Both the design and past performance of a control system can speak volumes about its reliability. The less reliable or weaker the control system is, the more likely it is that errors will be found. As these errors may translate to losses for the company, they should be considered risks.

Competence of management

While this particular risk can be difficult to measure objectively, the competence of the management of an audit unit directly impacts the reliability of the unit's operations. Mismanagement typically leads to lost opportunities and improper use of company funds, therefore, a greater level of incompetence should be met with a greater amount of auditing.

Integrity of management

The integrity of an audit unit's management relates specifically to fraud within the unit. Fraudulent activities are usually tied to overriding the control system, manipulating a loophole, or even circumventing it completely. These fraudulent activities usually result in the enrichment of an employee, or a group of employees, at cost to the company. Unfortunately, ascertaining the integrity of an audit unit's management is difficult, if not impossible, and is usually determined through audits.

Size of unit

The size of an audit unit is determined by the assets associated with it, along with attributes such as cash flow and revenue. Because the loss as a result of a single audit unit is rarely greater than the size of the unit, a bigger unit will usually be associated with a greater possible loss to the company if an incident occurs.

Recent change in accounting system

A change in the unit's control system has consequences the most important among which is that any measure using past performance is invalidated. Another consequence is that the relative strength of the control system is compromised during its "break-in" period, which means that errors are bound to surface while the unit adjusts to the new control system.

Complexity of operations

The operating complexity of an audit unit directly correlates to the complexity of its information and control systems. In addition, as an audit unit's operations become more complex, those operations become increasingly harder to monitor. This means that, as the operational complexity of a unit increases, both the effort required to control the unit and the likelihood of errors increase.

Liquidity of assets

The liquidity of an asset describes how active and mobile the asset is. As an asset becomes more liquid, it also becomes more attractive as a target for defalcations. This usually results in a situation whereby a unit with a substantial number of liquid assets require a greater amount of audit attention than the size of the unit would suggest.

Recent change in key personnel

An audit unit's control system usually depends upon the judgements of competent key personnel, and therefore the reliability of the control system depends upon a certain degree of continuity in personnel. Any changes in key personnel would therefore have a direct impact not only on the control system itself, but on the usability of past performance data on determining the risk associated with the audit unit.

Economic condition of unit

The economic condition of a unit is typically associated with the risk that the unit's control has broken down, or is about to. The result is that units that are in a poor economic state typically pose a greater threat to the company. The control system breakdowns are usually caused by management pressuring the unit to improve its economic condition.

Rapid growth

Rapid growth, in this context, refers to growth that exceeds the ideal limits of the resources that the unit has at its disposal such as personnel. While rapid growth does have its advantages, the rapid change in the unit's environment may cause control problems to emerge.

Extent of computerised data processing

This particular risk factor is concerned with the potential damage that may be caused as a result of computerised data processing. The damage may be caused by any number of things, such as overconfidence in a faulty system, under-confidence in a reliable system, loss of information due to poor technical risk management, user incompetence, etc. Depending upon the specific computerised system used by an audit unit, the extent of computerised data processing may even serve to make its control system more reliable. The result is that the risks inherent to using computerised data processing techniques may be either positive (advantageous) or negative.

Time since last audit

There is an English saying that goes: "A watched pot never boils." The same principle applies here, namely that an audit unit's personnel will aim to avoid committing fraud while an audit is on-going. Subsequently, an audit always has the greatest impact just before and just after the audit, as the management of an audit unit will attempt to either rectify or obscure any evidence of mismanagement or fraud. The result is that a unit's control system is likely to be in its best condition just after an audit. As time progresses, however, the system will likely begin to degrade in the absence of auditing. The time since a unit's last audit may therefore be indicative of possible problems with its control systems.

Pressure on management to meet objectives

As with the economic condition of the audit unit, the pressure on the management of an audit unit to meet objectives may result in a situation whereby the management of that unit will aim to circumvent the control systems, resulting in possible long term losses for the company.

Extent of government regulation

While government regulations are mentioned specifically, this factor ultimately has to deal with any number of unpredictable factors that may pose a risk to the company. Government regulations are used as a standard, as they tend to have significant legal implications if they are not adhered to.

Level of employees' morale

A low morale among the employees may be indicative of significant differences between the employees and management. This may pose a significant risk to the organization, as an unhappy employee that has become disillusioned with management may choose to leave the company only after inflicting damage on the company, either in the form of damage to the control systems, or by helping himself to company assets.

Audit plans of independent auditors

While external and internal auditors have concerns and objectives that differ greatly, their auditing activities may overlap. This could result in a situation whereby the efficacy or efficiency of the internal auditing process may be compromised as a result of the external audit.

Political exposure

While the other risk factors deal with direct financial risks, this factor deals with the impact of a political incident. Any company, no matter how perfect their control systems may be, can fall foul of public opinion. As this may cripple a company, audit units that might experience public scrutiny should be carefully audited.

Need to maintain appearance of independence by internal auditor

In some cases, the efficacy of an internal auditor may depend upon his detachment from the politics and circumstances of the units he audits. Should such detachment be necessary, an auditor that cannot distance himself from the unit's politics may end up causing the organization a significant amount of damage.

Distance of unit from home office

This risk factor merely refers to the possibility that an audit unit that is far away from the home office might experience a less efficient form of internal auditing. It may also refer to the risk that a distant audit unit may utilise ingenious exploits of the control system to commit fraud.

For the purposes of this study these 19 risk factors are assumed to be the most crucial risk factors in evaluating internal audit risk, and as such these 19 factors are included as default in the system.

The process involved in evaluating risk is not limited to picking a number of risk factors for a list, however. The next step requires the selection of a subset of the risk factors mentioned above. Research has shown that, due to the impact of human cognitive ability on the decision making process, the ideal number of risk factors are between five and nine, as any more would make it increasingly difficult for a human to make decisions while keeping track of each of the risk factors (Patton *et al.*, 1983). The selection of the specific risk factors will depend greatly upon the auditor and the nature of the organization conducting the internal audits. However, as the intention here is to distribute audit resources, a simple first step would be to exclude any risk factors that, on their own, do not distinguish between various audit units. An example of this would be to exclude the size of the audit units as a risk factor if the units are of a more or less equal size, as the subsequent inclusion of audit unit size is unlikely to contribute meaningfully to the process. How these risk factors are then used to calculate the allocation of audit resources is discussed in chapter 4.

2.2.2.3 Allocation of Audit Resources

Now that audit planning and risk management has been discussed, all that remains is the selection of audit units. Based on the literature, it can be deduced that there are two primary ways audit units are selected, namely selective and distributive ways.

Selective

The first method used to select audit units is based upon the principle that if an audit unit is selected, it should be audited completely (Sueyoshi *et al.*, 2009). The result is that each of the selected audit units are audited more completely and therefore the length of time that can pass between audits is slightly longer. The disadvantage is that, as not all of the audit units are audited, a problem that may arise in a previously low risk unit may go unnoticed for long enough to become a major problem.

Distributive

The second method is also the method followed by the system developed for this study. Unlike the selective method, which limits the selection of audit units by adding the requirement that the units be audited completely, the distributive method follows the principle that each of the audit units should receive some attention (Patton *et al.*, 1983). The use of this method does have its drawbacks though, as the audit resources are distributed between all of the audit units, a full audit of any of the audit units is unlikely. The second drawback is that an auditor's experience alone usually is not sufficient to calculate the distribution, and a mathematical model is therefore needed to process the auditor's observations into actual percentage allocations.

2.3 Resource Allocation

Because of the complexity of auditing an organization's books and business processes, it is seldom possible to do a full audit of an organization, as the primary resource needed (man hours, money, etc.) are limited. As such, it is usually necessary to allocate the available resources, in a scaled manner, to where they are needed most. The goal in allocating these resources therefore corresponds to that of internal auditing, namely to minimise the risk to an organization (Patton *et al.*, 1983).

In general, any problem that involves the allocation of limited resources to a number of various projects or divisions is referred to as a resource allocation problem (Lin & Gen, 2008). The aim in solving these types of problems is either to minimise cost or company losses by minimising the resources used, or to maximise the efficacy of the limited resources in order to maximise profit. As mentioned above, the goal of internal auditing is to minimise risk and, as such, audit resources should be allocated in a manner that minimises the overall potential losses that an organization might experience. In this section, some of the various methods used to allocate and manage resources are discussed.

2.3.1 General Principles of Resource Allocation

The general principle of resource allocation is that a limited amount of resources are available and that those resources have to be assigned in some way in order to minimise loss or maximise profit. Through analysis of the literature given in section 2.3.4, it becomes clear that a generic structure exists that describes all of the referenced literature and can therefore be used to describe resource allocation in general. An overview of this structure will now be given.

2.3.2 Audit Resource Allocation

There are two primary types of resource allocation techniques, namely those that minimise the amount of resources used, and those that maximise profit (or any type of relevant output, for that matter) by optimising the allocation of resources. An example of the first type would be the study "Energy-aware resource allocation heuristics for efficient management of data centres for Cloud computing" (Beloglazov *et al.*, 2012), in which energy use is minimised, whereas an example of the latter would be "SLA based resource allocation policies in autonomic environments" (Ardagna *et al.*, 2007), where a company's revenue income is maximised (see section 2.3.4 for a more complete description of these studies).

Both of these types of optimization techniques have the same basic structure, in that both:

- Have resources that can be allocated;
- Utilise the allocated resources towards the fulfilment of some quantifiable goal; and
- Make use of a mathematical model to optimise the allocation of said resources.

Audit resource allocation is clearly a maximise profit type of problem, as the resources are limited and the goal is to maximise the amount of negated loss. However, as there may be any number of subjective ways in which audit resources can be allocated, the IIA has created a standard that clarifies which aspects should be analysed when allocating audit resources. A brief overview of this standard will now be given

2.3.3 IIA Standards

The IIA has identified a number of aspects that should receive preference when determining the resources needed to perform an audit. It should be noted that the IIA refers to audit resources as engagement resources. According to the IIA, the following are some of the aspects that should be evaluated when determining overall engagement resource requirements:

- *The number and experience level of the internal auditing staff should be based on an evaluation of the nature and complexity of the engagement assignment, time constraints, and available resources.*
- *Knowledge, skills, and other competencies of the internal auditing staff should be considered in selecting internal auditors for the engagement.*
- *Training needs of internal auditors should be considered, since each engagement assignment serves as a basis for meeting developmental needs of the internal auditing activity.*
- *Consideration of the use of external resources in instances where additional knowledge, skills, and other competencies are needed.*

(Institute of Internal Auditors, 2015)

Based on this, it becomes clear that the proper allocation of audit resources is crucial to the success of audit engagements. It also emphasises that that both the nature of the engagement and the experience of the audit staff are relevant when allocating resources. In this, calculating audit resources based on risk has three clear advantages: one, it addresses the more serious problems first. Secondly, it allows for the assigning of the correct personnel to the correct assignments, and finally, it allows for risk management to be incorporated directly into the resource allocation process. This simplifies the process, as a second risk analysis process in no longer needed.

2.3.4 Relevant Literature

In this section, several examples of literature that discuss resource allocation are shown. While not all of the examples reference auditing specifically, the principle inherent to resource allocation is universal and as such all of these sources are inherently relevant.

TABLE 2.3: RESOURCE ALLOCATION STUDIES

Title	Description	Reference
Optimized resource allocation for emergency response after earthquake disasters	This paper discusses a resource allocation method that aims to minimise the total number of fatalities after an earthquake. A dynamic optimization model is used to calculate resource efficacy and performance for each of the response tasks.	(Fiedrich *et al.*, 2000)
The resource allocation syndrome: the prime challenge of multi-project management?	In this study the so-called "resource allocation syndrome", whereby management focuses primarily on project prioritization but has no available resources, is discussed. The study also discusses the underlying mechanism causing the syndrome.	(Engwall & Jerbrant, 2003)
Energy-aware resource allocation heuristics for efficient management of data centres for cloud computing	A method to improve the energy efficiency of computing clouds through proper resource allocation is discussed. The method uses various scheduling and quality of service (QoS) techniques to minimise the power usage of a cloud.	(Beloglazov *et al.*, 2012)
SLA based resource allocation policies in autonomic environments	This study describes a method used to maximise a company's Service Level Agreement (SLA) revenue income by scheduling the network traffic and ON/OFF time of the company's various servers. The resource in this instance therefore consists of both network capacity and server time.	(Ardagna *et al.*, 2007)
Using mobile telephones: cognitive workload and attention resource allocation	In this paper the impact of using a mobile phone on reaction times while driving is discussed. The resource allocation in this instance is "attention resource allocation", which is significant as it illustrates how the human mind uses natural resource allocation principles when prioritising the execution of certain tasks.	(Patten *et al.*, 2004)

Allocating scarce financial resources across regions for environmental management in Queensland, Australia	A multiple criteria analysis technique is proposed to aid in the allocation of funds to various regional governance agencies in Australia. The technique involves developing a “needs index” which -is then used to calculate how the funds should be distributed between the agencies.	(Hajkowicz, 2007)
Transparency, accounting knowledge and perceived fairness in UK universities’ resource allocation: Results from a survey of accounting and finance	This paper provides a so-called “bottom-up” view of how universities in the United Kingdom allocate resources to its various departments. The paper also describes the impact of transparency and describes how the transparency of the process can affect how fair the process is perceived to be.	(Angluin & Scapens, 2000)
Multi-criteria human resource allocation for solving multistage combinatorial optimization problems using multi-objective hybrid genetic algorithm	A multi-stage decision-making model is proposed to tackle the problem of multi-criteria human resource allocation. The proposed model utilises a multi-objective, hybrid genetic algorithm to solve the optimization problem.	(Lin & Gen, 2008)
The effect of audit scope and auditor tenure on resource allocation decisions in local government audit engagements	The study examines the relationship between audit scope, auditor tenure, and the allocation of audit resources. The study is significant in that it illustrates how audit resource allocation conforms to the set standards in practice, showing that the standards are not merely theoretical.	(Johnson, 2006)
A combined AHP-GP model to allocate internal auditing time to projects	An integrated approach is discussed that utilises both the AHP and Goal Programming (GP). The approach involves the use of the AHP to assess risk, which is a qualitative process, and a GP model to distribute available hours.	(Krüger & Hattingh, 2006)
Audit Resource Planning Success in B2B E-Commerce:	This study describes the development of measurement scales that can be	(Pathak & Baldwin, 2008)

Development and testing of a measurement scale	used to calculate the effectiveness of audit resource planning in a business to business environment	
An application of data envelopment analysis to the evaluation of audit risk	A method is described and demonstrated that shows how data envelopment analysis can be used to calculate consensus for use with the AHP	(Bradbury & Rouse, 2002)
A model for audit engagement planning of E-commerce	A number of critical success factors are identified that can be used to maximise a business' chances of success. The study also introduces a model that can be used to allocate audit resources to this effect.	(Pathak, 2003)
Allocating internal audit resources to minimize detection risk due to theft	In this study a method utilizing the allocation of audit resources to detect theft is evaluated. The method involves auditing a number of units that are controlled by one employee in order to detect possible misconduct.	(Newman *et al.*, 1998)
Client risk factors and audit resource allocation decisions	The broad audit risk factor categories are evaluated based on individual client risk factors in order to determine if these individual risk factors can indeed be categorised in a broad manner. The study also studies the use of these broad categories by auditors to ascertain whether the categories are useful.	(Fukukawa *et al.*, 2011)
Resource allocation decisions in audit engagements	The empirical relationship between audit resource allocations and engagement characteristics is evaluated.	(Hackenbrack & Knechel, 1997)

2.4. CHAPTER SUMMARY

In this chapter the basics of auditing are discussed. This discussion primarily focuses on internal auditing, as the system developed for this study is intended for internal audit use.

Now that an applicable background into auditing is provided, the system itself can be described. Clarity regarding several techniques are still needed, however, and these techniques are discussed in the next chapter.

Chapter 3 : Management Science Techniques Used in this Study

3.1 Introduction

In this chapter some of the various mathematical techniques used in management science is discussed. This discussion serves as background to the algorithms and techniques implemented in the system, as discussed in chapter 4.

First multi-criteria problems are discussed followed by a discussion of two of the techniques used to solve these types of problems. These techniques represent the two main distinct types of multi-criteria problems, namely quantitative and qualitative. The qualitative techniques are represented by the analytical hierarchy process, while the quantitative techniques are represented by goal programming.

The second part of the chapter focuses on consensus and the techniques used to calculate consensus. Three techniques in particular are discussed, namely the Maximise Agreement Heuristic (MAH), the Minimise Regret Heuristic and a distance based approach.

In the third part of this chapter non-linear optimization techniques will be discussed. This discussion will focus on two of the less complex methods, namely the substitution method, and the method of Lagrange multipliers.

In the final section of this chapter some of the various resource allocation techniques that exist are discussed. This section discusses, among others, how the Analytic Hierarchy Process (AHP) can be used to allocate audit resources.

3.2 Multi-criteria and Multi-Objective Techniques

Linear programming is often used to support decision making processes, as it provides a relatively simple mathematical way of calculating the impact of certain decisions. There is a limitation to simple linear programming however, namely the technique's aim is to maximise or minimise a specific goal, such as profit or losses. Most decisions, in contrast, require that the decision maker keep a multitude of goals in mind when making a decision. A company may, for example, require that one of its factories keep production costs as low as possible, while also maintaining its production output and keeping its employees satisfied. This is an example of a **multi-objective** problem, i.e. a problem whereby a decision is made depending upon how well it satisfies a variety of goals. In internal auditing, this translates to a situation whereby the decision surrounding audit units depend upon how well certain risk factors are addressed by allocating resources to that particular audit unit. A

multi-criteria problem, on the other hand, features a number of criteria, e.g. risk factors, which have to be evaluated in conjunction in order to reach a common goal. As such, multi-criteria and multi-objective problems have inverse methods of operation, in that multi-objective makes use of a number of objectives to calculate solution criteria, whereas multi-criteria use given criteria to calculate an ideal objective given the various criteria specified. In this section two techniques are discussed, namely goal programming, that represents multi-objective optimization, and the Analytical Hierarchy Process (AHP), which represents multi-criteria evaluation.

3.2.1 Goal Programming

The principle behind goal programming is relatively simple: each of the secondary goals is formulated as so-called goal constraints. These constraints are then used in a normal linear program, with one exception: if a goal with a lower priority directly conflicts with a higher priority goal, then the constraint associated with the lower priority goal is ignored when formulating the decision. Because the aim of goal programming is to obtain a solution that satisfies all or most of the goals to a satisfactory degree, a number of deviation variables are included. There are two types of deviation variables, namely the variable d_i^+ indicates an overachievement with regards to goal *i*, while the variable d_i^- indicates an underachievement with regards to goal *i.* By minimising the desired deviations of the relevant goals, a solution will be obtained that is as close to optimal as possible.

The intention of goal programming is therefore simply to minimise how much a solution deviates from the goals in general. If a particular deviation is not relevant to the problem, its variable can simply be removed from the goal function. An example of this would be to ignore the overachievement deviation with regards to profit; if a minimum profit margin is the goal, then making more profit should not be a problem.

The standard form of the goal programming model can be written as:

$$Minimise \sum_{i=1}^{m} (d_i^+ + d_i^-), \quad for\ m\ goals, \tag{3.1}$$

$$subject\ to \quad \sum_j a_{ij}x_j \leq b_i, \qquad for\ all\ i, \tag{3.2}$$

$$\sum_j a_{ij}x_j - d_i^+ + d_i^- = b_i, \qquad for\ all\ i, \tag{3.3}$$

$$All\ x_j \geq 0;\ d_i^+\ and\ d_i^-\ \geq 0, \tag{3.4}$$

where a_{ij} is the coefficient, b_i is the right-side value, and x_j is the decision variable.

While there are other methods that can be used to solve goal programming models, such as the Visual Interactive Method (Korhonen & Laakso, 1986), the *Weights* and *Pre-emptive* methods are discussed in this study as they both convert multiple goals into a single objective function and are therefore more closely related to the model shown above. The discussion of the aforementioned model, as well as the description of the methods used to solve it, is based on the work done by Emrouznejad & Ho (2010).

Weights Method

The weight method involves assigning weights to each of the goals to represent their relative importance. The weights $w_1 = 1$ and $w_2 = 2$, for example, imply that the second goal is twice as important as the first one. Once the weights have been assigned, the weighted goals are summed together to form a final objective function that takes each of the goals into consideration.

Pre-emptive Method

The pre-emptive method involves the assignation of several priority levels to which each of the goals are assigned. The goals are then solved from highest priority to lowest, and any lower priority goals that conflict with higher priority goals are ignored. In fact, even if a lower priority goal doesn't directly conflict with a higher priority goal, if the inclusion of the lower priority goal degrades the outcome of any of the higher priority goals, then the goal with the lower priority is ignored.

3.2.2 Analytical Hierarchy Process (AHP)

Goal programming is used when the decision to be made is quantitative is nature. The AHP, in contrast, is used when a more subjective qualitative decision has to be made. This means that when a decision has to be made surrounding quantities, goal programming is used, but when a qualitative decision has to be made, e.g. the selection of a warehouse, the AHP is a more suitable choice. For this reason, the AHP is used when allocating audit resources rather than goal programming, as the AHP can account for the qualitative nature involved in internal auditing.

The basic premise of the AHP is that any multi-criteria, subjective decision-making situation can be structured such that weights can be assigned to the various criteria involved in an objective manner. The discussion that follows is based upon the description given by of the AHP given by Tadisina *et al.* (1991).

The AHP follows the following process: given *n* alternatives and *k* criteria, a number of pairwise comparison matrices are developed. Of these matrices, one is composed of the pairwise comparisons between the various criteria, and *k* matrices for the pairwise comparisons between each of the *n* alternatives with regards to each specific criterion. For each of these matrices a normalised eigenvector is calculated; the eigenvector of the first matrix provides the weights for each criterion ($w_{criterion}$), while the eigenvector of a matrix related to criterion *i* provides the relative weights of each of the alternatives with respect to that particular criterion ($w_{alternative,criterion-i}$). The maximal eigenvalue (λ_{max}) is taken for calculating the eigenvector. The final weight of any alternative *j* is calculated using the following equation:

$$FS_j = \sum w_{criterion-i} \times w_{alternative,criterion-i}$$

(3.5)

Because the eigenvectors are normalised, it follows that $0 \leq FS_j \leq 1$.

The pairwise comparisons are done using a scale ranging from 1 to 9. The specifics of the scale, along with the meaning of the values, are focused on in chapter 5. The standard AHP up to this point is illustrated in Algorithm 3.1.

Because the AHP is based upon subjective inputs, a certain amount of inconsistency is expected within the pairwise comparisons. To ensure that these inconsistencies lie within an acceptable range, a consistency ratio (CR) needs to be calculated. If the CR is less than 10%, the matrix is considered to be acceptably consistent. The equation used to calculate the CR is:

$$CR = \frac{Consistency\ Index\ (CI)}{Random\ consistency\ number}$$

(3.6)

Where

$$CI = \frac{\lambda_{max} - k}{k - 1}$$

(3.7)

The random consistency number is based upon statistical simulation. The random consistency numbers (RI) of matrices with 2 – 10 attributes are given in Table 3.1.

TABLE 3.1: RI VALUES FOR CALCULATING CONSISTENCY RATIO OF A PAIRWISE COMPARISON MATRIX (TAYLOR, 2013)

N	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Algorithm 3.1 illustrates the basic steps followed when using the AHP after the comparisons have been made.

ALGORITHM 3.1: Analytical Hierarchy Process

Input: A set C of comparison matrices and a criteria comparison matrix R
Output: A single set of values indicating the relative importance of each of the criteria evaluated
Variables:

$\boldsymbol{L_i}$ **–** Length of comparison matrix *i*
$\boldsymbol{S_{mi}}$ **–** Sum total of elements in column *i* of matrix *m*
T_{mi} – Average of elements in row *i* of matrix *m*
H_{mi} – Element *i* of result set H_m
C_{num} – Number of criterion result matrices
r – Length of criteria comparison matrix
e_{mij} – Element of matrix *m* at row *i* and column *j*
H_m – Result set for matrix *m*
A – Return set
B – temporary value used to calculate final values

Determine r from R
for k = 1 to r, **do**
    calculate S_{Rk}
    alter the value of each element in column *k* such that $e_{Rik} = e_{Rik} / S_{Rk}$
end
for k = 1 to r, **do**
    calculate T_{Rk}
    add T_{Rk} to H_R
end
for each comparison matrix c in C, **do**
    calculate length v of c
    for k = 1 to v, **do**
        calculate S_{ck}
        alter the value of each element in column *k* such that $e_{cik} = e_{cik} / S_{ck}$
    end
    for k = 1 to v, **do**
        calculate T_{ck}
        add T_{ck} to H_c
    end
end
for each H_m, **do**
    alter each H_{mi} by multiplying it with its corresponding criteria comparison weight in H_R
end
Set C_{num} equal to number of result matrices H_m that have been developed
for k = 1 to C_{num}, **do**
    $B = \sum_{j=1}^{C_{num}} H_{jk}$
    add B to A
end
return *A*

3.3 CONSENSUS TECHNIQUES

In the following section several techniques used to calculate consensus from the inputs of several parties are discussed. Within the scope of this study, consensus will be defined as a set or ranking that represents the overall agreement of all of the participants. This does not need to be an absolute agreement; some deviation from some of the participants' input is expected.

In this section three techniques that can be used to calculate consensus are focused on, namely the Maximise Agreement Heuristic (MAH), the Minimise Regret Heuristic (MRH), and a distance based heuristic. The discussion of the maximise regret and minimise regret heuristics are based on the work done by Beck & Lin (1983), whereas the discussion of the distance based approach is based on the description given by Kruger & Kearney (2008).

3.3.1 MAXIMISE AGREEMENT HEURISTIC

The MAH is based on the idea that overall agreement with a specific ranking should be maximised. To this end, the following will be observed. Given a group of *k* rankers, who have each ranked a collection of *n* objects according to their own preference, an agreement matrix A may be defined, wherein each element a_{ij} of matrix A represents the number of raters who have indicated that they prefer object *i* over object *j*. By calculating the sum of each object *i* across every row in A, a row vector *P* can be produced that indicates how many times object *i* was preferred over object *j*. This positive preference vector *P* may therefore be described as such:

$$P_i = \sum_{j=1}^{n} a_{ij} \quad i = 1, 2, 3, \dots, n$$

(3.8)

In the same manner, if the sum for each object *j* is taken down the columns of A, a column vector N will be produced wherein each element *i* indicate the number of times object *j* was not preferred over any of the other objects. This negative preference vector *N* may be described as such:

$$N_i = \sum_{j=1}^{n} a_{ji} \quad i = 1, 2, 3, \dots, n$$

(3.9)

Using these two equations, the following criterion can be developed:

- If an object *i* has a zero-value entry in the negative preference vector N, i.e. if $N_i = 0$, then there are no instances of object *i* being ranked below any other object; and
- Similarly, if an object *i* has a zero-value entry in the positive preference vector P, i.e. if $P_i = 0$, then there are no instances of *i* being ranked above any other object.

Using these criteria, the objects with the highest and lowest overall rankings can be easily identified. They do not, however, account for the number of instances where a difference of opinion exists between rankers with regards to two particular objects. If, for example, an object A is ranked above object B by one ranker, but another ranker ranks object B above object A, then the above criteria can no longer be used to calculate the consensus rankings of objects A and B. In order to calculate the consensus rankings of the remaining objects, it is therefore necessary to use another criterion.

The criterion that is used to rank the remaining objects is the quantity $(P_i - N_i)$. This quantity can be used to show one of two things:

- If $(P_i - N_i) > 0$, then object *i* was preferred over other objects more often than the other objects were preferred over it; and
- If $(P_i - N_i) < 0$, then there are more instances of an object being preferred over object *i* than there are instances of object *i* being the preferred one.

In order to determine the remaining rankings, $(P_i - N_i)$ is calculated for each of the objects, and if $Max|(P_i - N_i)|$ is positive for an object *i*, then object *i* is allocated to the highest available spot in the rankings, as it serves to maximise the overall agreement towards the ranking. If $Max|(P_i - N_i)|$ is negative, however, then object *i* should be allocated to the lowest available ranking as that will minimise the negative impact upon the final agreement towards the ranking.

The practical application of the above discussion is illustrated in Algorithm 3.2.

ALGORITHM 3.2: Maximise Agreement Heuristic

Input: A set of rankings (K)
Output: A single ranking representing the consensus of set K
Variables:

A - The agreement matrix
P_i - The positive preference vector for object *i*
N_i - The negative preference vector for object *I*
R - The final consensus ranking
D_i - The difference value for object *I*
N - Number of objects that have yet to be ranked

1. Create *A* from *K*
2. Set *n* equal to the number of objects in *K*
3. **while** *n > 0,* **do**
4.   **for** *i = 1 to n* **do**
5. $P_i = \sum_{j=1}^{n} a_{ij}$
6. $N_i = \sum_{j=1}^{n} a_{ji}$
7.   **end**
8.   **for each** P_i calculated in (4), **do**
9.   **if** $P_i = 0$, **then**
10.   enter object *i* in the next available position at bottom of *R*
11.   remove object *i* from *A*, and recalculate the values for *A*
12.   set *n = n - 1*
13.   **end**
14.   **end**
15.   **for each** N_i calculated in (5), **do**
16.   **if** $N_i = 0$, **then**
17.   enter object *i* in the next available position at top of *R*
18.   remove object *i* from *A*, and recalculate the values for *A*
19.   set *n = n - 1*
20.   **end**
21.   **end**
22.   **If** there is no N_i or P_i that equals 0, **then**
23.   **for** *i = 1 to n* **do**
24. $D_i = (P_i - N_i)$
25.   **end**
26.   **select** $Max(|D_i|)$; if multiple options exist, select one arbitrarily
27.   **if** D_i selected in (25) is positive, **then**
28.   enter object *i* in the next available position at top of *R*
29.   remove object *i* from *A*, and recalculate the values for *A*
30.   set *n = n - 1*
31.   **else**
32.   enter object *i* in the next available position at bottom of *R*
33.   remove object *i* from *A*, and recalculate the values for *A*
34.   set *n = n - 1*
35.   **end**
36.   **end**
37.   **if** *n = 1*, **then**
38.   enter remaining object in last available position in *R*
39.   set *n = 0*
40.   **end**
41. **end**
42. **return** *R*

3.3.2 Minimise Regret Heuristic

The MRH is similar to the MAH in that it also utilises an agreement matrix A with elements a_{ij} indicating the number of raters that have ranked object *i* over object *j*. The primary difference between the two methods is that, where the MAH used both the number of agreements and disagreements as its criteria, the MRH only used the disagreement. The main criteria of the MRH are as follows:

- If any ranker preferred object *i* over object *j*, then there will be a net regret, or disagreement, of r_{ji} if object *j* is placed above object *i* in the final rankings; and
- similarly, if there were no rankers that preferred object *i* over object *j*, then the net regret over placing object *j* above object *i* will be 0, i.e. $r_{ji} = 0$.

From this it follows that if a_{ij} is less than a_{ji}, i.e. if more rankers preferred object *j* over object *i,* then the objective function experiences a net regret of $a_{ji} - a_{ij}$ when object *i* is ranked above object *j*, and zero regret if *j* is ranked above object *i*.

The calculated regret values can be defined as elements of a regret matrix R, where each element r_{ij} represents the regret experienced when object *j* is ranked above object *i*. The negative preference vector elements N_i may be obtained by calculating the sum of the rows in the regret matrix R for each column *i.* This may be stated as follows:

$$N_i = \sum_{j=1}^{n} r_{ji} \qquad i = 1, 2, 3, \dots, n$$

(3.10)

In order to develop the regret matrix, each element a_{ij} of the agreement matrix A is compared its inverse element a_{ji}. The following criteria are used to populate the regret matrix:1

- If $a_{ij} \leq a_{ji}$, then there will be a regret value $r_{ij} = a_{ji} - a_{ij}$, as more rankers rated object *j* higher than object *i*. As there are more rankers that preferred object *j* over object *i*, the regret value $r_{ji} = 0$
- If $a_{ij} \geq a_{ji}$, then there will be a regret value $r_{ji} = a_{ij} - a_{ji}$, as more rankers rated object *j* higher than object *i*. As there are more rankers that preferred object *j* over object *i*, the regret value $r_{ij} = 0$

The practical application of the above discussion is illustrated in Algorithm 3.3.

ALGORITHM 3.3: Minimise Regret Heuristic

Input: A set of rankings (K)

Output: A single ranking representing the consensus of set K

Variables:

A - The agreement matrix

P_i - The positive preference vector for object *i*

N_i - The negative preference vector for object *I*

R - The final consensus ranking

D_i - The difference value for object *i*

N - Number of objects that have yet to be ranked

r_{ij} - Regret value of selecting object *i* over object *j*

r_{ji} - Regret value of selecting object j over object *i*

a_{ij} - Value at matrix coordinates *ij*

Create *A* from *K*
Set *n* equal to the number of objects in *K*
while *n > 0,* **do**
    for *i = 1 to n* **do**
        if $a_{ij} \leq a_{ji}$, **then**
            $r_{ij} = a_{ij} - a_{ji}$
            $r_{ji} = 0$
        else
            $r_{ji} = a_{ji} - a_{ji}$
            $r_{ij} = 0$
        end
    end
    for *i = 1 to n* **do**
        $P_i = \sum_{j=1}^{n} a_{ij}$
        $N_i = \sum_{j=1}^{n} r_{ji}$
    end
    for *i = 1 to n* **do**
        $D_i = (P_i - N_i)$
    end
    select $Max(D_i)$
        enter object *i* in the next available position at top of *R*
        remove object *i* from *A*, and recalculate the values for *A*
        set *n = n – 1*
    end
    if *n = 1*, **then**
        enter remaining object in last available position in *R*
        set *n = 0*
    end
end
return *R*

3.3.3 A DISTANCE BASED APPROACH

The distance based approach follows a completely different line of reasoning than the previous two methods. For this approach, a set of *n* individuals and *m* objects will be considered. Let r_{ij} be the rank of the i[th] individual on the j[th] object. If c_j is the consensus rank for the j[th] object, then the i[th] individual's absolute distance, which represents the disagreement with the consensus ranking, is represented by:

$$d_i = \sum_{j=1}^{m} \left| r_{ij} - c_j \right| \quad i = 1, 2, 3, \dots, n$$

(3.11)

The total distance, or disagreement, of all individuals can then be expressed by

$$\sum_{i=1}^{n} d_i = \sum_{i=1}^{n} \sum_{j=1}^{m} \left| r_{ij} - c_j \right|$$

(3.12)

If c_j is assigned an index number k, where k = 1, 2, 3, …, m, then the equation for total distance can be rewritten as

$$\sum_{j=1}^{m} d_{jk}, \quad where\ d_{jk} = \sum_{i=1}^{n} \left| r_{ij} - k \right|$$

(3.13)

As this total distance represents the total disagreement with the ranking, the consensus would be the ranking for which the total distance, of disagreement, is the smallest. This principle can then be applied to an assignment problem, wherein the goal is to minimise the total disagreement, and the assignments are to positions within the ranking. The linear program that represents this problem is as follows:

$$Min \quad \sum_{j=1}^{m} \sum_{k=1}^{m} d_{jk} x_{jk}$$

(3.14)

$$subject\ to \ \sum_{j=1}^{m} x_{jk} = 1 \quad k = 1, 2, 3, \dots, m$$

(3.15)

$$\sum_{k=1}^{m} x_{jk} = 1 \quad j = 1, 2, 3, \dots, m$$

(3.16)

$$x_{jk} \geq 0$$

(3.17)

$$with \quad x_{jk} = \begin{cases} 1 & if\ c_{jk} = k \\ 0 & otherwise \end{cases}$$

(3.18)

3.4 NON-LINEAR OPTIMIZATION

The model used to calculate resource allocations using the AHP, as discussed in section 3.5.3, is a non-linear model. This means that, whereas a linear model has a finite number of solutions, the resource allocation model has a potentially unlimited number of solutions. As such, different modus operandi are needed to solve these types of optimization problems. Two of the more common techniques used to solve non-linear optimization problems, namely the substitution method and the method of Lagrange Multipliers, are discussed in sections 3.4.1 and 3.4.2. These sections are largely based on the work done by Taylor (2013), and verified using the work done by Render *et al.* (2009). It should be mentioned that as only the techniques are relevant to solving the model, the techniques will not be discussed in depth mathematically.

3.4.1 SUBSTITUTION METHOD

While this method is simple computationally, it does have the limitation that it can only be used in situations where only equality constraints are used. This method involves finding each of the possible optimal points on the goal function using graphic analysis, and then substituting the values obtained into the goal function in order to obtain an answer. There are ultimately three steps to this method, namely use substitution to develop a goal function that incorporates each of the constraints, calculate values associated with optimal points, and substitute those values back into the goal function to obtain values for the remaining variables.

The first step involves developing a goal function that accounts for each of the constraints. As this can be done using elementary mathematical techniques, the first step is not discussed in detail. The second step, however, requires utilization of a more complex mathematical principle in order to obtain optimal points. In order obtain these optimal points a simple application of derivatives is used. The derivative of any function *f(x)* is quite simply the function, given as *f'(x)*, which defines the slope of all tangents to *f(x)* in any point *x* (Stewart, 2003). A graphical representation of this principle is shown in Figure 3.1, where the curve $y = x^2 - 8x + 9$ is *f(x)*, and the slope of the line $y = -2x$ is given by the derivative of *f(x)*, which is $f'(x) = 2x - 8$.

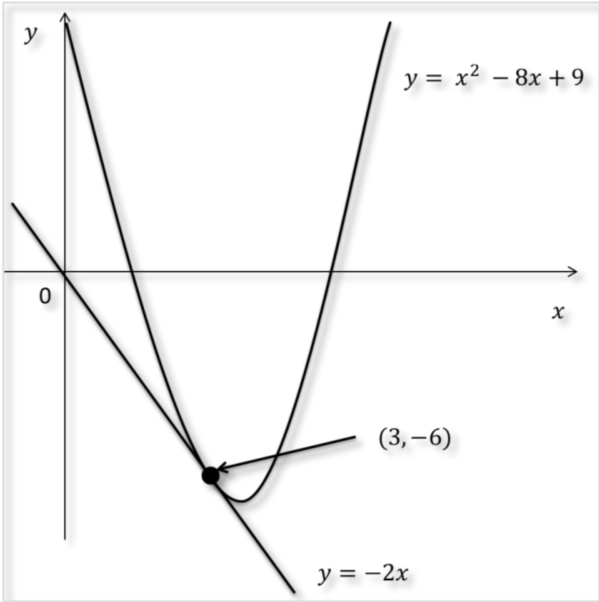


FIGURE 3.1: GRAPHIC REPRESENTATION OF THE DERIVATIVE OF A FUNCTION (STEWART, 2003)

Because *f'(x)* is equal to the slope of all tangents of *f(x)*, it can be used to calculate the value of *x* if the slope is known. When calculating the optimal values of any given goal function, it follows logically that those optimal points will be located at those points where the direction of the goal function changes either from positive to negative or from negative to positive[1]. This is shown in Figure 3.2, where tangents B and C indicate the local minima and maxima[2]. Assuming, for argument's sake, that the curve in Figure 3.2 is not continuous, then B would be the global maxima and C the global minima. The slope of the tangents, and therefore the derivative of *f(x)*, will always be equal to zero in these points.

Therefore, in order to calculate the values for each of the variables in the optimal points, the expanded goal function need only be derived over each of the variables in the goal function. Each of the derived functions are then equalled to zero, simplified, and then substituted back into the goal function. This process is repeated until a value has been assigned to each of the variables.

In the interest of clarity, the following example from Taylor (2013) illustrates how the method is used. For this example, the following program will be solved:

$$Maximize \qquad Z = 4x_1 - 0.1x_1^2 + 5x_2 - 0.2x_2^2$$

(3.19)

[1] Positive and negative in this context refers to the direction of the goal function in relation to the vertical axis of the plane.

[2] Minima are minimum points and maxima are maximum points. A local minima or maxima is any point where the direction of the curve changes. The global minima and maxima are those points where the function has its absolute highest or lowest values.

$$Subject\ to \qquad x_1 + 2x_2 = 40$$

(3.20)

The constraint used in this model already provides for a substitutable value, as both x_1 and x_2 have already been solved in terms of one another. It is therefore possible to substitute the variable x_1 such that the objective function becomes:

$$Z = 4(40 - 2x_2) - 0.1(40 - 2x_2)^2 + 5x_2 - 0.2x_2^2$$

(3.21)

$$= 13x_2 - 0.6x_2^2$$

(3.22)

This is an unconstrained optimization function, which can be solved by calculating the function of the tangent with a gradient of 0. This is done by calculating the derivative of the function and setting it equal to zero:

$$\frac{\partial Z}{\partial x_2} = 13 - 1.2x_2$$

(3.23)

$$0 = 13 - 1.2x_2$$

(3.24)

$$x_2 = 10.8$$

(3.25)

x_1 can then be obtained by substituting the value of x_2 into the constaint equation:

$$x_1 + 2x_2 = 40$$

(3.26)

$$x_1 + 2(10.8) = 40$$

(3.27)

$$x_1 = 18.4$$

(3.28)

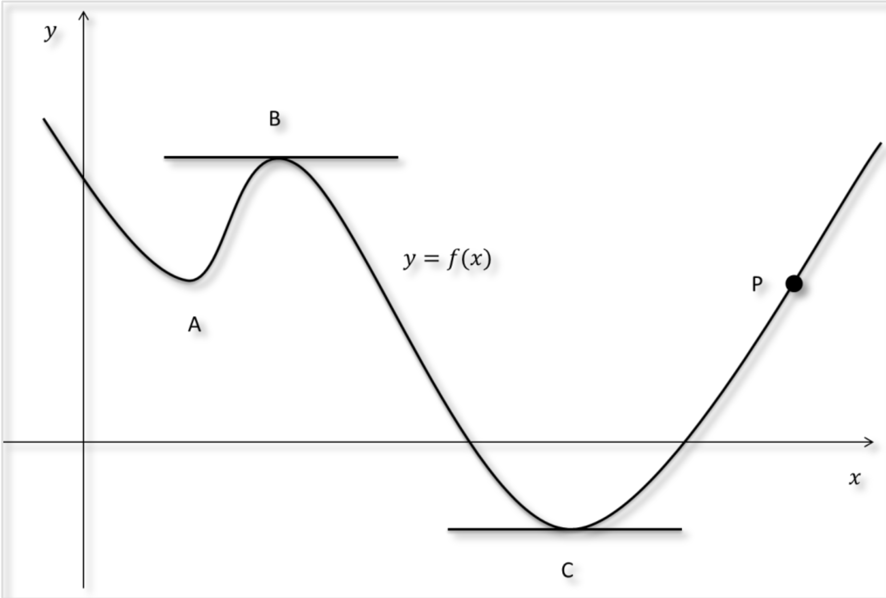


FIGURE 3.2: GRAPHIC REPRESENTATION OF THE TANGENTS TO A FUNCTION'S MINIMA AND MAXIMA (STEWART, 2003)

3.4.2 METHOD OF LAGRANGE MULTIPLIERS

The method of Lagrange Multipliers is of particular interest to this study as it is implemented as an optimization method in the DSS. The method is explained here using basic mathematical principles, as well as a small illustrative example. It should be noted that a complete mathematical and technical account of the technique does not fall within the scope of this study. A comprehensive mathematical presentation of the method of Lagrange Multipliers can be found in Anton (1999).

The method of Lagrange Multipliers is similar to the substitution method in that it utilises the same basic principles. The main difference is that it accommodates a greater variety of constraint types by using a different method to develop a goal function that incorporates all of the constraints.

Consider the following two-variable extremum problem with one constraint: maximise (or minimise) the function $f(x,y)$ subject to the constraint $g(x,y) = 0$. The following procedure for optimization is now followed:

- Create a Lagrange function which is composed of the function to be optimised combined with the constraint function. The function is given by:

$$F(x,y,\lambda) = f(x,y) + \lambda g(x,y)$$

(3.29)

where λ is referred to as the Lagrange Multiplier.

This function suggests that the maximum of $f(x, y)$, if it exists, occurs at a point (x_0, y_0) where the gradient vectors ∇f and $\nabla \mathrm{g}$ are scalar multiples of one another. This can then be expressed as $\nabla \mathrm{f}(x_0, y_0) = \lambda \nabla \mathrm{g}(x_0, y_0)$ for some scalar λ.

- Following from multivariable calculus theory on partial derivatives and extreme values, which are not discussed here, the next step is to find the partial derivative with respect to each variable x, y and λ. The partial derivatives are given by

$$\frac{\partial F}{\partial x} = \frac{\partial f}{\partial x} - \lambda \frac{\partial g}{\partial x}, \tag{3.30}$$

$$\frac{\partial F}{\partial y} = \frac{\partial f}{\partial y} - \lambda \frac{\partial g}{\partial y}, \tag{3.31}$$

$$\frac{\partial F}{\partial \lambda} = g(x, y). \tag{3.32}$$

- Set each of the partial derivatives equal to 0 and, by using $\frac{\partial F}{\partial x} = 0$ and $\frac{\partial F}{\partial y} = 0$, proceed to solve for *x* and *y* in terms of λ. Substitute the solutions for *x* and *y* so that $\frac{\partial F}{\partial \lambda}$ is expressed in terms of λ only. Solve for λ and use this value to find the optimal values for *x* and *y*.

This explanation can be extended to an optimization problem in $\mathbb{R}^n$. Consider the case where the maximum (or minimum) of the function

$$f(\overline{x}) = f(x_1, x_2, \dots, x_n) \tag{3.33}$$

has to be determined, subject to the constraints

$$g_1(\overline{x}) = 0, \qquad g_2(\overline{x}) = 0, \qquad \dots, \qquad g_m(\overline{x}) = 0. \tag{3.34}$$

In this case the Lagrange function is given by

$$F(\overline{x}, \lambda) = f(\overline{x}) + \sum_{i=1}^{m} \lambda_i g_i(\overline{x}). \tag{3.35}$$

The partial derivatives, set to 0, are then given by

$$\frac{\partial F}{\partial x_j} = \frac{\partial f}{\partial x_j} + \sum_{i=1}^{m} \lambda_i \frac{\partial g_i}{\partial x_j} = 0, \qquad j = 1,2, \dots, n$$

(3.36)

$$\frac{\partial F}{\partial \lambda_i} = g_i(\overline{x}) = 0, \qquad i = 1,2, \dots, m$$

(3.37)

The method of Lagrange Multipliers can now again be stated as a search for points on the constraint curve $g(x, y) = 0$ at which $\nabla \mathrm{f}(x_0, y_0) = \lambda \nabla \mathrm{g}(x_0, y_0)$ is satisfied for some scalar value λ.

Example of the method of Lagrange Multipliers

Consider the problem: at which point(s) on the circle $x^2 + y^2 = 1$ does $f(x, y) = xy$ have an absolute maximum distance? This can be stated as the following maximization model:

$$Maximise \qquad f(x, y) = xy$$

(3.38)

$$subject\ to \qquad g(x, y) = x^2 + y^2 - 1 = 0$$

(3.39)

Following the steps explained earlier, the Lagrange function is given by:

$$F(x, y, \lambda) = xy + \lambda(x^2 + y^2 - 1),$$

(3.40)

And the respective partial derivatives are

$$\frac{\partial F}{\partial x} = y + 2x\lambda,$$

(3.41)

$$\frac{\partial F}{\partial y} = x + 2y\lambda,$$

(3.42)

$$\frac{\partial F}{\partial \lambda} = x^2 + y^2 - 1.$$

(3.43)

From (3.41) and (3.42) it follows that

$$\lambda = \frac{-y}{2x} \quad and \quad \lambda = \frac{-x}{2y}$$

(3.44)

which can be simplified such that

$$\frac{-y}{2x} = \frac{-x}{2y},$$

(3.45)

$$=> \ 2x^2 = \ 2y^2 \quad or \quad x^2 = \ y^2.$$

(3.46)

Substituting this into $g(x, y)$ delivers

$$x^2 + \ x^2 - 1 = 0$$

(3.47)

$$=> \ x^2 = \frac{1}{2} \quad or \quad x = \ \pm\frac{1}{\sqrt{2}}.$$

(3.48)

When these values are then substituted into (3.46), the value of y is obtained as $y = \ \pm\frac{1}{\sqrt{2}}$. Thus the function $f(x, y)$ has an absolute maximum of $\frac{1}{2}$ occurring at the points $(\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}})$ and $(-\frac{1}{\sqrt{2}}, -\ \frac{1}{\sqrt{2}})$.

The method of Lagrange Multipliers is referred to again in chapter 4 where the developed DSS is discussed.

3.5 Techniques Used for Resource Allocation

In this section two of the simpler techniques used to allocate resources are discussed. Both of these techniques utilise linear programs to allocate a specific resource towards a specific utility. The first of these techniques, which deals with personnel assignment, can be used directly when developing an audit plan whilst the second, which concerns the selection of projects within a budget, can be adapted for use in selecting audit units. Both the "personnel assignment" and "portfolio selection" techniques are discussed by using general forms that were derived from examples developed by Taylor (2013) and Render *et al.* (2009).

3.5.1 Personnel Assignment

The personnel assignment problem can be described as follows: suppose there are *i* number of unassigned employees, and *j* number of available posts. Each of the employees possesses skills that affect how well they are suited to each of the various posts. This suitability is indicated by the variable x_{ij}, where x is the suitability, or efficacy, of employee i towards job j. In this same scenario it can also be stated that each employee can only be assigned to one post and each post can only receive one employee. This allows for the inclusion of a binary selection variable y_{ij}, where y is equal to 1 when employee i is allocated to post j. The program can then be formulated as a binary integer linear program that has the following format:

$$Max \sum x_{ij} y_{ij}\,, \quad where\ i = 1,2,3, \dots, m\ and\ j = 1,2,3, \dots, n \tag{3.49}$$

$$subject\ to\ \sum_{i=1}^{m} y_{ij} \le 1, \qquad for\ all\ j \tag{3.50}$$

$$\sum_{j=1}^{n} y_{ij} \le 1, \qquad for\ all\ i \tag{3.51}$$

$$y_{ij} = \begin{cases} 1\ if\ employee\ i\ is\ assigned\ to\ post\ j \\ 0\ otherwise. \end{cases}, \tag{3.52}$$

This linear program can easily be adjusted for any situation where a number of objects have to be assigned based upon utility. A technique such as this would be well suited during audit planning to assign specific employees once it has been determined what the optimal overall assignments to each of the audit units are.

3.5.2 Portfolio Selection

The general portfolio selection problem involves the following: suppose there are i number of entities to select from. Each of these entities has a specific value y_i that indicates the relative value of the entity i. If the entities are stocks, for example, y_i would indicate the expected return on investment for each of the stocks. Furthermore, there exists a value x_i

that indicates the amount that has been invested in entity i. For each of the entities there also exists a value z_i that indicates the maximum amount that can be invested in i. Finally, the value Z indicates the maximum amount that can be invested overall. Taking all of this into consideration, the problem can then be formulated into the following linear program:

$$Max\ y_i x_i, \quad where\ i = 1,2,3, \dots, n$$

(3.53)

$$subject\ to\ \ x_i \ \leq\ z_i \qquad for\ all\ i$$

(3.54)

$$\sum_{i=1}^{n} x_i \ \leq Z.$$

(3.55)

By application of simple logic this problem can be restated to deal with the selection of audit units. This can be done by changing the linear problem such that it minimises the total loss suffered depending upon the amount of funds assigned to each of the various entities. In fact, the allocation technique discussed in section 3.5.3 makes use of this very principle.

3.5.3 Minimising Loss Through the Evaluation of Weighted Risk

The following model, as described by Patton *et al.* (1983), is used to assign resources to each of the various audit units being evaluated. In this model the impact of each of the risk factors for a specific audit unit are assigned a weight. This ensures that a less important risk factor has a smaller impact upon the final result. The model also follows a simple rule with regards to the allocation of audit resources, namely as the amount of resources allocated to a specific unit increases, the loss associated with that unit decreases. This means that the loss suffered due to a certain audit unit is inversely proportional to the amount of audit resource allocated to that audit unit. This means that while the total loss caused by a unit can be expressed by the formula

$$(w_1 f_1 +\ w_2 f_2 + \cdots +\ w_n f_n)$$

(3.56)

for *n* risk factors, where w_i is the weight for risk factor f_i, the total loss for an audited unit *I* can be expressed as

$$\int_i = \frac{(w_1 f_1 +\ w_2 f_2 + \cdots +\ w_n f_n)}{a_i}$$

(3.57)

where $\mathcal{L}_i$ is the total loss caused by unit *i* and a_i is the proportion of audit resources allocated to unit *i*.

By altering the "portfolio selection" problem as described in section 3.4.2, the model can be implemented as such:

$$\text{Minimise} \quad \frac{w_1 f_{11} + w_2 f_{21} + \ \ldots + w_n f_{n1}}{a_1} + \frac{w_1 f_{12} + w_2 f_{22} + \ \ldots + w_n f_{n2}}{a_2} + \ \ldots \ + \frac{w_1 f_{1k} + w_2 f_{2k} + \ \ldots + w_n f_{nk}}{a_k}$$

(3.58)

$$subject\ to \ \sum a_i \ \leq 100\%$$

(3.59)

where $\mathcal{L}_i$ = total loss of audit unit *i*, f_{ij} = audit risk factor *i* in audit unit *j*, w_i = importance weight of audit risk factor *i*, and a_i = audit resources allocated to unit *i*

As illustrated in Figure 3.3, the goal-function for this linear program in non-linear. As such, obtaining a solution using this model requires non-linear programming techniques, as described in section 3.4.

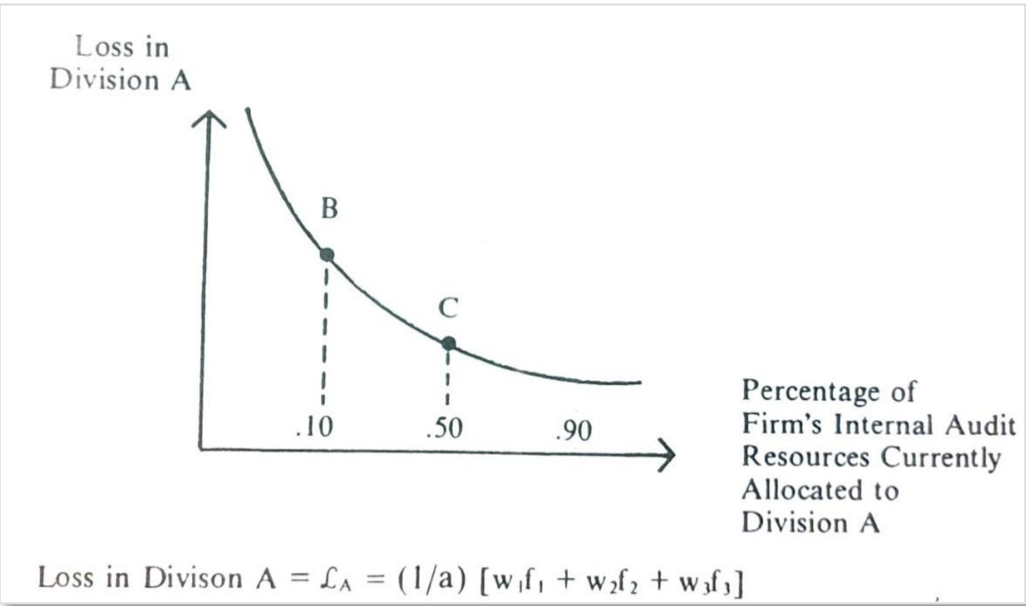


FIGURE 3.3: DIMINISHING EFFECTS OF INTERNAL AUDITING (PATTON *ET AL.*, 1983)

The non-linear solution method used to solve this problem is the Method of Lagrange Multipliers. Subsequently, solving this problem starts with developing a Lagrange goal function by adding the budget constraint $\sum a_i \leq 1$to the goal function, after multiplying it with a Lagrange multiplier λ. The result is the Lagrange function

$$\frac{w_1 f_{11} + w_2 f_{21} + \cdots + w_n f_{n1}}{a_1} + \frac{w_1 f_{12} + w_2 f_{22} + \cdots + w_n f_{n2}}{a_2} + \ldots + \frac{w_1 f_{1k} + w_2 f_{2k} + \cdots + w_n f_{nk}}{a_k} + \lambda(a_1 + a_2 + \cdots + a_k - 1)$$

(3.60)

The next step involves obtaining the *k* simultaneous equations that must be satisfied by the optimal allocation of audit resources. These equations are obtained by taking the partial derivatives with respect to each of the decision variables $(a_1, a_2, .., a_k)$, and equalling them to zero. The result is that, for the first two decision variables, the equations

$$\frac{\partial \int}{\partial a_1} = -\frac{w_1 f_{11} + w_2 f_{21} + \ldots + w_n f_{n1}}{a_1^2} = 0$$

(3.61)

and

$$\frac{\partial \int}{\partial a_2} = -\frac{w_1 f_{12} + w_2 f_{22} + \ldots + w_n f_{n2}}{a_2^2} = 0$$

(3.62)

Repeating this procedure for each of the *k* decision variables produces *k* equations that can then be solved simultaneously using standard algebraic techniques. This produces a set of values for the decision variables, which indicate the percentage of resources that should be allocated to each of the audit units.

Once the weights for each of the risk factors have been obtained, using the AHP in this study, the following equations can be derived:

- The AHP is used to produce a weighted scale. This scale corresponds to the values of w_i in (3.60). For simplicity, the specific AHP scale will be referred to as *b*, with b_i being the i^{th} element of the weighted scale. For each value of *b*, the following equation exists:

$$a_i^2 = \frac{b_i}{\lambda}$$

(3.63)

- However, as an equation is needed to calculate a_i, rather than a_i^2, (3.63) will be restated as:

$$a_i = \left[\frac{b_i}{\lambda}\right]^{\frac{1}{2}}$$

(3.64)

- As the model assigns all available resources, the sum total of all assigned resources will be 100%. Therefore, the following equation can be used to describe the resources allocated using the model:

$$\sum_{i=1}^{k}(a_i) = 1$$

(3.65)

These equations do not, however, provide for a direct way to calculate the value of a_i or λ, so a bit of expansion is necessary.

By substituting every a_i in (3.65) with its corresponding (3.64), the following series is obtained:

$$\sum_{i=1}^{k}\left[\frac{b_i}{\lambda}\right]^{\frac{1}{2}} = 1$$

(3.66)

Solving for λ, the following equation is obtained:

$$\lambda = \left(\sum_{i=1}^{k}\sqrt{b_i}\right)^2$$

(3.67)

Using the values of b_i, λ can be calculated. Once λ has been obtained, (3.64) can be used to calculate the distribution of the audit resources among the audit units.

3.6 CHAPTER SUMMARY

In this chapter some of the techniques used in management science were discussed. The discussion focused on multi-criteria techniques, such as the AHP, techniques for calculating consensus, non-linear programming, and resource allocation.

Now that a working background on auditing and various mathematical techniques has been obtained, the decision support system that has been developed can be discussed.

Chapter 4 : Development of the Decision Support System

4.1 Introduction

In chapter 2 the basic principles of auditing were discussed and in chapter 3 an overview of relevant management science techniques was given. In this chapter the system that was developed using the knowledge gained from the literature in chapters 2 and 3 are discussed.

The chapter starts with a discussion of the type of system that was developed, i.e. a Decision Support System (DSS). This discussion centres on concepts such as the definition of a DSS and its characteristics. The chapter also includes the description of a new consensus heuristic that was developed for the system, as well as an example illustrating why this method was needed. Following this, the actual process follows when using the AHP is illustrated using an example.

Following the given example of the AHP, the chapter shifts focus towards the specific DSS that is developed for this study. This discussion includes an overview of the system, followed by a brief description of how each of the system's various sections function. This discussion also includes a description of how some of the techniques were implemented and how the system develops an answer overall.

4.2 Overview of Decision Support Systems

As this study involves the development of a Decision Support System (DSS), it is necessary to provide a brief overview of what a DSS is. To this end, this section starts by examining some of the existing definitions of a DSS. These definitions are then expanded upon in order to develop a unified definition for a DSS that can then be used to aid in the development of the system proposed in this study.

The next part of this section focuses on a discussion of the various characteristics of a DSS. This discussion is focussing both on the characteristics that follow from the definition for a DSS, and the characteristics as mentioned in the literature.

The third part of the section attempts to clarify the differences between Expert Systems and DSS, as well as to illustrate how this distinction is crucial to the development of a DSS.

The section then concludes by briefly discussing some of the DSS that are mentioned in the literature. The DSS that is discussed ranges from generic DSS to DSS focused on auditing and the allocation of audit resources.

4.2.1 DEFINITION

The term “Decision Support System” is often used to describe any system that aids in the decision-making process, as this description follows naturally from the name. This informal definition does have its weakness, because within this definition *any* system, computerised or not, that aids in the decision-making process can be considered a DSS, even if such a system is, for example, used by a gambler to choose lottery numbers. It is therefore necessary to limit the scope of the definition. One of the simpler definitions for a DSS is as follows:

“Decision support systems (DSS) are computer-based information systems that are designed with the express purpose of improving the process and outcome of decision-making.”

(Arnott, 1998)

This definition adequately describes a DSS in general, but for the purposes of this study it is not clear enough. What distinguishes a DSS from a management system that collects and simplifies financial reports? In what way does it support decision-making? In order to answer these questions, it is necessary to take a deeper look at the characteristics that a DSS has in practice, namely that a DSS (Sprague, 1980):

1. is typically used in cases where the problem is underspecified and not well structured; a common example of such a problem is when management has to select a profitable project from several viable ones;
2. typically uses mathematical models or analytical techniques in order to produce a result using normal data access and retrieval methods;
3. is usually an interactive system developed for “non-computer” people; and
4. is flexible and can adapt to the changes in its operating environment.

Following this, the definition for a DSS can be expanded as follows:

A Decision Support System (DSS) is a flexible and user-friendly interactive computer-based information system that utilises mathematical modelling and analytical techniques to aid in the decision-making process where the problem lacks structure and is poorly specified.

With this definition in hand, some of the more common characteristics of DSS can be discussed. It should also be noted that this expanded definition is the definition adhered to for the remainder of the study.

4.2.2 Characteristics

Following from the definition in section 4.2.1, the following properties can already be assigned to a DSS:

- It has a user-friendly interactive interface.
- It uses mathematical techniques to solve a problem.
- It can easily adapt to changes in its operating environment.
- It *aids* in the decision-making process.

In addition to these properties, which follow naturally from the definition in section 4.2.1, other researchers have also identified several important features of DSS. The following is a brief description of some of the more important properties, as identified by Arnott (1998) and Sprague (1980).

The first feature in this list describes the purpose of a DSS when it comes to the decision-making process, namely *to improve both the performance and efficacy of the process*. It should be noted that this does not necessarily mean that decisions are made faster, only that the process is more robust and that the outcome is more reliable.

The second feature describes the role of a DSS when it comes to facilitating communication. As a large number of decisions within an organization cannot be made in isolation, a DSS has to provide for *communication and coordination between role-players*, especially when the aforementioned communication is critical to the decision-making process.

Another feature involves the actual role of a DSS in the decision-making progress. As will be further explained in section 4.2.4, a DSS and an expert system each play a very different role within the process. The specific role of a DSS is to *utilise the available information to make recommendations, not to make the decisions*. A DSS is therefore not an autonomous system that can function on its own.

The final feature in this list describes the adaptability of a DSS. In order for a DSS to be useful, it needs to adapt to sudden and, in some cases, unexpected changes in its operating environment. These changes can come as a result of a sudden change in legislation or policy, or even changes in the financial state of the organization. As these changes may affect the organization's decision-making process, the DSS has to adapt to incorporate these changes to the process. These changes may range from altering the data that is used in the process, to altering the models used by the system.

All of the above properties need to be present for a system to be considered a DSS.

4.2.3 DSS Framework

In the following section the characteristics and capabilities of a DSS are discussed. This framework aims to describe DSS through the inclusion of most of the characteristics and capabilities that have been found to be common among DSS. The Association for Information Systems' Special Interest Group on Decision Support Systems (AIS SIGDSS) classification scheme for DSS is also discussed briefly, as this serves to illustrate how the purpose and use of a DSS may influence its characteristics.

4.2.3.1 DSS Characteristics and Capabilities

The following section is based upon the work done by Turban *et al.* (2011) in an effort to describe DSS based upon a collection of characteristics that all or some DSS have been shown to possess. Whilst this is neither an exhaustive nor defining list, all DSS possess at least some of the following characteristics. Each of the points in Figure 4.1 is described following Figure 4.1; these points correspond numerically to the items in Figure 4.1.

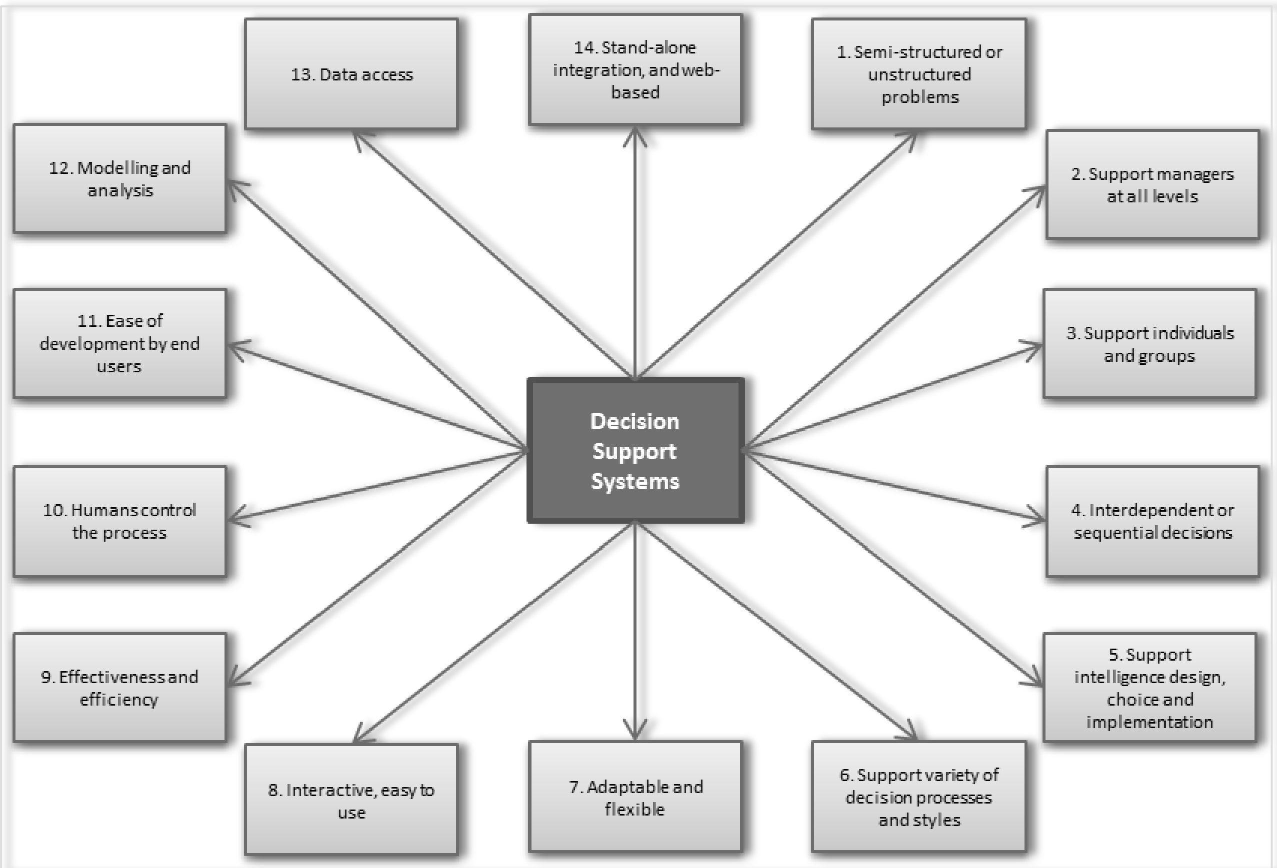


FIGURE 4.1: DDS CHARACTERISTICS AND CAPABILITIES (TURBAN *ET AL.*, 2011)

1. **Semi-structured or unstructured problems:** A typical DSS is designed to support decision makers by solving unstructured or semi-structured problems that, under normal circumstances, cannot be solved using standard computerised techniques. A DSS can therefore be said to combine computerised information and human judgement to solve a complex problem.
2. **Support managers at all levels:** A DSS is not limited to top management, but can also be used to solve managerial problems at any level.
3. **Support individuals and groups:** Both individuals and groups can be supported by a DSS. There are, in fact, situations where collaboration is crucial to solving the problem. A web-based DSS can prove to be quite a boon for groups where there are geographical borders separating the various members.
4. **Interdependent or sequential decisions:** There may be cases where the outcome of one decision can have a profound impact upon another decision. A DSS should be able to adapt to these interdependent decisions, in order to provide an answer that is not based upon isolated information.
5. **Support intelligence design, choice and implementation:** A DSS should support each of the four phases of the decision-making process, i.e. intelligence, design, choice and implementation.
6. **Support variety of decision processes and styles:** A DSS should be flexible enough to adapt to any number of decision-making processes and styles that are used by management. This ultimately returns to the principle of aiding the decision-making process, and not making a decision independently of human input.
7. **Adaptable and flexible:** As operating conditions change, the DSS must change in order to continue providing useful decision-making support. As such, the DSS must be flexible enough to adapt to any changes that may influence the accuracy of its results or impact its usefulness.
8. **Interactive, easy to use:** A DSS should be designed with user-friendliness in mind. In most cases the end-user of a DSS is not a "tech-savvy IT person", but rather a manager with more important things to do than receive training for a new system. A DSS should therefore have a simple, straight-forward, easy-to-use graphical interface.
9. **Effectiveness and efficiency:** The focus of a DSS should not be to improve the efficiency of the decision-making process, but its efficacy. In other words, the DSS should aid in making a decision that is more accurate or beneficial to the user, rather than making the process faster. This usually results in situations where the use of a DSS makes the whole process slower, but leads to outcomes that more than make up for it.
10. **Humans control the process:** The purpose of a DSS is to *aid* a decision maker, not replace him. The final step in the decision-making process therefore involves the decision maker utilising the information provided by the DSS in order to make a final decision.

11. **Ease of development by end users:** This characteristic ties in with the flexibility of a DSS. An end-user should be able to develop and modify a simple DSS independently.
12. **Modelling and analysis:** Unlike management information systems, DSS use models in order to analyse decision-making situations, make predictions and produce useable information based upon certain facts. This enables a DSS user to experiment with different situations and strategies in order to optimise the end result.
13. **Data access:** A DSS can provide access to a large variety of data sources, formats and types. The data can be in any form, from numerical data, to multimedia and documents.
14. **Stand-alone, integration and web-based:** The distribution of a system has no impact on whether it is a DSS or not. A DSS can be a stand-alone desktop application, a web-based application, or even a mobile application.

It should also be noted that the characteristics described in this framework correlate with those in section 4.2.2.

4.2.3.2 AIS SIGDSS Classification

The following classification scheme has been adopted by the AIS SIGDSS. The aim of the classification scheme is to describe various DSS based upon their intended use, as well as the type of data and data processing techniques that they utilise during the decision-making process. Such a classification scheme has merit in that it ties a specific set of characteristics to the operating environment of a DSS. While the scheme does allow for hybrid, or compound systems, the scheme clearly illustrates how the type of DSS influences its characteristics and capabilities. The scheme places a DSS into one of five categories, namely communications-driven and group DSS, data-driven DSS, document-driven DSS, knowledge-driven DSS and model driven DSS.

Communications-Driven and Group DSS

This group contains any and all DSS that support group work that use computer, collaboration and communication technologies. As such, any DSS designed to aid collaborative or communal functions fall into this category. Examples of DSS within this category would include any DSS that supports meetings, design collaboration, or supply chain management.

Data-Driven DSS

A data-driven DSS is a DSS specifically focused on data, processing the data to obtain useable information and presenting the information to the decision-maker. These DSS usually do not require the use of complex mathematical models to function and instead depend upon proper database design.

Document-Driven DSS

A DSS in this category are focused on knowledge coding, analysis and search when aiding decision-making. The data that document-driven DSS usually utilise are in a natural language format, i.e. documents or multimedia created for human consumption. These systems rarely utilise mathematical models, as mathematical data are rarely used by DSS in this category. The aim of the systems in this category is therefore to utilise the data taken from documents in order to aid the decision-making process.

Knowledge-Driven DSS

This category contains DSS that are easily confused with expert systems (see section 4.2.4). A knowledge-driven DSS utilises knowledge processing techniques, such as those associated with artificial intelligence, to address specific decision support needs. These systems are typically used in situations where decisions have to be made quickly and a set of rules can be relied upon to help make a mostly acceptable decision.

Model-Driven DSS

Model-driven DSS are DSS that are built around mathematical models. These models range from optimization models used to improve certain processes, to simulation models used to predict outcomes and suggest alternative solutions. The development of these systems are typically focused on model formulation, model management and model maintenance.

4.2.4 DSS versus Expert Systems

As the two can seem similar at a high level of complexity, it is necessary to properly distinguish between a DSS and an expert system; it could also easily happen that one is used to emulate the other. The first step in explaining the differences between the two is to illustrate the differences between their definitions. One of the simpler definitions for an expert system is as follows:

"An expert system is an intelligent computer program that uses knowledge and inference techniques to solve problems that are difficult enough to require significant human expertise for their solution"

(Giarratano & Riley, 2005)

For concurrency, the expanded definition of a DSS from section 4.2.1 is:

A Decision Support System (DSS) is a flexible and user-friendly interactive computer-based information system that utilises mathematical modelling and analytical techniques to aid in the decision-making process where the problem lacks structure and is poorly specified.

Following these two definitions, it is relatively easy to deduce the core difference between a DSS and an expert system, namely that whereas a DSS is focused on *aiding* the decision-making process, an expert system emulates an expert, i.e. it uses available knowledge to *make* the decision. It should therefore be clarified that the system developed for this study is not an expert system and can therefore only be seen to aid the decision-making process, not automate it entirely. As this use implies functions that a DSS does not possess, a DSS used in this way has a negative impact upon productivity. The recommendations produced by a DSS should not be followed blindly, but should be used within the context of intelligent decision-making processes.

Another difference between DSS and expert systems lie in the overall structure of the systems. In Figure 4.2 and Figure 4.3 the components of the two systems are illustrated. By comparing these two diagrams it becomes clear that, while an expert system has little room for deviation in its structure, a DSS's structure can take on any number of forms.

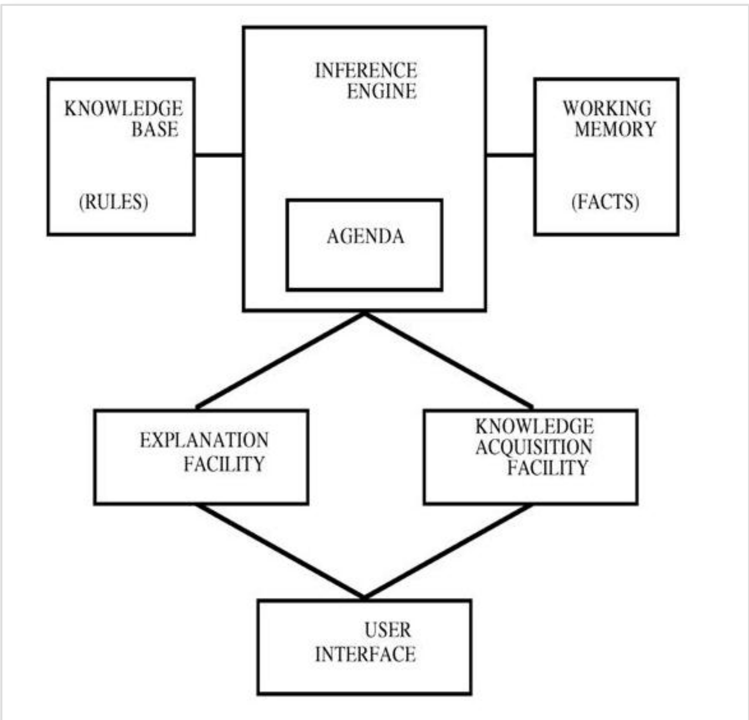


FIGURE 4.2: STRUCTURE OF A RULE-BASED EXPERT SYSTEM (GIARRATANO & RILEY, 2005)

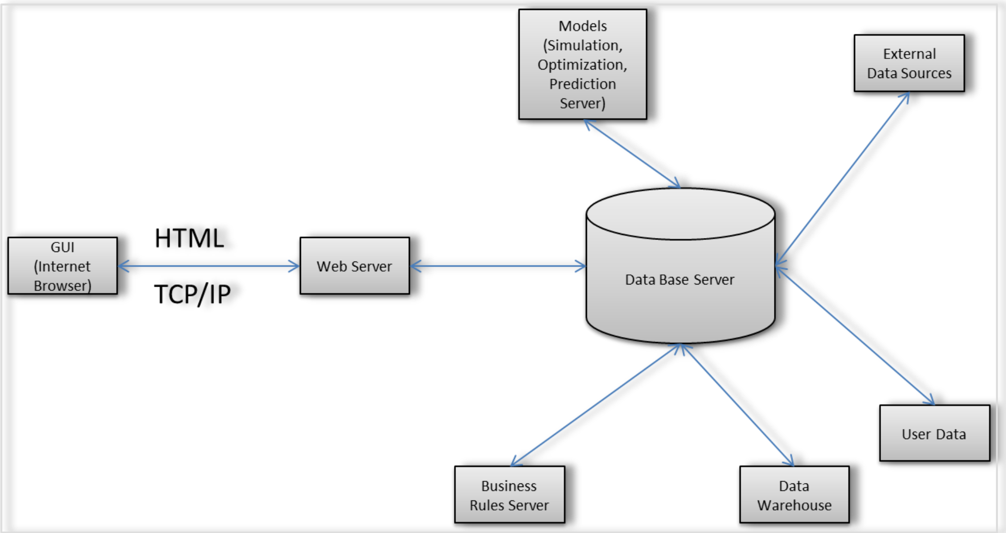


FIGURE 4.3: MULTITIERED ARCHITECTURE FOR INCORPORATING OPTIMIZATION, SIMULATION, AND OTHER MODELS INTO WEB-BASED DSS (TURBAN *ET AL.*, 2011)

Some of the advantages and limitations of expert systems have been tabulated in Table 4.1. This table was compiled using the work done by Giarratano & Riley (2005) and Turban *et al.* (2011). Developing a similar table for DSS is problematic, as there are far too many discordant DSS to develop a singular list of advantages and limitations. This comes as a result of the differing uses for expert systems and DSS, namely that a DSS may be developed to aid the decision-making process in any number of ways, whereas an expert system is always developed to emulate an expert and make the decision. The result is that one DSS may have advantages or limitations that another does not have, while all expert systems have similar advantages and limitations. There are, however, some general advantages to DSS, namely (Louw, 2002):

- Improved internal control;
- Better management awareness of internal strengths and weaknesses;
- Improves the quality of decision making;
- Faster response to changes in the business environment; and
- Allows managers to reuse past experiences in future scenarios.

TABLE 4.1: ADVANTAGES AND LIMITATIONS OF EXPERT SYSTEMS (ES)

Expert Systems (ES)	
Advantages	**Limitations**
Limited expertise is made available to any system with the necessary hardware	Knowledge is not necessarily available
The expertise of an ES is more permanent than that of a human	It may be difficult to transfer human expertise to the system

An ES may contain expertise from multiple experts that it can use simultaneously to solve a problem	Multiple experts may have different solutions to the same problem, and all of the solutions may be correct
An ES may provide an answer faster than a human expert would	Even a skilled expert may have difficulties in making good, abstract assessments when working under pressure. This limitation may have a significant impact upon the reliability of the ES developed while observing such an expert
An ES will produce a consistent, complete response unhindered by emotion	An ES, just like the human expert upon which it is based, is capable of producing a less than ideal recommendation.
An ES may improve the reliability of a human decision by providing a second opinion	ES work at their best within a narrow domain of knowledge
An ES can act as an instructor by letting its students run various simulations. The ES would then explain its reasoning process and in so doing educate its student.	Experts generally have no way to check if their conclusions are reasonable. This may lead to the development of an ES that produces largely incorrect answers.
An ES has the ability to explain its reasoning process	There is no guarantee that an ES will provide a useable answer
The cost of providing expertise to solve a problem is greatly reduced	The development of an ES usually requires a knowledge engineer, which increases the cost of developing the system
An ES can be used in environments that may be hazardous to humans	There may be a lack of trust in the ES, which limits its use
	Perceptual and judgemental bias tends to negatively affect knowledge transfer
	Expert knowledge typically includes jargon that is limited and difficult for those unfamiliar with the area of knowledge to understand
	There are limits to the cognitive abilities of ES users

4.2.5 Examples of DSS

In substantiation of the previous sections, a brief overview of several proposed or existing DSS are given in order to illustrate the validity of, among other things, the expanded definition as given in section 4.2.1, as well as to illustrate the importance of DSS in an industrial environment. Several frameworks that describe resource allocation DSS are also mentioned.

- DSS for Winemaker (Haddou *et al.*, 2011): This DSS is a system developed to aid in controlling the fermentation step of winemaking, as the process of fermentation determines the pH of the end product, and thus both the taste and quality. The DSS makes use of several mathematical models and is designed for use by individuals with minimal training in the use of computerised systems.
- DSS for sustainable forest management (Varma *et al.*, 2000): This paper proposes a DSS aimed at improving the sustainability of forest land use by utilizing a multi-criteria evaluation technique that builds upon spatial and temporal data.
- DSS to improve the efficiency of resource allocation in healthcare management (Aktas *et al.*, 2007): The DSS proposed in this paper aims to improve the efficiency of a hospital's patient care by proposing strategies to improve the management of a hospital's resources.
- A DSS for supplier selection (Ghodsypour & O'Brien, 1998): In this paper a DSS is proposed that allows a manager to select the best suppliers based upon both tangible and intangible factors. This particular DSS also utilises the AHP.
- A decision support framework for internal audit prioritization in a rental car company (Sueyoshi *et al.*, 2009): The framework proposed in this paper utilises both the Data Envelopment Analysis (DEA) and AHP to identify the most crucial departments within an organization. The core principle is to audit the most crucial business units entirely, rather than allocating percentages of available audit resources to each department.
- A web-based DSS for inventory classification: (Cakir & Canbolat, 2008): In this paper a DSS that utilises fuzzy AHP to assist in inventory classification is discussed.
- Review of Manure Management DSS (Karmakar *et al.*, 2007): This particular paper focuses on the DSS that have been developed to aid in proper manure management. Manure, in this context, is described as a complex resource that has to be used properly in order to maximise the fertility of agricultural soil.

In this section the basic principles of DSS were discussed. The discussion was based upon the definition of DSS, its characteristics and how a DSS differs from an expert system. The following section proceeds with the description of the DSS developed for this study.

4.3 A Simple Heuristic for Consensus Within a Bounded Integer Set

As stated in section 4.2.3, an important characteristic of a DSS is its ability to facilitate communication and cooperation between various role-players. As such, a DSS developed for auditing would necessarily have to account for the multitude of opinions that exist within the field and among its practitioners. A requirement for a system that allocates audit resources using the AHP would therefore be that the system be able to calculate some form of agreement based upon the inputs of the various role-players. In this section a method for calculating such a form of agreement is described.

In chapter 3, two of the techniques that can be used to calculate consensus were discussed. Unfortunately, both of these techniques suffer from the same limitation in that they are both used to produce an ordered set that represents the consensus of a number of ordered sets. Neither of these techniques can therefore be used to calculate consensus in this case, as the integer values they use do not correspond with actual values, but instead reference specific objects. Furthermore, because these techniques are used to calculate the consensus of rankings, all or most of the relevant values appear in all of the ordered sets used to calculate consensus. This ultimately means that a consensus technique that maintains the value of each element in a set is needed.

In the following section a technique based on the "Distance-based" consensus method is introduced. This is the technique that was ultimately used by the system to calculate consensus.

Solution through minimisation of total error

Consensus, within the context of this study, is the singular value that represents the minimum disagreement between the members of a group of participants. The consensus therefore would be the value that is as close as possible to each of the provided values.

To put it another way, consensus is reached when the sum of the differences between a consensus value *w* and each of the values provided is minimised. Calculating the consensus would therefore involve the following minimisation problem:

$$For\ a\ collection\ of\ k\ ratings\quad \{x_1, x_2, \dots, x_k\}, \qquad with\ i = 1,2,3,\dots,k, \tag{4.1}$$

$$Min \qquad \sum_{i=1}^{k} E_i, \tag{4.2}$$

subject to the following conditions:

- $E_i = |x_i - w|$,
- $w \, is \, an \, integer,$

where

- x_i is the *i*th ranking in a set of *K* rankings
- E_i is the absolute error of the consensus variable with regards to x_i,
- w is the consensus variable.

Once the above problem has been solved, the value of w will represent the consensus for the given integer set. Solving the above minimisation problem can be solved algorithmically by applying the basic principles of Particle Swarm Optimization (PSO) (Clerc, 2012). A PSO algorithm functions by defining a search space, a method for calculating fitness and a number of particles that represent solutions. The particles are then “moved” across the search space until an optimal solution is found.

ALGORITHM 4.1: Consensus Heuristic

Input: A set *K* with *k* number of values; a minimum value *I* and a maximum value *J*
Output: A single value representing the consensus of *K*
Variables:
w – Consensus value
E_{ix} – Error of value *i* with regards to *x,* where *x = w, m, n*
m – Comparative consensus value greater than *w*
n – Comparative consensus value less than *w*

Set *k* = number of elements in *K*
Calculate $w = \left\lfloor \frac{\sum_{i=0}^{k} x_i}{l} \right\rfloor$
Set $m = w + 1$
Set $n = w - 1$
Calculate $E_{iw} = \sum_{i=1}^{k} |x_i - w|$
Calculate $E_{im} = \sum_{i=1}^{k} |x - m|$
Calculate $E_{in} = \sum_{i=1}^{k} |x_i - n|$
while $n \geq I, m \leq J \; and \; (E_{in} \; or \; E_{im}) < E_{iw}$
    if $E_{im} < E_{iw}$
        set $n \leftarrow w$
        set $w \leftarrow m$
        set $m \leftarrow w + 1$
    else if $E_{in} < E_{iw}$
        set $m \leftarrow w$
        set $w \leftarrow n$
        set $n \leftarrow w - 1$
    end
    Calculate $E_{iw} = \sum_{i=1}^{k} |x_i - w|$
    Calculate $E_{im} = \sum_{i=1}^{k} |x_i - m|$
    Calculate $E_{in} = \sum_{i=1}^{k} |x_i - n|$
end
return *w*

The following example illustrates how the algorithm mentioned above can be implemented for a certain set of values. In this particular example the necessity of this method is also illustrated, as the average of the values would not have produced an accurate result. It should be noted that the values selected for this example do not necessarily correspond with expected real-world values, but were selected specifically to illustrate how the average of a set of integer values do not necessarily represent the consensus of the set.

Values from participants		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**

In step 1, in order to minimise the time needed to calculate the consensus, an initial consensus value is calculated by taking the floor of the average of the collection. The floor is used as the final consensus will necessarily be an integer, and the average of the set is likely to be a real number rather than an integer. Once *w* has been calculated, the search particles *m* and *n* are defined and the total deviation, or error, from the given set of values is calculated for *w*, *m* and *n*. The value of the search particle with the smallest total error is then assigned as the new value of *w.*

Step 1	**Calculate values for w, m = w + 1 and n = w - 1. Calculate total error for w, m and n.**																			
w (consensus value) =		6																		
Error		5	5	5	5	5	5	5	2	3	3	3	3	3	3	3	3	3	3	3
Total Error =		70																		
m (greater than search particle)=		7																		
Error		6	6	6	6	6	6	6	1	2	2	2	2	2	2	2	2	2	2	2
Total Error =		65																		
n (smaller than search particle) =		5																		
Error		4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4
Total Error =		75																		
Smallest total error is for m, so we assign the value of m to w, thus w = 7. Furtheremore, it is no longer necessary to calculate n, as n will never be the optimal value.																				

The remainder of the steps follow in a similar pattern until either one of the search particles return an error value greater than the error value for *w*, or the bounds of the set are reached.

Step 2	Repeat Process from Step 1.																			
w (consensus value) =		7																		
As calculated above, total error is 65.																				
m (greater than search particle)=		8																		
Error		7	7	7	7	7	7	7	0	1	1	1	1	1	1	1	1	1	1	1
Total Error =		60																		

Smallest total error is for m, so we assign the value of m to w, thus w = 8.

Step 3	Repeat Process from Step 2.																			
w (consensus value) =		8																		
As calculated above, total error is 60.																				
m (greater than search particle)=		9																		
Error		8	8	8	8	8	8	8	1	0	0	0	0	0	0	0	0	0	0	0
Total Error =		57																		

Smallest total error is for m, so we assign the value of m to w, thus w = 9. As 9 is the greatest possible value w can have within this set, final consensus is taken as 9.

This example clearly illustrates the necessity of using this method, as the average value for this example was 6, which would have produced a total error, or overall disagreement, of 70, whereas the calculated consensus of 9 only produces an overall disagreement of 57.

4.4 USE OF THE AHP TO ALLOCATE RESOURCES

In order to obtain the weighted scale mentioned in chapter 3, section 3.3, a mathematical comparative model known as the Analytical Hierarchy Process (AHP) is used. The AHP uses pairwise comparisons of the risk factors of audit units in order to produce a singular scale that shows the relative priorities of the audit units being compared. The process will now be discussed in greater detail, using an example adapted from Taylor (2013).

4.4.1 PAIRWISE COMPARISONS

The first step in the AHP is to identify the risk factors that have to be compared. As the audit units being compared are indeed considered comparable, the risk factors used are those that each of the audit units have and which is considered relevant to the decision making process. A relevant example of this would be to compare audit units based on the size of the unit, the liquidity of its assets, the complexity of its operations and the integrity of its managerial staff.

The second step involves assigning a value to the preference of one audit unit over another based upon a specific risk factor. In order to simplify the explanation of the rest of the process, consider an example where three audit units have to be evaluated in terms of their risk factors. Table 4.2 presents the data for the audit units where, for example, audit unit A is of medium size, has high liquidity of assets, is moderately complex and has a low level of integrity within its management.

TABLE 4.2: VALUES FOR AHP AUDIT UNIT EXAMPLE

Audit Unit	***Size of unit***	***Liquidity of assets***	***Complexity of operations***	***Integrity of management***
A	Medium	High	Moderate	Low
B	Small	Medium	High	High
C	Large	Very High	Simple	Low

Based upon the experience of the decision maker, a specific audit unit might require more attention because of, say, the size of the unit. In order to quantify this preference, the decision maker will then follow a guideline, such as the one given in Table 4.3, and assign a value to a specific comparison, for example when it comes to the size of the audit units, the decision maker believes unit A should be considered to be more important than unit B. If that preference is moderate, then the assigned value to that specific comparison is 3 (see Matrix 4.1).

These comparisons have then to be placed in a matrix, such as Matrix 4.1. This is done as a matrix is an ideal way to present these comparisons. When comparing an object to itself, the value is 1 as that object cannot be more important than itself.

TABLE 4.3: PREFERENCE SCALE FOR PAIRWISE COMPARISONS, ADAPTED FROM TAYLOR (2013)

Preference level	Numerical value
Equally important	1
Equally to moderately important	2
Moderately important	3
Moderately to strongly important	4

Strongly important	5
Strongly to very strongly important	6
Very strongly important	7
Very strongly to extremely important	8
Extremely important	9

When an object is less important than another, the value is reversed, i.e. its inverse is taken as the value. This means that if audit unit A is moderately more important than B, the value 3 is entered into the comparison matrix where A is placed in terms of B, which is the cell found at the second column of the first row in Matrix 4.1 for this particular example. The relationship of B to A is the inverse to the relationship of A to B, i.e. where A to B is 3, B to A is 1/3. The inverse value is therefore entered into the comparison matrix where B is placed according to A, which is in the first column of the second row in Matrix 4.1.

An example of a complete single risk factor matrix is as follows:

Size of the audit unit			
Audit unit	*A*	*B*	*C*
A	1	3	2
B	1/3	1	1/5
C	1/2	5	1

MATRIX 4.1: PAIRWISE COMPARISON OF AUDIT UNITS USING SIZE RISK FACTOR

Reading from this matrix one can deduce, for example, that the decision maker strongly prefers unit C over unit B because of its size, as a value of 5, which corresponds to “Strongly Important” in Table 4.3, was entered into the cell found in the second column of the third row, which represents the relationship of C over B.

Matrix 4.1 is only one of the matrices developed for this example. The process mentioned above is repeated for each of the risk factors being used to compare the audit units, and as four risk factors are being used in the example to compare the audit units, four risk factor comparison matrices will be produced as a result. The purpose of this step is therefore to produce a comparison matrix for each of the risk factors being used, which are the size of the unit, the liquidity of the unit’s assets, the complexity of the unit’s operations and the integrity of the unit’s managerial staff. Each of these risk factors will therefore be used in turn to compare each of the audit units with one another.

4.4.2 Obtain a Weighted Scale of Objects for Each of the Risk factors

Once the risk factor matrices have been obtained, the next step is to reduce each of the matrices to a singular weighted scale that represents the overall preference of each of the objects to each of the other objects with regard to a specific risk factor. There are two primary ways to derive this weighted scale:

1. Calculate the eigenvector for each of the rows in the matrix (Patton *et al.*, 1983).
2. Approximate the eigenvector for each of the rows by using a normalised matrix (Taylor, 2013).

In order to obtain the eigenvector a complex mathematical procedure is needed. This represents a problem in the larger scheme of things as specialised software is needed to obtain the eigenvector in a computerised environment. As the system is web-based, such software is likely to be expensive, and therefore the ideal is to use as simple a process as possible. The normalization method is a good approximation of the eigenvector method. Furthermore, as the normalization method requires far fewer calculations and is simpler overall, this is the method that will be used in this instance.

A normalized matrix can be obtained by altering the values such that they are representative of the column overall. This is accomplished by calculating the sum of each column, and then dividing each value in that particular column with that value. Each of the resulting column values are dependent upon the other values in that particular column and therefore mathematically tie them together. The final step in obtaining the weighted scale is to calculate the average of each row. These averages form the weighted scale and will be used as such when producing the final weighted scale. The normalised version of Matrix 4.1 is shown in Matrix 4.2. As shown, normalization results in a matrix whereby the sum of each column is equal to 1 and the sum of the row averages also equal 1. The averages of each row are the elements of the weighted scale with regard a particular risk factor. The results in Matrix 4.2 show that audit unit A, with a comparison value of 0.501263 is considered the most important, whereas audit unit B, with a comparison value of 0.118476, is the least important.

Size of the audit unit				
Audit unit	*A*	*B*	*C*	Average of row
A	0.545455	0.333333	0.625	0.501263
B	0.181818	0.111111	0.0625	0.118476
C	0.272727	0.555556	0.3125	0.380261
Sum of column	1	1	1	1

MATRIX 4.2: MATRIX 4.1 AFTER NORMALIZATION

4.4.3 Develop a Weighted Scale of Importance for the Risk Factors

The penultimate step of the AHP is almost identical to the first two. The primary difference is that where the first two steps were meant to compare the objects with one another using their common risk factors as comparators, this step is used to determine the importance of each of the risk factors relative to one another. By referring to the audit example, the first two steps involve deciding whether unit A is preferable to unit B because of its size, and then independently because of the liquidity of its assets. The penultimate step is to determine how important size is compared to the liquidity of a unit's assets, the complexity of its operations and the integrity of its managerial staff.

The process comprises the following:

1. Use the same guide, as in Table 4.3, and make pairwise comparisons between the various risk factors.
2. Develop a matrix from the pairwise comparisons.
3. Normalise the matrix.
4. Calculate the averages of each row to obtain a weighted scale.

The weighted scale obtained in this manner contains the relative importance of each of the risk factors when compared to the others. The final normalised comparison matrix for the risk factor comparisons is shown in Matrix 4.3. With this information in hand, the process can move onto its final step.

Risk factor comparisons					
Audit unit	*Size of the audit unit*	*Liquidity of unit's assets*	*Complexity of unit's operations*	Integrity of unit's management	Average of row
Size of the audit unit	0.1519	0.1375	0.2222	0.2857	0.1993
Liquidity of unit's assets	0.7595	0.6878	0.6667	0.5000	0.6535
Complexity of unit's operations	0.0506	0.0764	0.0741	0.1429	0.0860
Integrity of unit's management	0.0380	0.0983	0.0370	0.0714	0.0612
Sum of column	1	1	1	1	1

MATRIX 4.3:RISK FACTOR COMPARISON MATRIX

4.4.4 Producing the Final Weighted Scale for the Audit Units

The final step is relatively straightforward. Each of the values in the weighted scales of the audit units (i.e. those that were obtained in section 4.4.2 by comparing the audit units themselves using the risk factors as guides) is scaled according to the relative importance of the risk factor that was used to compare the audit units in that instance. To explain, consider the following example.

By using the row averages from Matrix 4.2, the weighted scale {0.5012, 0.1185, 0.3803} can be derived. If, for argument's sake, the relative importance of the risk factor size has been calculated to be 0.1993, then the scale should be adjusted by multiplying each value in the scale with the relative importance of the risk factor:

$$Overall\ risk\ of\ audit\ unit\ i = \sum_{j=1}^{n} \begin{bmatrix} Risk\ of\ audit\ unit\ i \\ on\ factor\ j \end{bmatrix} \times \begin{bmatrix} Importance\ of \\ factor\ j \end{bmatrix} \tag{4.3}$$

This will adjust the scale such that its values describe the preference of a unit based upon size, but not only size. The final scale for size would then be {0.0998, 0.0236, 0.0757}. This is done for each of the weighted scales and the final weighted score for a specific object is the sum of each of its risk factor values.

For the application of allocating audit resources, however, the final weighted scale does not provide a final answer, as the AHP produces a scale wherein each of the objects is described relative to one another. In order to get the percentage of resources that should be allocated to each department, a last step is needed.

The final step in calculating audit resource allocation requires the use of the Method of Lagrange Multipliers and the minimization model as discussed in sections 3.4.2 and 3.5.3 in chapter 3. By applying (3.64) and (3.67), the final resource allocations are obtained. In the interest of clarity, it should be mentioned that the scale obtained using the AHP is the same scale *b* used in (3.64) and (3.67). The application of (3.64) and (3.67) following a developed AHP weighted scale is illustrated using an example in section 4.6.

4.5 Web-based DSS for the Allocation of Audit Resources

In this section the DSS developed for this study is discussed. The discussion will follow the basic structure of the system as it handles the four basic steps of the audit allocation process, namely:

- Define the audit units that have to be evaluated.

- Select the risk factors to be used during an evaluation.
- Participate in the evaluation process.
- Calculate the results based on the given evaluations.

Each of these sections will feature a screenshot and a description, as well as a short description of the functioning of each of the sections. The discussion of the system focuses only on the main functions of the system.

The system was developed in Visual Studio 2012, using ASP.NET and the C# programming language. ASP.NET was selected because, as a managerial system, the DSS would necessarily require a relative amount of security. This in turn requires that the DSS use server-side processing, as client-side processing is vulnerable from a security standpoint. While the security of the DSS is not the focus of this study, it should still be mentioned as the choice between server-side and client-side processing has a direct impact upon the number of languages that can be used to build the system. ASP.NET and C# was selected because of its familiarity and the relative ease with which it can be used to develop web-based applications.

4.5.1 Audit Unit Selection

The purpose of this section, as shown in Figure 4.4, is quite straightforward in that it is used to define the various audit units to be evaluated. An audit unit, within the context of this system, is any separable entity within an organization that can be audited. An audit unit can therefore be anything from a single project team to a regional office or an entire department. Because of the varying manner that different organizations might use to define their own audit units, the system was developed such that the limitations to declaring audit units are minimal. At present the system only allows for 11 audit units to be defined – this is an arbitrary limitation that was included merely to simplify the development of the system, and has no relation to the AHP and has no real impact on the rest of the system. Subsequently, this limitation can be removed easily without impacting the system in any significant manner.

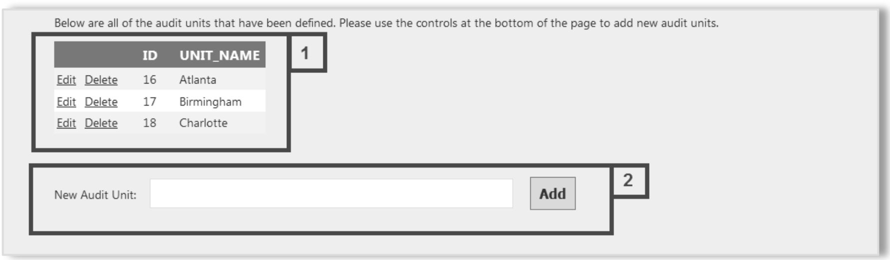


FIGURE 4.4: DSS SCREENSHOT - AUDIT UNIT SELECTION

Figure 4.4 shows two marked sections, of which each has a specific function. The purposes of each of these sections, as per their numbers, are:

1. **Existing audit units**: This table shows all of the audit units that have already been defined. From here all of an existing entry's details can be viewed and changed. From this table it is also possible to remove an existing audit unit entirely. The "ID" field shown in Figure 4.4 is the number the system uses to identify an audit unit, whereas the "UNITNAME" is the user provided name of an audit unit.
2. **Adding a new audit unit**: Using this field a user can add a new audit unit. The user enters text into the field and, when "Add" is clicked, an audit unit with the specified name will be added to the system, along with an automatically generated id.

4.5.2 Risk Factor Selection

As shown in Figure 4.5, each new evaluation process is associated with the various risk factors to be used in evaluating the audit units that were defined. While it is possible to start a new audit evaluation cycle without defining any audit units first, both steps are necessary in order to evaluate the audit units as is shown in section 4.5.3. As there is a greater probability that the audit units will be changed less often, defining the audit units is chosen as the arbitrary first step.

In Figure 4.5 three sections have been marked, each with its own function. These functions, as per their numbers, are:

1. **Describing the evaluation process**: This section contains two fields that are used to describe a new evaluation process. Both fields receive text, of which the contents of the first is used as the process name and the contents of the second is used as the process's description.
2. **Selecting the audit risk factors to use**: This section features a checked list that can be used to select between three and six risk factors to use in the evaluation. These risk factors are not "hard-coded" into the system and are read from the system's database. By altering the values in the database, any number of risk factors can be added or removed. The functionality to do so has been included in the system, but will not be discussed specifically as the default risk factors are assumed to be sufficient for system evaluation purposes.
3. **Starting the risk factor comparison process**: Once the correct number of risk factors has been selected and the evaluation process's name and description have been entered, the user may proceed to compare the audit risk factors. By clicking on "Compare Factors", the page is expanded to include the section shown in Figure 4.6.

The comparison of the selected risk factors, a step that is mentioned as the penultimate step in section 4.5.3, is done at this point. This is done so that the auditor that creates the evaluation process does not need to provide further input past this point. It also has no impact upon the rest of the AHP, as the comparisons provided between the risk factors are used to calculate the relative weights that each of the risk factors have when calculating the final score.

As shown in Figure 4.6, a significant number of the possible comparisons have been removed. In a normal AHP, the number of comparisons that have to be made are:

$$(n-1) + (n-2) + \cdots + 2 + 1 \tag{4.4}$$

where *n* is the number of audit units being compared.

However, as the work done by Ishizaka & Lusti (2004) shows, if AHP consistency as discussed in section 3.2.2 is required then, according to the transient rule that will be observed in a perfectly consistent matrix, only $(n-1)$ comparisons are needed. This corresponds to either a horizontal row, or a diagonal row adjacent to the principal diagonal. If the diagonal row is selected, each of the various risk factors is compared only with the next one in the row, e.g. for factors A, B and C, the comparisons would be A to B and B to C. If the horizontal row is selected, each of the factors is compared to a common factor, e.g. for factors E, F, and G the comparisons would be E to F and E to G. The advantages and disadvantages to each of these methods, as identified by Ishizaka & Lusti (2004) and discovered during the course of this study, are briefly shown in Table 4.4.

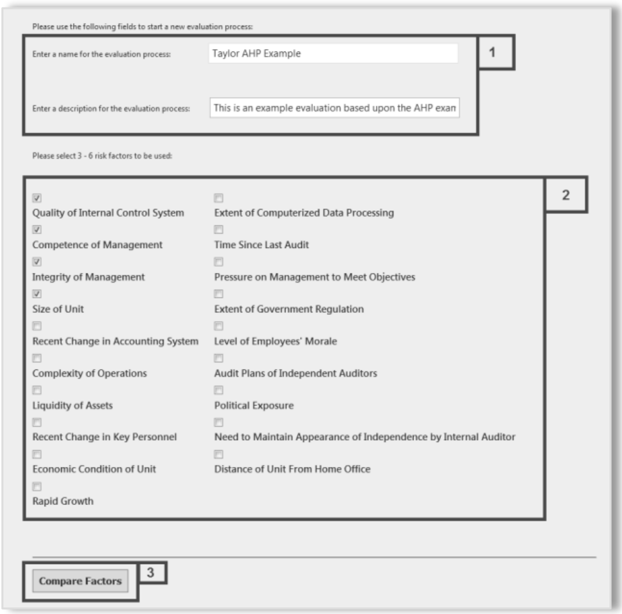


FIGURE 4.5: DSS SCREENSHOT - RISK FACTOR SELECTION

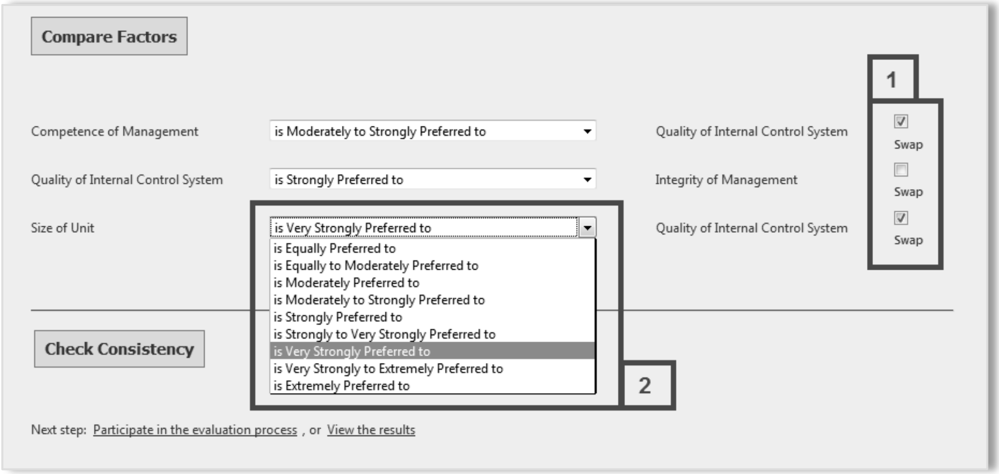


FIGURE 4.6: DSS SCREENSHOT - COMPARISON OF AUDIT RISK FACTORS

Figure 4.6 shows two marked sections which, as per their numbers, have the following functions:

1. **Reverse the direction of the comparison**: The "Swap" checkboxes shown in this section are used to reverse the direction of the comparison. In Figure 4.6, the comparison "Competence of management is Moderately to Strongly Preferred to Quality of internal Control System" is made, with the "Swap" checkbox checked. If the checkbox is unchecked, then the comparison would reverse and would change to "Quality of internal Control System is Moderately to Strongly Preferred to Competence of management". The same rule applies to each of the comparisons.
2. **Possible comparisons**: The list shown in this section is merely the list of possible qualitative comparisons that can be made between each of the various risk factors. This list is based on the comparisons as shown in Table 4.3 and provides the system with a numerical value that is representative of the comparison made.

TABLE 4.4: ADVANTAGES AND DISADVANTAGES TO EACH OF THE METHODS THAT CAN BE USED TO REDUCE THE NUMBER OF AHP COMPARISONS NEEDED TO ENSURE CONSISTENCY

Horizontal		Diagonal	
Advantage	**Disadvantage**	**Advantage**	**Disadvantage**
More lenient when making comparisons	Increased chance of inconsistency	Perfect consistency is a given	Is much less lenient when making comparisons
	May compromise psychological independence of comparisons	Maintains psychological independence of comparisons	

The DSS originally used the diagonal comparison type, but after initial testing of the system it was deemed to be too restrictive. The restrictions caused by this method come as a result of the transient nature required for consistency: if A is strongly preferred to B and B is extremely preferred to C then, following the guidelines in Table 4.3, A to C would have a value equal to the preference of $(A\ to\ B) \times (B\ to\ C)$, which is 45. As 45 does not lie within the range of the AHP scale, these selections cannot exist in a perfectly consistent AHP matrix with a scale of 1 – 9. As the use of the diagonal selection method strongly enforces this rule, and subsequently prohibits certain comparisons from being made, the system was altered to use the horizontal method instead. This change required the inclusion of a consistency checker, as the horizontal method uses division where the diagonal method uses multiplication, and errors such as those caused by rounding can affect the consistency of the comparisons.

Apart from increased consistency, the removal of most of the comparisons has another advantage, in that it promotes the usability of the system. To most users, the necessity of having to make a vast number of comparisons would make using the system a chore and would also directly affect the number of willing users. By removing most of the comparisons, the amount of work that needs to be done in order to participate in an evaluation process is drastically reduced. This is a significant improvement, as one of the AHP's greatest weaknesses is that the number of comparisons that have to be made increase significantly as the number of comparison criteria (risk factors in this case) increase. Without removal of the additional comparisons, the process that would have to be followed is to make the comparisons, check for consistency, and then redo the comparisons if they are not consistent enough. This is a lengthy iterative process that would not be favourable among the users.

4.5.3 Participation

The participation section of the system, shown in Figure 4.7 and Figure 4.8, forms the core of the evaluation process. The functions in this section are greatly similar to those described in section 4.5.2, in that the number of comparisons is reduced in the same fashion and that the same method of consistency checking is used. The main difference between the two sections is that where section 4.5.2 deals with selecting and then comparing the various risk factors, this section uses those risk factors in evaluating the defined audit units. As the system is designed to handle input from multiple participants, there are no limitations to the number of comparisons that can be provided in this section. Although implementing strict control processes, e.g. enforcing one comparison per risk factor per auditor, would be possible, these controls were not included as they were unnecessary for the purposes of this study.

Due to the similarity between this section and section 4.5.2, the controls are not discussed in such detail as in section 4.5.2. Figure 4.7 contains effectively two controls, namely a list that contains all of the available evaluation processes, and a button marked "Participate".

Once the user has selected a process to participate in and have clicked on “Participate”, the page expands to include the section shown in Figure 4.8.

The controls as shown in Figure 4.8 are greatly similar to those shown in Figure 4.6 and explained in section 4.5.2. The only real difference is the presence of a list of risk factors. Once a user has selected a particular risk factor and has made his comparisons, the aforementioned user can then check the consistency of the comparisons that have been made by clicking on “Check Consistency”, and then save the comparisons to the database by clicking on “Submit”. It is possible to save inconsistent comparisons but, as most of the comparisons have already been removed, it should be relatively unlikely to obtain a set of inconsistent comparisons.

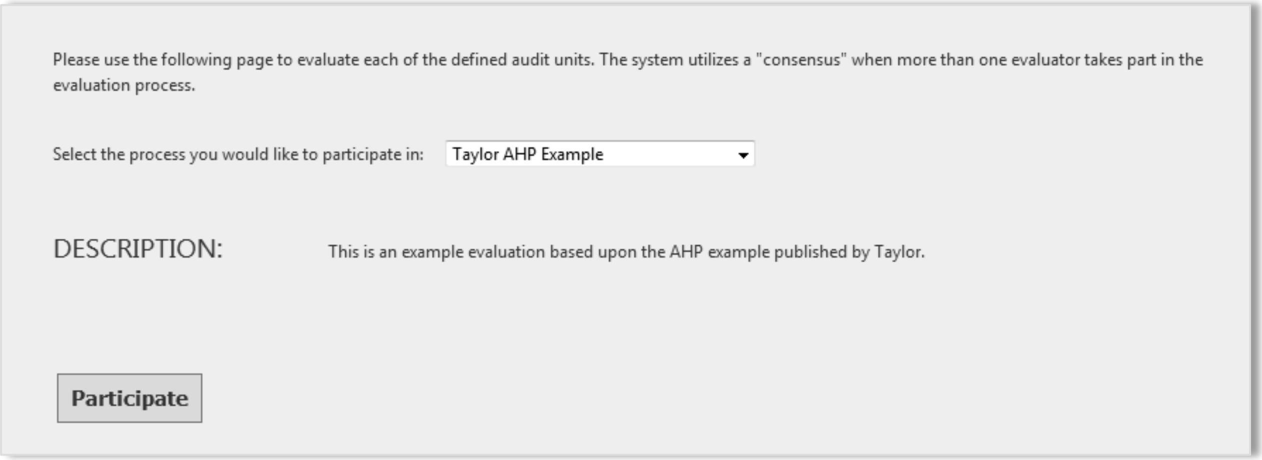


FIGURE 4.7: DSS SCREENSHOT – SELECTION OF A PROCESS TO PARTICIPATE IN

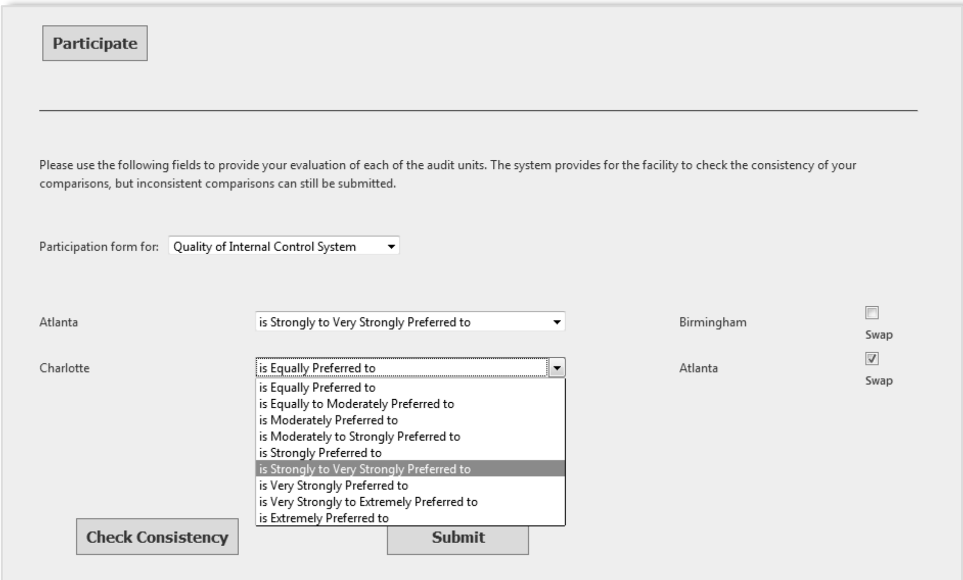


FIGURE 4.8: DSS SCREENSHOT – COMPARING AUDIT UNITS BASED ON A SPECIFIC RISK FACTOR

4.5.4 RESULTS

The results section of the DSS, shown in Figure 4.9, is where the various comparisons submitted to the system are processed in order to calculate a result. When the user clicks on “Calculate Result”, a number of things happen:

1. The system retrieves the comparisons that were submitted, including the risk factor comparisons.
2. The consensus for each of the comparisons are calculated.
3. The comparisons are then used to develop the AHP matrices.
4. The consistency for each of the AHP matrices are calculated.
5. A preliminary result is calculated using the AHP.
6. The preliminary result is used to calculate the actual percentage distributions among the various audit units. The Method of Lagrange Multipliers and the minimization model discussed in chapter 3, sections 3.4.2 and 3.52 are implemented here.;
7. The average inconsistency is given as a percentage of the borderline value of 0.1.

As the essence of the study, and in fact the system, is contained in step 6, it will now be discussed in greater detail.

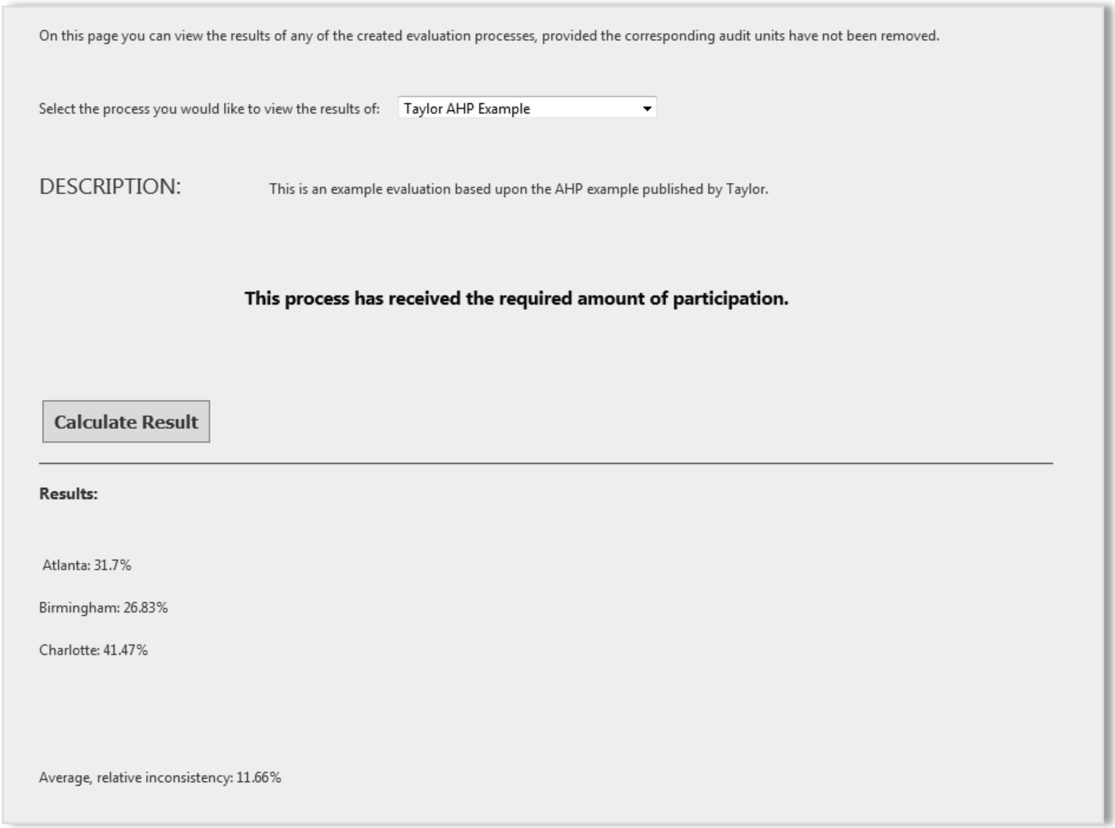


FIGURE 4.9: DSS SCREENSHOT – RESULTS

Recall that in section 3.5.3 a minimization model is discussed that uses a weighted scale to allocate audit resources. The model is:

$$\text{Minimise} \quad \frac{w_1 f_{11} + w_2 f_{21} + \ \dots + w_n f_{n1}}{a_1} + \frac{w_1 f_{12} + w_2 f_{22} + \ \dots + w_n f_{n2}}{a_2} + \ \dots \ + \frac{w_1 f_{1k} + w_2 f_{2k} + \ \dots + w_n f_{nk}}{a_k} \tag{4.5}$$

$$subject\ to \ \sum a_i \ \leq 100\% \tag{4.6}$$

where f_{ij} = audit risk factor *i* in audit unit *j*, w_i = importance weight of audit risk factor *i*, a_i = audit resources allocated to unit *i*.

When this model is then optimised using the Method of Lagrange Multipliers, it produces two equations, namely:

$$a_i = \left[\frac{b_i}{\lambda}\right]^{\frac{1}{2}} \tag{4.7}$$

$$\lambda = \left(\sum_{i=1}^{k} \sqrt{b_i}\right)^2 \tag{4.8}$$

In both of these equations, b_i is the i^{th} element of the AHP scale developed in step 5. Both of these equations are relatively easy to implement programmatically once a weighted scale has been obtained. The value of λ is calculated first by using (4.8), after which the percentage allocation to each of the audit units is calculated using (4.7) for each of the various audit units.

4.6 An Illustrative Example

In this section an example is used to illustrate how the models used by the system functions. The example shown in this section, which is based on the one provided by Patton *et al.* (1983), illustrates how the system obtains the final resource allocations given a set of comparisons. The purpose of this example is to show how the various comparisons are used to calculate the final resource allocations and does therefore not take the comparisons removed by the system into consideration.

The first step in the process is to evaluate each of the audit units based on various risk factors. This evaluation process is illustrated in Figure 4.10. As shown, 4 audit units, indicated by D1, D2, D3, and D4 are evaluated based on 5 risk factors. The comparisons obtained using each of the risk factors are placed in a matrix, such as the one shown in Matrix 4.4. While only one of these matrices are shown here, a total of 5 matrices were developed, one for each of the risk factors. Apart from the audit unit comparisons, the risk factors are also compared to determine their relative importance to one another, as shown in Matrix 4.5. It should be mentioned at this point that this example makes use of the eigenvector method to develop the scales, whereas the developed DSS uses a normalise-and-average method. As the normalise-and-average method is a close approximation for the eigenvector method, this has no appreciable impact.

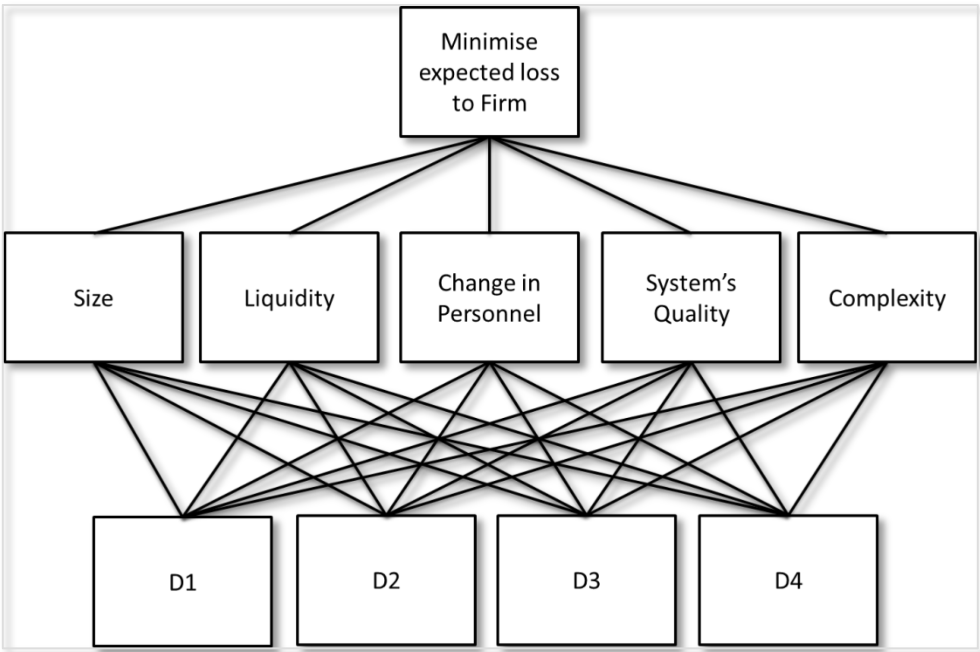


FIGURE 4.10: WORKING EXAMPLE - AHP DIAGRAM (PATTON *ET AL.*, 1983)

Risk factor: Size					
	D1	**D2**	**D3**	**D4**	**Scale**
D1	1	3	4	8	0.5735
D2		1	2	4	0.2334
D3			1	2	0.1287
D4				1	0.0644

MATRIX 4.4:ILLUSTRATIVE EXAMPLE – COMPARISONS BETWEEN AUDIT UNITS USING SIZE RISK FACTOR

Risk factors		Comparison matrix					Scale
		1	**2**	**3**	**4**	**5**	**Eigenvector**
1	**Size**	1	5	3	2	7	0.4475
2	**Liquidity**		1	1/2	1/3	2	0.0897
3	**Personnel change**			1	1/2	3	0.1540
4	**System quality**				1	4	0.2534
5	**Complexity**					1	0.0554

MATRIX 4.5:ILLUSTRATIVE EXAMPLE - RISK FACTOR COMPARISON MATRIX

Once all of the audit units have been evaluated, i.e. a comparison matrix has been obtained for each of the audit units, the next step involves making the relative importance of the risk factor used to evaluate a particular audit unit relevant. This is done as the overall risk of a division depends upon both the risk as result of a particular factor and the importance of that particular factor. This is mathematically expressed as shown in (4.9).

$$Overall\ risk\ of\ audit\ unit\ i = \sum_{j=1}^{n} \begin{bmatrix} Risk\ of\ audit\ unit\ i \\ on\ factor\ j \end{bmatrix} \times \begin{bmatrix} Importance\ of \\ factor\ j \end{bmatrix} \tag{4.9}$$

Thus each of the scales are made relevant to one another by multiplying each value in a particular scale with the relative importance value of the risk factor used to obtain that scale. By then calculating the sum of the resultant weighted scales a value can be obtained for each of the various audit units. For audit unit 1, as an example, the final weight is equal to the relative risk on the size factor (0.5735, as shown in Matrix 4.4) multiplied by the importance of the size factor (0.4475, as shown in Matrix 4.5) plus the relative risk on the liquidity factor multiplied by the importance of the liquidity factor and so on for each of the risk factors. This process is repeated until a single scale is obtained that shows the risk inherent to each of the audit units relative to the importance of the factors used to evaluate them. This scale is shown in Table 4.5.

TABLE 4.5: WORKING EXAMPLE - WEIGHTED SCALE SHOWING OVERALL RISK FOR EACH OF THE AUDIT UNITS

Division	Overall risk measure
1	0.3935
2	0.2300
3	0.1359
4	0.2406

Now that a weighted scale has been obtained for the audit units, the next step is to apply the Lagrange Optimization method discussed in sections 3.4.2 and 3.5.3 in order to calculate the resource allocations. By applying this technique, an equation can be obtained that describes the resources each of the four audit units should receive. As the resources are limited to 100%, a fifth equation is also obtained that describes the relationship between the resources allocated to each of the audit units. These equations are:

$$-\frac{w_1 f_{11} + w_2 f_{21} + w_3 f_{31} + w_4 f_{41} + w_5 f_{51}}{a_1^2} + \lambda = 0$$

(4.10)

$$-\frac{w_1 f_{12} + w_2 f_{22} + w_3 f_{32} + w_4 f_{42} + w_5 f_{52}}{a_2^2} + \lambda = 0$$

(4.11)

$$-\frac{w_1 f_{13} + w_{23} + w_3 f_{33} + w_4 f_{43} + w_5 f_{53}}{a_3^2} + \lambda = 0$$

(4.12)

$$-\frac{w_1 f_{14} + w_2 f_{24} + w_3 f_{34} + w_4 f_{44} + w_5 f_{54}}{a_4^2} + \lambda = 0$$

(4.13)

$$a_1 + a_2 + a_3 + a_4 = 1$$

(4.14)

These equations can now be simplified by substituting the weighted risk factors:

$$-\frac{0.3935}{a_1^2} + \lambda = 0$$

(4.15)

$$-\frac{0.2300}{a_2^2} + \lambda = 0$$

(4.16)

$$-\frac{0.1359}{a_3^2} + \lambda = 0$$

(4.17)

$$-\frac{0.2406}{a_4^2} + \lambda = 0$$

(4.18)

By applying equation (3.67) the value for λ can be calculated, and the calculated value for λ in this instance is 3.8653. By substituting for λ and applying standard arithmetic, the above equations can be used to calculate the final resource allocations, which are:

- 32% to audit unit 1
- 24% to audit unit 2
- 19% to audit unit 3
- 25% to audit unit 4

As the above shows, the optimal resource allocation given the risk factor evaluation is 32% of the audit resources, which may include both money and personnel time, allocated to audit unit 1, 24% to audit unit 2, and so on.

4.7 CHAPTER SUMMARY

In this chapter the various definitions and characteristics of DSS were discussed. This discussion was followed by the description of a heuristic that was developed for this study, an example of how the AHP works and finally a description of the DSS that was developed for this study. The chapter closed with an example that illustrates how the models described in this study are used to allocate audit resources.

In the next chapter, the procedures used in testing the developed DSS, along with the results of those tests, are discussed.

Chapter 5 : RESULTS AND DISCUSSION

5.1 INTRODUCTION

In Chapter 4 the Decision Support System (DSS) that was developed for this study was described. In this chapter, the various methods used to evaluate the system are discussed, along with the result of those evaluations.

The chapter starts with an evaluation based upon the characteristics of DSS as described in chapter 4. This evaluation will serve to ascertain whether or not the developed system is indeed a DSS. The focus then shifts to describing the procedures followed when testing the DSS. These tests mainly involve the use of simulations to determine whether or not the system is capable of producing the correct answers with regard to the mathematical models as described in chapter 3. A summary of the comments received when the system was evaluated by an external evaluator is also given.

The final part of this chapter is a discussion of the actual value that this particular DSS, should it be shown to in fact be a DSS, has with regard to the allocation of internal audit resources, as well as the overall contributions made by this study.

5.2 EVALUATION BASED ON CHARACTERISTICS OF DSS

The purpose of this study is not to merely develop an information system, but a decision support system specifically, and therefore the first step in evaluating the system should be to ascertain whether or not it is, in fact, a DSS. It is for this exact purpose that the characteristics of a typical DSS are named in section 4.2.2. The system will now be evaluated using each of these characteristics in turn.

A DSS is user-friendly

The first characteristic that is used to evaluate the DSS is easily the most subjective among the evaluation criteria. This comes as a result of the innate nature of the concept of "user-friendly", meaning that just because one person has a user-friendly experience with a system, does not necessarily mean that another person will have the same experience. Nevertheless, with the simplicity of the developed DSS, it can be assumed, with reasonable certainty, that the overall experience will be universal.

In order to determine the user-friendliness of the developed DSS, it should first be mentioned that the properties most associated with user-friendliness are simplicity, normal expectation, and self-explanation.

As is clear from the overall design of the system, simplicity has been given a premium. The system has a clean design and does not hide any of the significant functions behind option menus and tricky dialogues. This form of system design also addresses the second property, normal expectation, in that everything is where a user would expect it to be. Options are kept hidden until they become relevant and, in doing so, the user's attention is drawn to the necessary steps in an intuitive manner.

The final property, namely that of self-explanation, is also easily illustrated using the screenshots shown in figures Figure 4.4 to Figure 4.9 in chapter 4. The DSS at no point assumes that the user is informed about the function of the system, save for the purpose of the system. In that, the DSS clearly explains what is expected of the user and in doing so improves the user-friendliness of the system. Overall, the system appears to be user-friendly, however it should be emphasised once again that user-friendliness is a mostly subjective concept.

A DSS uses mathematical techniques

Evaluating the DSS based upon the fact that it utilises mathematical techniques is relatively simple in that the only requirement is that a mathematical model is used. The developed DSS does in fact utilise mathematical techniques, in that the AHP was used to evaluate the defined audit units in terms of the various risk factors. It also utilises a method for calculating consensus that is essentially rooted in geometric principles, and can therefore be considered mathematical in nature. The DSS also makes good use of the transient property that naturally exists within consistent comparisons in order to reduce the number of comparisons that are needed overall. Finally, the system makes use of the Method of Lagrange Multipliers, which is a technique that, when implemented as discussed in section 3.5.3 in chapter 3, can be used to make the results of an AHP analysis relevant when allocating internal audit resources. Without this particular model, the AHP would have been useless with regards to allocating audit resources. The developed DSS therefore most certainly makes use of mathematical techniques in order to function and is, in fact, wholly dependent upon them.

A DSS can adapt to sudden changes in the operating environment

Evaluating the adaptability of a DSS can be quite difficult in normal circumstances. In order to do this evaluation, the various parts of the DSS that can in fact not be altered are mentioned first.

The system is not flexible in all respects. By utilizing the transient nature of consistent comparisons, the number of comparisons that need to be made are greatly reduced. However, because there is no option to develop complete AHP matrices, the system would be unable to naturally adapt should the use of finely tuned AHP matrices be required. As the system is also at present limited to the selection of three to six risk factors and can only be used to evaluate 11 audit units simultaneously, the system would suffer if more than six risk factors are expected, or when more than 11 audit units need to be evaluated. While removing these limitations is a relatively trivial task, it does require adaptions to the system's code.

The remainder of the system is fairly adaptable, however. The various risk factors used by the system can be changed with relative ease, along with any audit units that have been defined. Because of the simplicity of the system and the ease with which its primary evaluation variables (risk factors and audit units) can be changed, the developed DSS is considered to be fairly adaptable. The same can be said of the mathematical models used by the system, as their function is not dependent upon the number or nature of the system's input variables.

The purpose of a DSS is to improve the performance and efficacy of the decision-making process

In ascertaining the precise impact, the DSS has on the decision-making process, the properties of the process that should be evaluated are the robustness of the process, along with the reliability and predictability of the process. When allocating resources under normal circumstances, an auditor may choose to evaluate the various audit units in a more subjective manner. While the developed DSS still requires subjective analysis, this analysis is refined and focused in order to remove some of the factors that may influence the decision-making process in an unexpected manner. Additionally, because the inputs required by the system are predictable, a more experienced user can begin the evaluation process accessing the system, thereby enhancing the process. Furthermore, because long discussions surrounding the selection of audit units are rendered mostly unnecessary, there is a definite chance that the developed DSS may even improve the speed of the decision-making process. The DSS also utilises a number of mathematical models, all of which are robust and function in a predictable manner. The reliability of these models is also dependent upon the reliability of their inputs, and therefore the models themselves are wholly reliable. Taking all of this into consideration, it is reasonable to claim that the developed DSS does, in fact, improve on the performance and efficacy of the decision-making process.

A DSS should facilitate communication between the various stakeholders it supports

The primary goal in using a web-based DSS, rather than a stand-alone DSS, was to allow various stakeholders to participate in the process. To this end, the system placed no restrictions on the number of participants and utilises a consensus heuristic in order to calculate the overall evaluation of a particular audit unit. While the system does not directly facilitate communication, such as could be done using a messaging service, the system does provide for a certain innate form of communication, in that the results are influenced by the input of various stakeholders. The DSS therefore facilitates a specific form of communication, in that the system can be used by the stakeholders to communicate with a central authority using very specific inputs, namely audit unit evaluations, and the outputs can then again be communicated to all of the stakeholders.

Under no circumstances does the DSS make the decision, it only provides a recommendation

Determining the exact purpose of a complex DSS can, in practice, become quite complicated. The DSS developed for this study is, however, not particularly complex and its role in the decision-making process is made quite clear in Figure 4.9 in chapter 4, in that the DSS does not make a decision, but merely provides a recommendation. In this, it is also clearly a DSS and not an expert system. This does however not mean that the system produces a result that is open to interpretation or evaluation; the system produces a result that can be used directly to allocate audit resources but, as it does not directly allocate the resources itself, for example by transferring company funds to audit teams, the system cannot be said to make the final decision.

In conclusion, the DSS has been shown to possess the following six characteristics:

- The DSS is user-friendly.
- It is dependent upon mathematical techniques.
- It can adapt to sudden changes in the operating environment.
- The DSS has a positive impact upon the efficacy and reliability of the decision-making process.
- It facilitates the communication between the various stakeholders.
- The DSS produces a recommendation, and does not autonomously make decisions.

Based upon the six characteristics mentioned above, it can be safely stated that the developed system is indeed a DSS. Now that the first requirement for the system has been met, the second requirement, namely that of usability in terms of accuracy, can be discussed.

5.3 TESTING PROCEDURE

In testing the system, a number of simulations were done in order to determine the reliability of the system in using the mathematical models. As the system provides the user with the option of both checking consistency and submitting inconsistent comparisons, the simulations focused on pairwise comparisons that were both consistent and necessarily within the range of the AHP scale. The simulations were conducted in three steps:

1. An Excel spread sheet, such as the one shown in Appendix B Figure B.0.1, was used to both randomly assign input variables for a particular matrix and calculate the consistency and result of the specific matrix.
2. The results of the simulated matrices were then assigned to the various comparisons and a result was calculated; for simplicity's sake the simulations assumed the use of five risk factors to evaluate five audit units.
3. A second Excel spread sheet, such as the one shown in Appendix B Figure B.0.2, was then used to calculate a theoretical expected result.
4. The assignments done in step 2 were then replicated within the system and the results were compared.

As the core of this study is the allocation of audit resources, the system simulations focused only on testing the part of the system concerned with resource allocation. The remainder of the system was however tested indirectly, as the simulation procedure mentioned above cannot be executed without using the system. Therefore, even though the results are not mentioned here, the majority of the system was tested and was found to function satisfactorily.

5.4 EVALUATION OF THE SYSTEM USING SIMULATIONS

In this section the results gathered by following the testing procedures as outlined in section 5.3 are presented. It should be emphasised once more that only the principal part of the system, i.e. the part concerned with resource allocation, was tested in a quantitative manner. The remainder of the system needed to function properly in order to get these results, but as aspects such as "look-and-feel" are not crucial to the success of the system as far as resource allocation is concerned, these aspects were not evaluated quantitatively. The ultimate goal of these simulations was to test whether or not the results produced by the system correlate to what is expected based on a known set of values. A large number of simulations were done and the values produced by only the first five of these simulations will be shown.

The procedure followed when running the simulations will now be explained using the first of the simulations run. The first step in running these simulations is to obtain randomly generated pairwise comparisons. These values, which can have any value between 1 and 9, correspond to the numerical value associated with a particular comparison. An example would be to select a value of 3 when A and B are compared, should A be considered to be moderately more important than B. The full list of comparison values are given in Table 4.3 in chapter 4.

As the system is designed such that only $(n-1)$ comparisons are needed for any particular comparison matrix with n number of audit units (see chapter 4 section 4.5.2), only four values were generated for each of the comparison matrices as five audit units were evaluated using five risk factors in every simulation. The specific risk factors that were selected were the same each time, as the goal was to determine the accuracy of the mathematical implementation.

For the first simulation shown, the pairwise comparisons {3, 5, 4, 3} were generated. These values were then entered into an Excel spread sheet, such as the one shown in Appendix B Figure B.0.1, and the spread sheet as shown in Figure 5.1 was obtained as a result. In Figure 5.1 the random values were generated in row 2 columns G through J, were placed into the comparison matrix as input variables in row 6 columns G through J, and the scale for this particular comparison is found in the average column of the normalised matrix, which is column K rows 15 through 19.

	E	F	G	H	I	J	K
2	Random Input		3	5	4	3	
3							
4	Comparison Matrix						
5		A	B	C	D	E	
6	A	1	3	5	4	3	
7	B	0.333333	1	1.6666667	1.3333333	1	
8	C	0.2	0.6	1	0.8	0.6	
9	D	0.25	0.75	1.25	1	0.75	
10	E	0.333333	1	1.6666667	1.3333333	1	
11	Sum	2.116667	6.35	10.583333	8.4666667	6.35	
12							
13	Normalized Matrix						
14		A	B	C	D	E	Avg
15	A	0.472441	0.4724409	0.4724409	0.4724409	0.4724409	0.472441
16	B	0.15748	0.1574803	0.1574803	0.1574803	0.1574803	0.15748
17	C	0.094488	0.0944882	0.0944882	0.0944882	0.0944882	0.094488
18	D	0.11811	0.1181102	0.1181102	0.1181102	0.1181102	0.11811
19	E	0.15748	0.1574803	0.1574803	0.1574803	0.1574803	0.15748
20	Sum	1	1	1	1	1	1

FIGURE 5.1: SIMULATION 1 AHP SPREAD SHEET

This process was repeated six times, five times for each of the audit units and once in order to compare the risk factors. The result was a single set of comparisons that represents one resource allocation process. The complete set of values for Simulation 1 is shown in Figure 5.2. Comparisons 1, 2, 3, 4, and 5 are the evaluations of the audit units according to a specific risk factor, and the Risk Factor Comparison column contains the input and result values for the pairwise comparisons between the risk factors. The columns indicated as "Input" represent the pairwise comparisons.

	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD
3	Comparison 1		Comparison 2		Comparison 3		Comparison 4		Comparison 5		Risk Factor Comparison	
4	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result
5	3	0.472441	9	0.64632	3	0.479087	9	0.520661	8	0.503496503	3	0.455696203
6	5	0.15748	9	0.071813	7	0.159696	7	0.057851	2	0.062937063	4	0.151898734
7	4	0.094488	5	0.071813	9	0.068441	2	0.07438	9	0.251748252	2	0.113924051
8	3	0.11811	8	0.129264	2	0.053232	6	0.260331	4	0.055944056	9	0.227848101
9		0.15748		0.08079		0.239544		0.086777		0.125874126		0.050632911

FIGURE 5.2: COMPARISON VALUES FOR SIMULATION 1

This procedure was then run a large number of times, and the results of the first five simulations are shown in Figure 5.3. In this figure the randomly generated pairwise comparisons are shown, along with the result calculated for an AHP matrix with those given input variables.

	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
3	Comparison 1		Comparison 2		Comparison 3		Comparison 4		Comparison 5		Risk Factor Comparison		
4	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result	
5	3	0.472441	9	0.64632	3	0.479087	9	0.520661	8	0.503496503	3	0.455696203	
6	5	0.15748	9	0.071813	7	0.159696	7	0.057851	2	0.062937063	4	0.151898734	
7	4	0.094488	5	0.071813	9	0.068441	2	0.07438	9	0.251748252	2	0.113924051	
8	3	0.11811	8	0.129264	2	0.053232	6	0.260331	4	0.055944056	9	0.227848101	
9		0.15748		0.08079		0.239544		0.086777		0.125874126		0.050632911	
10													
11	Comparison 1		Comparison 2		Comparison 3		Comparison 4		Comparison 5		Risk Factor Comparison		
12	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result	
13	4	0.491803	5	0.611799	9	0.473684	6	0.401338	7	0.497630332	1	0.37366548	
14	3	0.122951	6	0.12236	4	0.052632	8	0.06689	5	0.071090047	5	0.37366548	
15	5	0.163934	7	0.101966	4	0.118421	1	0.050167	6	0.099526066	7	0.074733096	
16	4	0.098361	8	0.0874	2	0.118421	5	0.401338	2	0.082938389	3	0.053380783	
17		0.122951		0.076475		0.236842		0.080268		0.248815166		0.12455516	
18													
19	Comparison 1		Comparison 2		Comparison 3		Comparison 4		Comparison 5		Risk Factor Comparison		
20	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result	
21	5	0.555556	4	0.626087	9	0.45	3	0.549618	2	0.430107527	9	0.297520661	
22	5	0.111111	8	0.156522	2	0.05	9	0.183206	8	0.215053763	4	0.033057851	
23	5	0.111111	9	0.078261	2	0.225	4	0.061069	5	0.053763441	1	0.074380165	
24	5	0.111111	9	0.069565	9	0.225	8	0.137405	2	0.086021505	1	0.297520661	
25		0.111111		0.069565		0.05		0.068702		0.215053763		0.297520661	
26													
27	Comparison 1		Comparison 2		Comparison 3		Comparison 4		Comparison 5		Risk Factor Comparison		
28	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result	
29	8	0.516923	3	0.483871	6	0.514286	7	0.639594	1	0.351758794	1	0.302013423	
30	2	0.064615	5	0.16129	2	0.085714	7	0.091371	5	0.351758794	1	0.302013423	
31	7	0.258462	5	0.096774	9	0.257143	6	0.091371	7	0.070351759	9	0.302013423	
32	6	0.073846	3	0.096774	6	0.057143	9	0.106599	2	0.050251256	5	0.033557047	
33		0.086154		0.16129		0.085714		0.071066		0.175879397		0.060402685	
34													
35	Comparison 1		Comparison 2		Comparison 3		Comparison 4		Comparison 5		Risk Factor Comparison		
36	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result	Input	Result	
37	9	0.553846	3	0.338028	8	0.59364	1	0.276923	6	0.542635659	2	0.466666667	
38	3	0.061538	8	0.112676	7	0.074205	1	0.276923	3	0.090439276	4	0.233333333	
39	4	0.184615	1	0.042254	4	0.084806	9	0.276923	7	0.180878553	7	0.116666667	
40	9	0.138462	2	0.338028	6	0.14841	2	0.030769	5	0.07751938	4	0.066666667	
41		0.061538		0.169014		0.09894		0.138462		0.108527132		0.116666667	
42													

FIGURE 5.3: PAIRWISE COMPARIONS CALCULATED USING SIMULATIONS, ALONG WITH INITIAL AHP UNWEIGHTED SCALES

These input variables were then input into the system where the inputs corresponded to the various comparison values as shown in chapter 4 Table 4.3. The final AHP scales and resource allocations were also calculated using a spread sheet such as the one shown in Appendix B Figure B.0.2, and the results produced by the system were input alongside the theoretical results and a deviation, or “Error”, was calculated. The results obtained for Simulation 1 are shown in Figure 5.4. Here the values shown in column AF are the result of the last step of the AHP, where the scales of the comparison matrices, such as the ones shown in Figure 5.1, column K rows 15 through 19, are multiplied by the relative weight of the risk factor used to evaluate it, and the values of each of the audit units are added to produce a final weighted scale. For simulation 1 comparison 1, the value of 0.5121694 is calculated as follows (refer Figure 5.2, where the weight of the risk factor is given in column AD):

$$(0.4556962 * \ 0.4724) + (0.1518987 * 0.6463) + (0.1139241 * 0.4791) \\ + (0.2278481 * 0.5207) + (0.0506329 * 0.5034965)$$

The Lagrange Multiplier λ was then calculated using (3.67), as shown in chapter 3 section 3.5.3. In this instance, the values for each b_i are the values as shown in column AF. Column AH contains the results of the resource allocations for each of the audit units expressed as A1, A2, A3, A4 and A5, whereas column AI contains the same result expressed as percentage allocations. Column AJ contains the results as obtained from the system, given the exact same inputs. The final column contains the calculated absolute difference, or “Error”, between the system output and the calculated expected output.

The final results for the first five simulations are shown in Figure 5.5. The error values in this case were calculated on the final percentage allocations, and are therefore percentage values. The deviations were primarily caused by the different methods used by the DSS and Excel to round values. The deviations would therefore only be of concern if the error was greater than 5%, and none of the deviations are greater than 3%.

AF	AG	AH	AI	AJ	
AHP Result	Resource Allocation			System Output	Error
	λ	4.442116			
0.5121694	A1	0.339556	33.95563	34.05	0.094366
0.1172327	A2	0.162454	16.24536	17.45	1.204637
0.09145747	A3	0.143488	14.34877	14.07	0.278768
0.14167025	A4	0.178585	17.85847	16.51	1.348475
0.13747018	A5	0.175918	17.59176	17.93	0.33824
1		1	100		

FIGURE 5.4: SIMULATION 1 RESULTS

AF	AG	AH	AI	AJ	
AHP Result	Resource Allocation			System Output	Error
	λ	4.442116			
0.5121694	A1	0.339556	33.95563	34.05	0.094366
0.1172327	A2	0.162454	16.24536	17.45	1.204637
0.09145747	A3	0.143488	14.34877	14.07	0.278768
0.14167025	A4	0.178585	17.85847	16.51	1.348475
0.13747018	A5	0.175918	17.59176	17.93	0.33824
1		1	100		
AHP Result	Resource Allocation			System Output	Error
	λ	4.398913			
0.53118411	A1	0.347496	34.7496	35.29	0.540396
0.10802268	A2	0.156706	15.67057	16.28	0.60943
0.12328242	A3	0.167409	16.74086	17.3	0.559135
0.11001639	A4	0.158145	15.81452	15.08	0.73452
0.1274944	A5	0.170244	17.02444	16.06	0.964441
1		1	100		
AHP Result	Resource Allocation			System Output	Error
	λ	4.432304			
0.5109461	A1	0.339526	33.95258	35.91	1.957419
0.16044167	A2	0.190258	19.02584	16.53	2.49584
0.08654546	A3	0.139736	13.97357	15.83	1.856429
0.11856694	A4	0.163556	16.35562	15.96	0.395622
0.12349982	A5	0.166924	16.69239	15.76	0.932386
1		1	100		
AHP Result	Resource Allocation			System Output	Error
	λ	4.416693			
0.50028448	A1	0.336558	33.6558	34.08	0.424201
0.11842672	A2	0.163748	16.37481	15.5	0.874809
0.19226211	A3	0.20864	20.86403	21.32	0.455967
0.0754	A4	0.130658	13.06583	13.24	0.174168
0.11362668	A5	0.160395	16.03953	15.85	0.189527
1		1	100		
AHP Result	Resource Allocation			System Output	Error
	λ	4.485948			
0.48836176	A1	0.329947	32.99466	33.15	0.155336
0.09267906	A2	0.143735	14.37354	13.45	0.923538
0.14547103	A3	0.180078	18.00782	17.42	0.58782
0.17189832	A4	0.195753	19.57531	21.13	1.554688
0.10158983	A5	0.150487	15.04867	14.85	0.198666
1		1	100		

FIGURE 5.5: FINAL COMPARABLE SIMULATION RESULTS

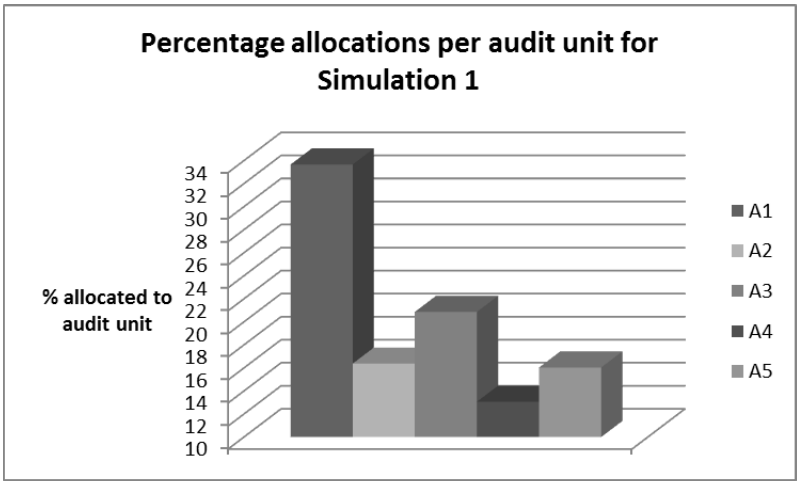
In conclusion, these results show that the system produces a reliable result based on the results that were expected theoretically and the results that were actually obtained.

5.5 Viability of "What-if" Analyses

One of the advantages mentioned is that the system can aid in performing certain "what-if" analyses. In order to illustrate how this is possible, one of the simulations above were randomly selected and used to perform four "what-if" analyses. The simulation that was selected is shown in Figure 5.6. The four altered simulations were run using an Excel spread sheet, as this simplified the process and it has been shown in section 5.4 that the system's outputs are statistically similar to those of the spread sheet. To serve as an aid to illustrating the impact of the "what-if" analysis, the results of the original simulation are shown graphically in Graph 5.1.

Comparison 1		Comparison 2		Comparison 3		Comparison 4		Comparison 5		Risk Factor Comparison	
Input	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**
8	0.516923	3	0.483871	6	0.514286	7	0.639594	1	0.351758794	1	0.302013423
2	0.064615	5	0.16129	2	0.085714	7	0.091371	5	0.351758794	1	0.302013423
7	0.258462	5	0.096774	9	0.257143	6	0.091371	7	0.070351759	9	0.302013423
6	0.073846	3	0.096774	6	0.057143	9	0.106599	2	0.050251256	5	0.033557047
	0.086154		0.16129		0.085714		0.071066		0.175879397		0.060402685

FIGURE 5.6:"WHAT-IF" SIMULATION 1



GRAPH 5.1: ORIGINAL "WHAT-IF" ANALYSIS RESULT

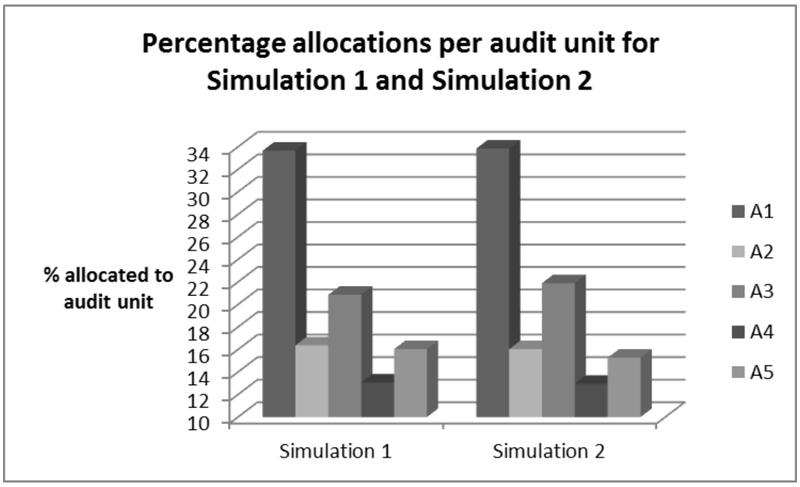
The principle of "what-if" analysis is to adjust the input parameters so as to ascertain what the impact on the final answer will be. In order to illustrate how the system would be able to handle "what-if" analyses, the simulation shown in Figure 5.6 was altered in four different scenarios, as shown in Figure 5.7. The impacts the alterations have made are presented graphically in Graph 5.2, Graph 5.3 and Graph 5.4.

Simulation 2											
Comparison 1		Comparison 2		Comparison 3		Comparison 4		Comparison 5		Risk Factor Comparison	
Input	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**
8	0.516923	3	0.483871	6	0.514286	7	0.639594	1	0.351759	1 → 9	0.652174
2	0.064615	5	0.16129	2	0.085714	7	0.091371	5	0.351759	1 → 9	0.072464
7	0.258462	5	0.096774	9	0.257143	6	0.091371	7	0.070352	9	0.072464
6	0.073846	3	0.096774	6	0.057143	9	0.106599	2	0.050251	5	0.072464
	0.086154		0.16129		0.085714		0.071066		0.175879		0.130435
Simulation 3											
Comparison 1		Comparison 2		Comparison 3		Comparison 4		Comparison 5		Risk Factor Comparison	
Input	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**
8	0.59364	3	0.483871	6	0.514286	7	0.639594	1	0.351759	1	0.2
2 → 4	0.074205	5	0.16129	2	0.085714	7	0.091371	5	0.351759	1	0.2
7	0.14841	5	0.096774	9	0.257143	6	0.091371	7	0.070352	9 → 1	0.2
6	0.084806	3	0.096774	6	0.057143	9	0.106599	2	0.050251	5 → 1	0.2
	0.09894		0.16129		0.085714		0.071066		0.175879		0.2
Simulation 4											
Comparison 1		Comparison 2		Comparison 3		Comparison 4		Comparison 5		Risk Factor Comparison	
Input	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**
8	0.358209	3	0.483871	6	0.514286	7	0.639594	1	0.351759	1	0.2
2	0.044776	5	0.16129	2	0.085714	7	0.091371	5	0.351759	1	0.2
7 → 1	0.179104	5	0.096774	9	0.257143	6	0.091371	7	0.070352	9 → 1	0.2
6	0.358209	3	0.096774	6	0.057143	9	0.106599	2	0.050251	5 → 1	0.2
	0.059701		0.16129		0.085714		0.071066		0.175879		0.2
Simulation 5											
Comparison 1		Comparison 2		Comparison 3		Comparison 4		Comparison 5		Risk Factor Comparison	
Input	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**	**Input**	**Result**
8	0.516923	3	0.483871	6	0.514286	7	0.639594	1	0.351759	1	0.2
2	0.064615	5	0.16129	2	0.085714	7	0.091371	5	0.351759	1	0.2
7	0.258462	5	0.096774	9	0.257143	6	0.091371	7	0.070352	9 → 1	0.2
6	0.073846	3	0.096774	6	0.057143	9	0.106599	2	0.050251	5 → 1	0.2
	0.086154		0.16129		0.085714		0.071066		0.175879		0.2

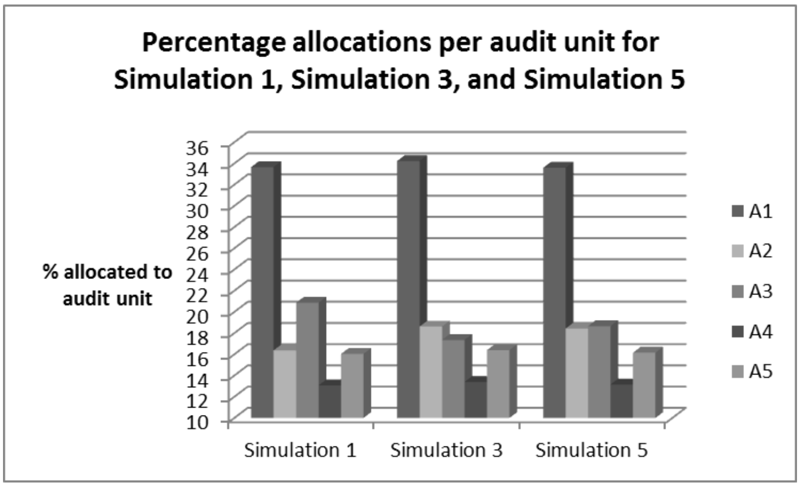
FIGURE 5.7: "WHAT-IF" ANALYSIS ALTERATIONS. BLACK CELLS INDICATE VALUES THAT WERE CHANGED.

In Simulation 2, only the Risk Factor Comparisons were altered. As shown in Graph 5.2, by changing the relative importance of the risk factors, no significant change is observed. This is caused by the fact that the original risk factors resulted in both Comparison 1 and Comparison 2 receiving equal weights. As their relative risk factor comparisons values are still equal, the observed impact is only a slight increase in the resources allocated to A3.

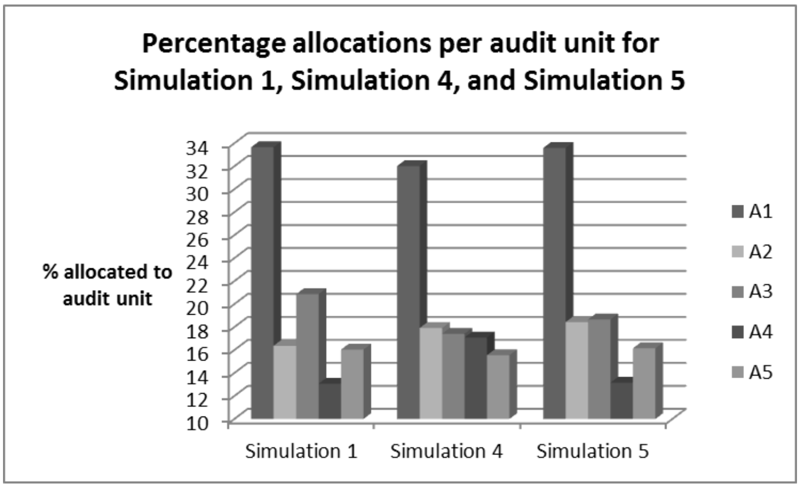
In order to illustrate which impact single deviations can have, Simulations 3 and 4 were run. In both of these simulations, the risk factor comparisons were all equalled to 1 in order to cancel out the impact of the risk factor weights. Simulation 5 was then run in order to ascertain the impact of removing the risk factor comparisons. As shown in Graph 5.3, removing the risk factor comparisons equalised the allocations to A2 and A3, while leaving the remainder mostly unchanged. By then changing a single value in Comparison 1 slightly, a greater percentage of resources are then allocated to A2. In Simulation 4, the second greatest value of Comparison 1 was selected and changed to 1. This alteration had the effect as shown in Graph 5.4. By reducing the importance of the particular audit unit, a significant amount of resources was made available for allocation to A4, which equalised the overall allocation.



GRAPH 5.2:"WHAT-IF" ANALYSIS - IMAPCT OF ALTERATIONS ON RISK FACTOR COMPARISONS



GRAPH 5.3:"WHAT-IF" ANALYSIS - IMAPCT OF ALTERATION OF SINGLE COMPARISON



GRAPH 5.4:"WHAT-IF" ALAYSIS – IMPACT OF ALTERATION OF SINGLE COMPARISON

The data presented above clearly show that the system can be used to conduct "what-if" analysis. It also shows that the types of "what-if" analyses to be conducted do not necessarily produce intuitively predictable results, as a single alteration can impact all of the allocations in unexpected ways, thus proving why these analyses are useful and indeed, important.

5.6 Expert Opinion

In order to determine if the system has any worth as far as real-world applications are concerned, an industry expert with experience in auditing within his organization, which is a petrochemical company with 32400 employees and an annual operating revenue of R 63 milliard, was approached and was asked to provide comments on the system. In this section a summary of his comments is given.

The first critique against the system was that the results provided were not descriptive enough, specifically that the results do not show the relationship between percentage allocation and the actual size and complexity of the audit unit. He explained the problem by referring to an industry practice whereby a single audit team will be tasked with auditing a large audit unit in one day, and would then be split into three separate teams to audit three smaller units the next day. While the system does provide for the option of using the size and complexity of an audit unit as risk factors, the system does not clarify how the final result incorporates the size and complexity of the audit units, and thus fails to clarify whether or not the size and complexity of the audit units still need to be brought into account. While this is indeed a current limitation of the system, these factors can still be evaluated by giving them higher importance during the "Risk Factor Comparison" step. It is therefore not that the system does not incorporate these aspects, but that they are considered risk factors at present. Clarifying the results would therefore make the system outputs more usable. He did however mention that the result obtained during the demonstration was comparable to what was expected given the inputs.

The second critique against the system was that the interface was not immediately intuitive; he would have had difficulty with using the system for the first time had he not had assistance. This was primarily caused by the use of a font that was uncomfortably small to use on a high resolution screen, as well as a general lack of detailed explanations. He also remarked that the problem could be remedied easily by including a so-called "roadmap" diagram on the site's homepage. He further remarked that the links used to describe the flow of the evaluation process in the system could have been made to be more obvious, which would have made navigating the system without help much simpler. He did however mention that the system had a very professional feel to it, and mentioned that is was more or less what he would have expected from an industry system in the later stages of development.

As for the usability of the system, he concluded that the system definitely addresses a problem his organization faces every year. According to his description, his organization's audit planning usually involves reusing the previous year's plans, with little or no change. Should they therefore choose to implement this system, or one similar to it, they would be managing the overall risk the company faces better and might be able to reduce the damage suffered as a result of insufficient auditing.

His final remarks on the system were that, even if an organization chooses to not use the system for auditing purposes, the system could, with minimal tweaking, be used to greatly improve the user acceptance testing (UAT) phase of systems development processes. He explained that, as his organization makes use of a large amount of proprietary software that they either develop in-house or through the use of consultants, he has on occasion been asked to participate in the UAT phase of the development of some of these systems. He remarked that, if the system was slightly tweaked to use risk factors associated with testing rather than auditing, it could be used to plan UAT engagements. He illustrated this point by referring to an instance where a UAT session, which was supposed to be a simple demonstration and feedback session, developed into a ten-hour discussion wherein most of the system as developed was either discarded or changed significantly. The result was that a session that was supposed to be an hour long at most eventually took an entire work day. He suggested that, should this system be adapted to be used with UAT, it could calculate a more ideal distribution of the resources needed for UAT activities, such as time needed, so that the organization does not experience any unexpected interruptions in productivity. To a lesser extent the system could also be used to determine the make-up of the testing groups, i.e. to use the system to determine how many members of each of the relevant departments should form part of a particular testing group. The system is therefore highly adaptable and can be used in any situation where qualitative evaluation is needed to calculate percentage allocations. The system is therefore not limited to auditing applications in its use.

While the DSS was not implemented within a commercial environment due to the constraints of the study period, the expert was of the opinion that the system is definitively usable in the real world. He was also of the opinion that the results obtained from the system were similar to what was expected intuitively, and that the implementation of the system would definitely contribute to the overall resource allocation process in practice.

5.7 CONTRIBUTIONS

Auditing involves the assessment of risk and, through this assessment, allows for risks to be managed more efficiently. By proposing a system that improves the effectiveness of audit planning processes, a direct contribution is made to the fields of auditing and risk management, but a contribution is also ultimately made within the field of information security, as an improved audit process would necessarily have a positive impact upon the safeguarding of the crucial information that an organization needs to function properly. However, as this is only a description of the contributions made overall, only the specific contributions made by this study are discussed. Seven primary contributions have been identified, and each of these contributions is discussed in turn.

5.7.1 Provides a centralised method for geographically separated users

The first of the contributions that the study makes has to do with the nature of the internal auditing environment within which it is set to operate. Within this environment, an organization may have several departments, or audit units that are likely to be separated geographically. Each of these audit units needs to be audited but, due to a limited amount of resources, such as money, manpower, etc., not all of the audit units can be audited fully. This ultimately means that the available resources have to be distributed amongst the various audit units in some manner. Ideally the decisions regarding the allocations would be made based on the input of the internal auditors that have working knowledge of the audit units, but because of the geographical constraints, these inputs are difficult to obtain through more conventional means such as meetings. Furthermore, because top management tends to take a particular interest in the results of the audit process, it should be centrally managed regardless of the geographical locations of the audit units.

The DSS developed for this study accounts for this idea of central management by allowing management to not only participate in the evaluation process, but it also allows them to provide key comparisons with regard to the importance of the various risk factors used to evaluate the audit units. This ultimately means that, even though the evaluations used as input come from various distinct geographical regions, a central management body still has a reasonable amount of control over the outcome of the evaluation process.

5.7.2 The study produces a flexible, web-based solution to address the question of audit resource allocation

The second contribution ties in closely with those mentioned in section 5.6.1. As mentioned, the DSS is designed to allow for various parties to participate in the evaluation process regardless of their physical location. This means that the system has to be accessible through some kind of network. Because the DSS is designed to work over the Internet specifically, the only factor that influences whether an evaluator, be it an auditor or member of management, can access the system is their own access to the Internet. This makes the system easily accessible, as the system can be accessed through any device that can connect to the Internet. It also means that the system is platform independent with regard to its users' devices, which also increases its overall user-friendliness. The system is also highly adaptable and can conceivably be used in any situation where percentage assignments based upon qualitative evaluation of similar entities are required, as is the case with planning user acceptance testing.

5.7.3 A NOVEL CONSENSUS METHOD IS DEVELOPED FOR THE DSS

While a distributed system with centralised control is already useful for solving some of the problems with allocating audit resources to geographically separated audit units, it still does not solve one of the biggest problems – each of the auditors providing input may have a different opinion and, because of the costs involved, they will not necessarily be able to meet and discuss their differences of opinion. Subsequently, a method is needed to quantitatively calculate what the auditors agree on, to a certain degree. A method is therefore needed to calculate what the "consensus" is with regards to the auditors' inputs.

This is where the developed DSS provides its next contribution. The available literature regarding consensus techniques did not mention a technique that can be used to calculate consensus among AHP inputs directly, where those inputs are pairwise comparisons with relative value, nor did it provide for a programmable, algorithmic solution. Because of this shortcoming, a new consensus heuristic needed to be developed that could both be used with the AHP *and* be easily programmable. This study provided exactly such a solution by first defining consensus as a state of minimum disagreement. This definition was then quantified into a simple heuristic that could then be used with an algorithm, based on the principles of particle swarm optimization which is easily implemented programmatically, to quickly produce an answer.

5.7.4 THE DSS UTILISES A METHOD THAT NATURALLY SUPPORTS CONSISTENCY

The AHP is, at its core, a qualitative analysis technique. This means that while it can be used to produce a quantitative result (i.e. resource allocations in percentages) its inputs are mostly subjective and open to opinion. Because the method also requires a vast number of comparisons, it is possible to make a comparison such that the relationship with previous comparisons does not make sense. Inconsistencies like these tend to have a negative impact on the efficacy and usability of the AHP, as the result produced by the AHP assumes a near perfect number of comparisons as input. Within a system, however, most people will be unaware of this and will be prone to making inconsistent comparisons.

The DSS developed for this study makes its next contribution in this regard. Within any group of interconnected, consistent comparisons, there will be a way to calculate what a particular comparison's value will be based upon other available comparisons. The system utilises this principle in order to both reduce the number of comparisons that have to be made, effectively making the system more user-friendly, and to decrease the risk of inconsistent comparisons being made.

5.7.5 Final decisions are easier to justify

While the developed DSS does produce a result indicating optimal resource allocations based upon comparative evaluations, the final decision with regard to resource allocation still lies with top management. This is where the system makes its next contribution, in that it specifically involves management in the evaluation process right at the start. This means that, unlike more arbitrary evaluations, justifying the final allocations to management is much easier. It also has the additional benefit of giving management the opportunity to indirectly influence the audit process according to the strategic goals of the company, as well as the opportunity to address possible problems in the company without being overly specific.

An additional advantage of using the system is that it is relatively easy to explain how the resource allocations were calculated. This follows as a result from the fact that the AHP is a structured method of qualitative analysis, and therefore naturally excludes "just because" methods of reasoning. This makes it easier for management to accept the final allocations, as there is both a clear method used to calculate the allocations, and the inputs can be shown to be reasonable to an acceptable degree.

5.7.6 The DSS provides certain "what-if" analysis advantages

Another contribution, while not directly implemented as such in the system, is that various "what-if" analyses are made possible. By making adjustments to a particular audit process's input variables, it becomes possible to evaluate the impact of certain risk factors on various audit units. These analyses can then in turn be used to identify the audit units that are most vulnerable to certain risks. This affords management the opportunity to shape the audit process according to company goals, as it can be used to adjust the priority with which certain risks need to be addressed, as well as to determine if a temporary or permanent increase in the audit budget might be necessary.

5.7.7 Makes the resource allocation process more structured

The allocation of audit resources, or "engagement resources" as they are also called, is usually based on the evaluations made by an experienced auditor, or group of experienced auditors. This process is generally very subjective in nature and tends to be effective as a direct result of the allocating auditor's experience. This in turn means that an experienced auditor is a necessity when calculating resource allocations. Because the DSS developed for this study takes a highly subjective process and gives it structure, it provides more junior auditors with the opportunity to calculate reliable resource allocations in spite of their lack of experience. This means that the junior personnel undergoing training can still provide generally reliable output in this regard.

In summary, the study makes a number of contributions in the field of information security by providing for a method to better manage risk by improving how audit resources are allocated. The specific contributions made are the following:

- The study describes a centralised method for allocating audit resources to a group of users that are separated geographically.
- A web-based solution is presented that addresses the problem of audit resource allocation.
- A novel consensus method was developed that can be used with the AHP.
- The study describes the implementation of a method that reduces the number of comparisons needed for the AHP.
- The implementation described in the study allows for decisions that are easier to justify.
- The developed system allows for certain “what-if” analyses to be performed
- The discussed implementation provides for a resource allocation process that is structured such that the impact of subjective decision-making is reduced.

5.8 PROBLEMS EXPERIENCED

One of the problems experienced during the course of the system’s development is that a consensus heuristic that takes the relative value of the elements into account could not be found. The available consensus heuristics, as shown in chapter 3, can only be used in instances where the ranking of a set of objects, rather than the value of the elements, are used. Additionally, the average value of a set could not be used, as this value is not equal to the consensus of the set. It was therefore necessary to develop a novel consensus heuristic that could be used to calculate the consensus among the input variables of the AHP.

Another problem faced was found in the reduction of the number of comparisons needed as input for the AHP. In order to make the system more usable, a technique was applied that significantly reduced the number of comparisons that needed to be made in order to use the AHP. The problem that was encountered, however, was that the method of exclusion used placed unrealistic restraints on the choices an evaluator could make, rendering the system unusable. The solution to this was to use a similar method that did not sacrifice evaluator choice as easily, but may have compromised the psychological independence of the AHP.

A limitation to the developed system is that a maximum number of audit units and selectable risk factors have been built into the system. This was done to address a minor coding problem that resulted in the selected comparisons being discarded before they could be saved to the system. By imposing limits on the number of risk factors and audit units, the problem could be solved within a much shorter time than would otherwise be necessary.

5.9 CHAPTER SUMMARY

In this chapter the methods used to evaluate the system, as well as the results obtained from those evaluations, were discussed. The chapter also provided a summary of the comments received from an external evaluator, and concluded with the contributions made by the study.

Chapter 6 : Conclusion

6.1 Introduction

The final chapter of the study presents the final remarks and comments on the study. The first part of the chapter focuses on the research objectives and how they were met, followed by mention of the problems experienced during the course of the study. The chapter then concludes with suggestions for possible further research.

6.2. Research Objectives

In this section a brief overview of the research objectives as described in chapter 1 is restated, along with a description of how these objectives were met. The secondary goals are discussed first, followed by a description of how the primary goal was met. This is done as achieving the primary goal is largely dependent upon first achieving the secondary goals.

6.2.1 Gain a functional understanding of how auditing works in general

In order to address this objective, the basic principles of auditing and specifically internal auditing were discussed in chapter 2. The discussion on auditing primarily focused on the definition of auditing, how audit planning and risk assessment works, and described two paradigms that can be followed when allocating audit resources, namely distributive allocation and selective allocation. The discussion on auditing also focused briefly on the standards as set out by the Institute of Internal Auditors (IIA).

6.2.2 Gain a clear Understanding of how the relevant mathematical models work and how they, along with the techniques, can be used in an implemented system

The goal in this instance was addressed by first describing both multi-criteria and multi-objective techniques in chapter 3. The discussion surrounding the mathematical techniques then shifted to consensus techniques, and then onto non-linear optimization techniques. By describing these techniques, the model used when calculating audit resource allocations could be explained properly. Several alternative methods that can be used to allocate resources were also briefly discussed to illustrate the underlying principles.

6.2.3 Properly describe DSS and its characteristics, and explain how a system can be evaluated in order to determine if it is indeed a DSS.

Chapter 4 started with a discussion surrounding the nature of a Decision Support System (DSS). The discussion started with an evaluation of the definition of a DSS, followed by an overview of the characteristics associated with DSS. A framework describing DSS was also discussed, followed by a comparison between DSS and expert systems in order to clarify the distinction between the two system types. As the goal was to obtain a significant amount of understanding with regard to DSS, the discussion in chapter 4 proved sufficient to address this goal.

6.2.4 Describe a testing procedure, follow the testing procedure and finally produce an evaluation of the system that addresses all of the aspects crucial to its viability.

In chapter 5 the developed DSS was first evaluated using the characteristics of a DSS as described in chapter 4. The system was then given several sets of simulated data in order to determine its accuracy compared to the predicted values. The outcomes of both these evaluations show that the developed system is indeed a DSS and that the results obtained from the system match the expected results, within an acceptable error margin. The system was finally evaluated by an external evaluator. This evaluation showed the system to not only be useable, but very versatile. The objective is therefore satisfied, as the evaluations were completed successfully.

6.2.5 Primary Goal: Develop a Web-Based Decision Support System to Aid in the Allocation of Audit Resources

The primary goal of the study was to illustrate how a number of mathematical models can be implemented in order to develop a DSS that can be used to aid in the allocation of audit resources. The goal as described above clearly illustrates how this objective was achieved, in that:

- The system can be used to allocate audit resources.
- The proposed and described mathematical models and techniques are used by the system.
- A system that was developed is indeed a DSS.
- The final system, upon evaluation, delivered reliable results.

It can be concluded that all of the research aims set in chapter 1 have been met. By meeting these goals, contributions have been made to the fields of internal auditing, and ultimately information security, by providing for a method to better evaluate audit risk in a more automated manner. A more comprehensive list of contributions is given in chapter 5 section 5.7.

6.3 LIMITATIONS

The greatest limitation to this study is that due to the limited timeframe within which the study was conducted, the developed system could not be tested within a practical commercial environment. While the opinion of an industry expert was obtained, this limitation to the study means that any problems that might have revealed themselves during the course of industry use, are currently unknown. Subsequently there is a significant risk that the system, after some time in use, might be shown to require additional functions and features that are as of yet unknown.

A further limitation is that, due to a lack of available funding, the system could not be deployed to a proper web server. While a working prototype was hosted on a free web server that could be accessed from the Internet, the system suffered such a significant reduction in performance that the system tests could only be performed on a local machine independent from the hosted system. As a result, any problems that may have presented themselves as a result of being hosted online, are unknown and could therefore not be resolved.

6.4 FURTHER STUDY

Several opportunities for further research have revealed themselves during the course of this study. They are the following:

- Improve the system by removing the limitations on the number of audit risk factors and audit units.
- Develop a method for reducing the number of AHP comparisons without compromising psychological independence.
- Adapt and evaluate the system for use with user acceptance testing applications.

6.5 CHAPTER SUMMARY

In this, the final chapter, the various research goals, along with how they were addressed, were discussed. Several of the problems experienced during the course of the study were mentioned and the chapter concluded with an overview of opportunities for future research.

APPENDIX A: MINIMUM SYSTEM REQUIREMENTS

The following are the minimum system requirements for accessing and using the system. As the system is web-based, the requirements given correspond to the requirements for a typical web-browser, as the browser is the only piece of software that needs to be run on the local machine. The vast majority of the system's processing is done by the server. The requirements for the server are similar to those given below, save for the fact that the server needs to run a Windows-based operating system running IIS version 8.

Hardware Requirements

- 1 GHz processor (Pentium 4 or equivalent);
- 512 MB RAM

The system can be accessed locally on any web-browser. As a result, the system does not have any requirements with regards to the specific operating system.

APPENDIX B: EXCEL SIMULATION SPREAD SHEETS

In this section all of the Excel spreadsheets used to conduct the system simulations will be provided. The first spreadsheet provided, shown in Figure B.0.1, is the spreadsheet used to calculate the initial weighted scale using the AHP. The second spreadsheet, shown in Figure B.0.2, is the spreadsheet used to calculate the final resource allocations, as well as the deviation from the result produced by the system.

	E	F	G	H	I	J	K
2	Random Input		=RANDBETWEEN(1, 9)	=RANDBETWEEN(1, 9)	=RANDBETWEEN(1, 9)	=RANDBETWEEN(1, 9)	
3							
4				Comparison Matrix			
5		A	B	C	D	E	
6	A	1	=1*G2	=1*H2	=1*I2	=J2	
7	B	=1/G6	1	=H6/G6	=H7*I8	=I7*J9	
8	C	=1/H6	=1/H7	1	=I6/H6	=I8*J9	
9	D	=1/I6	=1/I7	=1/I8	1	=J6/I6	
10	E	=1/J6	=1/J7	=1/J8	=1/J9	1	
11	Sum	=SUM(F6:F10)	=SUM(G6:G10)	=SUM(H6:H10)	=SUM(I6:I10)	=SUM(J6:J10)	
12							
13				Normalized Matrix			
14		A	B	C	D	E	Avg
15	A	=F6/F$11	=G6/G$11	=H6/H$11	=I6/I$11	=J6/J$11	=AVERAGE(F15:J15)
16	B	=F7/F$11	=G7/G$11	=H7/H$11	=I7/I$11	=J7/J$11	=AVERAGE(F16:J16)
17	C	=F8/F$11	=G8/G$11	=H8/H$11	=I8/I$11	=J8/J$11	=AVERAGE(F17:J17)
18	D	=F9/F$11	=G9/G$11	=H9/H$11	=I9/I$11	=J9/J$11	=AVERAGE(F18:J18)
19	E	=F10/F$11	=G10/G$11	=H10/H$11	=I10/I$11	=J10/J$11	=AVERAGE(F19:J19)
20	Sum	=SUM(F15:F19)	=SUM(G15:G19)	=SUM(H15:H19)	=SUM(I15:I19)	=SUM(J15:J19)	=SUM(K15:K19)
21							
22				Weighted Matrix			
23		A	B	C	D	E	Sum
24	A	=F6*K$15	=G6*K$16	=H6*K$17	=I6*K$18	=J6*K$19	=SUM(F24:J24)
25	B	=F7*K$15	=G7*K$16	=H7*K$17	=I7*K$18	=J7*K$19	=SUM(F25:J25)
26	C	=F8*K$15	=G8*K$16	=H8*K$17	=I8*K$18	=J8*K$19	=SUM(F26:J26)
27	D	=F9*K$15	=G9*K$16	=H9*K$17	=I9*K$18	=J9*K$19	=SUM(F27:J27)
28	E	=F10*K$15	=G10*K$16	=H10*K$17	=I10*K$18	=J10*K$19	=SUM(F28:J28)
29	Sum	=SUM(F24:F28)	=SUM(G24:G28)	=SUM(H24:H28)	=SUM(I24:I28)	=SUM(J24:J28)	=SUM(K24:K28)
30							
31							
32		Sum/Avg		CI	=(F38-5)/4		
33		=K24/K15					
34		=K25/K16		RI	1.12		
35		=K26/K17					
36		=K27/K18		CR	=I32/I34		
37		=K28/K19					
38	Avg	=AVERAGE(F33:F37)					

FIGURE B.0.1: EXCEL SPREADSHEET USED IN SIMULATING A SINGLE COMPARISON MATRIX

AF	AG	AH	AI	AJ	
AHP Result		Resource Allocation		System Output	Error
	µ	=POWER(SQRT(AF5)+SQRT(AF6)+SQRT(AF7)+SQRT(AF8)+SQRT(AF9), 2)			
=AD5*T5+AD6*V5+AD7*X5+AD8*Z5+AD9*AB5	A1	=SQRT(AF5/AH4)	=AH5*100	34.05	=ABS(AI5-AJ5)
=AD5*T6+AD6*V6+AD7*X6+AD8*Z6+AD9*AB6	A2	=SQRT(AF6/AH4)	=AH6*100	17.45	=ABS(AI6-AJ6)
=AD5*T7+AD6*V7+AD7*X7+AD8*Z7+AD9*AB7	A3	=SQRT(AF7/AH4)	=AH7*100	14.07	=ABS(AI7-AJ7)
=AD5*T8+AD6*V8+AD7*X8+AD8*Z8+AD9*AB8	A4	=SQRT(AF8/AH4)	=AH8*100	16.51	=ABS(AI8-AJ8)
=AD5*T9+AD6*V9+AD7*X9+AD8*Z9+AD9*AB9	A5	=SQRT(AF9/AH4)	=AH9*100	17.93	=ABS(AI9-AJ9)
=SUM(AF5:AF9)		=SUM(AH5:AH9)	=SUM(AI5:AI9)		

FIGURE B.0.2: EXCEL SPREADSHEET USED IN CALCULATING THE FINAL AHP RESULT AND RESOURCE ALLOCATION

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