THE DEVELOPMENT OF A STRUCTURED METHODOLOGY FOR THE CONSTRUCTION AND INTEGRITY CONTROL OF SPREADSHEET MODELS

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Declaration

I certify that this work has not been accepted in substance for any degree, and is not concurrently submitted for any degree other than that of Doctor of Philosophy (PhD) of the University of Greenwich. I also declare that this work is the result of my own investigations except where otherwise stated.

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Abstract

Numerous studies and reported cases have established the seriousness of the frequency and impact of user-generated spreadsheet errors. This thesis presents a structured methodology for spreadsheet model development, which enables improved integrity control of the models. The proposed methodology has the potential to ensure consistency in the development process and produce more comprehensible, reliable and maintainable models, which can reduce the occurrence of user-generated errors.

An insight into the nature and properties of spreadsheet errors is essential for the development of a methodology for controlling the integrity of spreadsheet models. An important by-product of the research is the development of a comprehensive classification or taxonomy of the different types of user-generated spreadsheet errors based on a rational taxonomic scheme.

Research on the phenomenon of spreadsheet errors has revealed the need to adopt a software engineering based methodology as a framework for spreadsheet development in practical situations. The proposed methodology represents a new approach to the provision of a structured, software engineering based discipline for the development of spreadsheet models.

It is established in this thesis that software engineering principles can in fact be applied to the process of spreadsheet model building to help improve the quality of the models. The methodology uses Jackson structures to produce the logical design of the spreadsheet model. This is followed by a technique to derive the physical model, which is then implemented as a spreadsheet. The methodology's potential for improving the quality of spreadsheet models is demonstrated.

In order to evaluate the effectiveness of the proposed framework, the various features of the proposed structured methodology are tested on a range of spreadsheet models through a series of experiments. The results of the tests provide adequate evidence of the methodology's potential to reduce the occurrence of user-generated errors and enhance the comprehensibility of the models.

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Keywords

Spreadsheet, Spreadsheet Model, Error, Methodology, Taxonomy, Software Engineering, Modularisation, Jackson Structured Programming (JSP), Integrity Control, Structured Methods, Structured Spreadsheet Development

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CHAPTER 1
INTRODUCTION

1.1 Overview

Over the years, spreadsheet users in business and academia have been completely taken aback by the appalling rates of user-generated errors occurring in spreadsheet models. Many publications have also described the adverse effect this phenomenon has had on businesses and other organisations. As a result, many groups of users and individuals from the commercial and non-commercial sectors have endeavoured to find solutions to the problem.

Despite all the efforts, the problem has been prevalent. The initial efforts to establish the magnitude of the problem of spreadsheet errors were based on measuring error rates and studying the impact of the errors on organisations. All the experiments and studies that were carried out proved beyond any doubt that this was indeed a very critical problem (Brown-87, Davies-87, Panko-96, Freeman-96, Ward-97) which had to be addressed urgently. However, there was very limited material available on specific types of spreadsheet errors. Therefore, far more extensive research had to be undertaken to identify, analyse and classify specific types of spreadsheet errors.

The focus of authors on the subject of spreadsheet model integrity subsequently turned towards ascertaining the cause of and reasons for the occurrence of user-generated spreadsheet errors. Many who carefully analysed the problem were able to conclude that the principal cause of these errors was the absence of standards for or a structured approach to designing and developing spreadsheet models (Ronen-89, Cragg-93, Isakowitz-95, Hall-96). Such standards and structured methods have however been adopted in other areas of software and systems development such as programming and database development. Authors responded to this discovery by recommending the adoption of software engineering principles and traditional programming techniques in the process of spreadsheet model building (Benham-93, Isakowitz-95, Panko-96, Davis-96, Kavanagh-97). However, none came up with a comprehensive methodology based on this requirement.

In general, two distinct approaches can be adopted to address the problem of user-generated spreadsheet errors. The first approach involves developing tools and methods to help identify errors in spreadsheet models so that they can be corrected. In a desperate pursuit for immediate solutions, this is the approach taken by most organisations at present, as a large number of existing spreadsheet models are already infested with errors. The second approach concentrates on preventing the errors from occurring in the first place. In order to achieve this, an effective methodology for controlling the integrity of spreadsheet models has to be developed and applied.

The principal objective of this research programme is to examine the possibility of developing a structured methodology for the quality or integrity control of spreadsheet models. This involves an investigation into the application of software engineering principles and techniques to the process of spreadsheet design and development.

1.2 Contributions of the Thesis

Basic Questions Posed at the Outset of this Work

These are the questions which the work described in this thesis has been directed towards:

Primary Question

- *Can a structured methodology be developed for the integrity control of spreadsheet models? Can such a framework for quality control of spreadsheet models reduce the occurrence of user-generated errors?*

Secondary Questions

- *Can a classification of the different types of user-generated spreadsheet errors be developed based on a rational taxonomic scheme?*
- *What framework for spreadsheet model development is most likely to be optimum in a practical situation?*
- *How effective is the framework?*
- *Can software engineering principles be applied to the process of spreadsheet model building to help improve the quality of the models?*

Contributions

Several contributions are made in this thesis. Firstly, a diverse collection of user-generated spreadsheet errors have been collected, analysed and categorised according to a rational taxonomic scheme. The provision of this comprehensive classification of the different types of spreadsheet errors is based on an analysis of the properties of user-generated errors. The errors are accumulated from numerous spreadsheet models. The spreadsheet error taxonomy is described in detail and supported by appropriate examples.

Secondly, structured techniques and principles have been proposed as the basis of a novel spreadsheet development methodology. The proposed structured methodology fundamentally adopts a software engineering approach and is based on established principles of structured analysis, design and development. It presents a systematic algorithm, consisting of a set of coherent stages addressing the analysis, design and development of spreadsheet models.

The main principle underpinning the proposed methodology has been derived from data structure diagrams akin to those proposed by Jackson in Jackson Structured Programming (Jackson-75, Ingevaldsson-86, Burgess-87). The methodology provides models in a structured form, allowing indentation and all its concomitant advantages in terms of comprehension and maintenance. It therefore enables improved integrity control of spreadsheet models, facilitating understanding and interpretation of the models in a standard and unambiguous manner. As a result of the structure and strict discipline introduced in the process of spreadsheet building, the occurrence of user-generated errors can be reduced.

In addition to that, the methodology has been tested on a wide spectrum of spreadsheet errors for its effect on quality. The various features of the proposed methodology are also tested on a wide range of spreadsheet models and users in academia. The results have demonstrated that the methodology is indeed effective in producing spreadsheet models that are more comprehensible and less prone to user-generated errors. In conclusion, the research has contributed significantly to the provision of additional knowledge and novel methods to the area of integrity control of spreadsheet models.

1.3 Outline of the Thesis

Chapter 1 of this dissertation provides an overview, and outlines the contributions made in this research programme. The chapter also includes a development story, time-line and chronology of publications produced. The last section gives details of the research approaches considered and adopted.

Chapter 2 presents an insight into spreadsheets and describes the problem of user-generated spreadsheet errors in terms of their frequency and impact. It also distinctly establishes the magnitude of the phenomenon of spreadsheet errors. At the end of the chapter, the importance of applying software engineering and structured methods to spreadsheet development is discussed.

Chapter 3 presents a framework for classifying user-generated spreadsheet errors based on a rational taxonomic scheme. The spreadsheet error taxonomy is produced by analysing the nature and characteristics of the different types and categories of errors. The various types of spreadsheet errors are described and appropriate examples are given.

Chapter 4 presents a review of a spectrum of existing tools and techniques for controlling the integrity of spreadsheet models. An analysis of the effectiveness and limitations of these techniques and methods is also carried out. Various life cycles and methodologies proposed for the development of spreadsheet models are also critically explored.

Chapter 5 presents findings of a preliminary investigation carried out into various methods and approaches that are deemed to have some potential in improving the quality of spreadsheet models. The core of this chapter is presented in the third section, *Section 5.3*. The second section concerns an analysis of spreadsheet structure.

Chapter 6 conveys an insight into related software engineering concepts and principles, especially *Jackson* Structures. This is in view of the fact that the main techniques and principles of the proposed structured methodology are derived from these methods and techniques. The discussion primarily covers the rationale for the selection of Jackson structural forms and the concepts, notations and rules of Jackson structures. This is followed by a discussion of the other relevant software engineering principles and their application to spreadsheets.

Chapter 7 presents the proposed structured methodology for the development and integrity control of spreadsheet models. It focuses on the synthesis of a framework or methodology based on the established software engineering principles and structured techniques described in *Chapter 6*. The various stages of the methodology are described in detail and supported by suitable examples. The methodology's potential for enhancing the quality of spreadsheet models is also addressed.

Chapter 8 begins by putting forth a plan for the evaluation of the proposed methodology based on experimental trials. The evaluation strategies underpinning the experiments are also discussed. The actual experiments conducted are subsequently described in detail. The experiments are aimed at testing the various features of the proposed structured methodology. The series of experiments involve a range of spreadsheet models used in educational institutions and industry. The elements of the methodology are tested on diverse groups of students.

Chapter 9 presents a detailed analysis of the results of the experiments conducted. The experiments are described in *Chapter 8*.

Chapter 10 presents the conclusions drawn based on the results of the experiments and from the doctoral research programme as a whole. The principal contributions of the research project are presented. The degree to which the objectives of the research have been achieved is also established. At the end of the chapter, future work to be undertaken is proposed.

1.4 Time-line of Developments

At the outset of the programme, the primary and secondary research questions to be answered were determined and specified (*Chapter 1*).

The research began with an investigation of the evolution and functions of spreadsheets, and the problem of user-generated spreadsheet errors in terms of their frequency and impact. The views and recommendations of authors and researchers on the subject were considered to identify possible causes and potential approaches to solving the problem (*Chapter 2*).

Having established the frequency and impact of spreadsheet errors, efforts were concentrated on two sets of activities that were undertaken in parallel. These activities were as follows:

- The examination and classification of specific types of user-generated spreadsheet errors based on a rational taxonomic scheme (*Chapter 3*). This was carried out so that the effects of improvements in methodology could be studied with regard to error types.
- A review of existing tools and techniques for controlling the integrity of spreadsheet models and the different life cycles and methodologies proposed for their development (*Chapter 4*).

Upon completion of these activities, an investigation was carried out into various methods and approaches that were deemed capable of improving the quality of spreadsheet models. The development of these initial methods and approaches was preceded by an analysis of spreadsheet structure (*Chapter 5*).

The next activity in the research programme was an elaborate examination of relevant software engineering methods and structured techniques, and their potential application to the design and development of spreadsheet models. The principal method focused upon was the use of *Jackson* Structures due to its capacity to model data dependencies, relative simplicity and likely acceptance in the spreadsheet community (*Chapter 6*).

Based on the software engineering methods and techniques investigated, a comprehensive structured methodology for the construction and integrity control of spreadsheet models was developed. Various spreadsheet models were used to assess the quality and effectiveness of the methodology (*Chapter 7*).

After the development of the proposed structured methodology, a plan was created for the evaluation of the methodology based on experimental trials. Various factors such as evaluation strategies, subjects, test models and other constraints were carefully taken into account. Following the development of the plan, the experiments were carried out accordingly (*Chapter 8*).

Various techniques and methods were subsequently employed to meticulously analyse the results of the experiments. Appropriate conclusions were drawn based on the results (*Chapter 9*).

Finally, overall conclusions were drawn based on the entire research programme, and appropriate recommendations were made pertaining to future work that can be undertaken (*Chapter 10*).

The following is a chronology of publications produced during the course of the research programme:

- **Rajalingham, K.** and Chadwick, D. (1998) "Integrity control of spreadsheets: organisation & tools". In: Jajodia, S., List, W., McGregor, G.W. and Strous, L. (eds) (1998) *Integrity and internal control in information systems*. Massachusetts: Kluwer Academic Publishers, pp. 147-168.

- **Rajalingham, K.**, Chadwick, D., Knight, B. and Edwards, D. (1999) "An approach to improving the quality of spreadsheet models". In: Hawkins, C., King, G., Ross, M. and Staples, G. (eds) (1999) *Software quality management VII – managing quality*. Great Britain: British Computer Society, pp. 117-131.

- Chadwick, D., **Rajalingham, K.**, Knight, B. and Edwards, D. (1999) "A methodology for spreadsheet development based on data structure", *CMS Press*, 99/IM/50.

- Chadwick, D., **Rajalingham, K.**, Knight, B. and Edwards, D. (1999) "An approach to the teaching of spreadsheets using software engineering concepts", *Proceedings of the Fourth International Conference on Software Process Improvement, Research, Education and Training, INSPIRE'99, 9-11 September 1999, Crete, Greece.* Great Britain: British Computer Society, pp. 261-273.

- **Rajalingham, K.**, Chadwick, D., Knight, B. and Edwards, D. (1999) "Efficient methods for checking integrity: an integrated spreadsheet engineering methodology (ISEM)". In: van Biene-Hershey, M.E. and Strous, L. (eds) (1999) *Integrity and internal control in information systems – strategic views on the need for control.* Massachusetts: Kluwer Academic Publishers, pp. 41-58.

- **Rajalingham, K.**, Chadwick, D., Knight, B. and Edwards, D. (2000) "Quality control in spreadsheets: a software engineering-based approach to spreadsheet development". In: Sprague, R.H., Jr. (ed.) (2000) *Proceedings of the Thirty-Third Annual Hawaii International Conference on System Sciences 2000 – abstracts and CD-ROM of full papers.* California: IEEE Computer Society.

- Chadwick, D., Knight, B. and **Rajalingham, K.** (2000) "Quality control in spreadsheets: a visual approach using color codings to reduce errors in formulae", *Software Quality Journal*, 9(2), pp. 133-143.

- Knight, B., Chadwick, D. and **Rajalingham, K.** (2000) "A structured methodology for spreadsheet modelling". In: Chadwick, D. (ed.) (2000) *EuSpRIG 2000 Symposium proceedings - spreadsheet risks, audit and development methods.* London: University of Greenwich, pp. 43-50.

- **Rajalingham, K.**, Chadwick, D. and Knight, B. (2000) "Classification of spreadsheet errors", *British Computer Society (BCS) Computer Audit Specialist Group (CASG) Journal*, 10(4), pp. 5-10.

- **Rajalingham, K.**, Chadwick, D. and Knight, B. (2001) "An evaluation of the quality of a structured spreadsheet development methodology". In: Chadwick, D. and Strous, L. (eds) (2001) *Controlling the subversive spreadsheet – risks, audit and development methods.* The Netherlands: EuSpRIG, pp. 39-59.

- **Rajalingham, K.**, Chadwick, D. and Knight, B. (2002) "Efficient methods for checking integrity: a structured spreadsheet engineering methodology", *Informatica: An International Journal of Computing and Informatics*, 26(1).

1.5 Research Approaches

The research methodology adopted for this work may be summarised by the following steps:

1. Obtain an understanding of the problem domain.
2. Make a comprehensive study of what had already been done by others.
3. Synthesise possible high-level solutions.
4. Select the most promising high level solution.
5. Elaborate the chosen solution.
6. Test the efficacy of the solution.

To obtain an understanding of the problem domain, several resources were used. These were published literature, interviews with modellers and attendances at a spreadsheet modelling training course and spreadsheet conferences. Among the main conferences were the *IFIP TC11 WG11.5 Working Conferences on Integrity and Internal Control in Information Systems*, *International Conferences on Software Quality Management* organised by the *British Computer Society*, *International Conferences on Software Process Improvement, Research, Education and Training (INSPIRE)*, the *Hawaii International Conferences on System Sciences* and the *Annual European Spreadsheet Risks Interest Group (EuSpRIG) Spreadsheet Symposiums.*

In order to gain an insight into what had already been done on the subject of integrity control of spreadsheet models and spreadsheet development, a thorough review of existing literature was deemed to be the most appropriate approach. The material reviewed included books, journal papers, conference proceedings and articles in other publications. Interviews and face-to-face meetings were considered very important in a research of this nature. Engaging in such interviews and meetings could provide a direct insight into the various aspects of the research, especially the phenomenon of spreadsheet errors and existing tools, techniques and methods used to control the integrity of spreadsheet models. In order to effectively benefit from the use of this research method, the people to be interviewed were carefully chosen. Interviews, meetings and discussions were subsequently held with researchers on the subject, spreadsheet users in academia and industry, people involved in the auditing of spreadsheet models, facilitators of training in spreadsheet modelling and developers of tools for spreadsheet auditing and quality control.

High-level solutions were generated by examining all existing software engineering methodologies, and examining their applicability to the current problem. Pros and Cons of each methodology were presented to the supervisory team, and a favoured candidate emerged (*Jackson Structures*).

The selected methodology was elaborated in logical mode and tried out on some standard business models. These were obtained from standard texts, and from industrial users.

The testing for efficacy was carried out on real users who were students attending courses where the researcher was lecturing. These users were used for trials, in view of the need for statistical significance. This was preceded and guided by research into relevant past experiments.

CHAPTER 2
BACKGROUND

2.1 Introduction

The primary and secondary research questions to be answered by this doctoral research programme were identified and specified in *Chapter 1*. In order to begin addressing these research questions, an investigation was undertaken into the evolution and functions of spreadsheets, and the problem of user-generated spreadsheet errors in terms of their frequency and impact. The views and recommendations of authors and researchers on the subject were subsequently explored to identify possible causes and potential approaches to solving the problem.

This chapter begins by presenting the results of the investigation into the evolution, functions and benefits of spreadsheets. This is followed by a discussion of the phenomenon of user-generated spreadsheet errors. The different aspects of the problem addressed are the trends in spreadsheet errors, the frequency of the errors, and their real-life impact and consequences. The views and recommendations of authors and researchers on the subject are subsequently presented. This also involves a discussion of the need to adopt software engineering and structured methods in spreadsheet development.

2.2 An Insight into Spreadsheets

Prior to the investigation of spreadsheet errors, it is appropriate to gain a basic understanding of spreadsheets as well as their evolution in recent years. Spreadsheet programs attained widespread use since the development of the first electronic spreadsheet package, *VisiCalc*, in 1979 (Brown-87). After the creation of VisiCalc, *Lotus 1-2-3* was built for the IBM PC, followed by *Microsoft Excel*, which is presently used on the Windows platform (Butler-97).

The spreadsheet provides a large matrix of rows and columns. Each column is assigned unique letters while each row is identified by a distinct number. Users organise parameters, variables, formulae and components of the spreadsheet model within this framework (Nardi-90). The intersection of a row and column defines a cell. A cell can contain a numeric constant, label or formula. According to Ronen et al (Ronen-89), the tremendous power of spreadsheets is attributable to its ability to relate cells with formulae.

The underlying formula of a cell is not readily visible to the user. It is only the numeric result of the calculation defined by the formula, which is displayed (Brown-87). Formulae perform calculations on absolute values and references to other cells, represented by the corresponding cell addresses. Users can model problems in a spreadsheet and easily automate the calculation of large complex systems using cell formulae (Igarashi-98). When Lotus 1-2-3 was developed in 1983, macros were added. Creeth (Creeth-85) defines a *macro* as a single computer instruction that stands for a sequence of operations. Macros further enhanced the functionality of spreadsheets.

Igarashi et al (Igarashi-98) state that spreadsheets are one of the most successful applications making use of visual language techniques, and have the capacity to display and manipulate complex information in tabular form. With the advent of spreadsheets, end-users in business could more easily computerise laborious and time-consuming custom calculations that were needed for a wide range of commercial activities (Butler-97). Bodily (Bodily-86) believes that an important function of the electronic spreadsheet is its ability to support *what-if* analyses of all kinds.

Olsen and Nilsen (Olson-87-88) have described three major advantages offered by spreadsheets. First, the spreadsheet can be easily edited. Second, the values of certain cells can be automatically calculated from the contents of other cells by using formulae. The third advantage is the ability to *copy* a formula from one cell to another while keeping constant the relative location of cells that are referenced.

Spreadsheet based systems are an important part of end-user computing (Cragg-92). They are used for a wide variety of applications. Ronen et al (Ronen-89) believe that the most frequent use of spreadsheets is for decision support and personal productivity. They, however, also state that many spreadsheet applications can in fact be regarded as mainstream information systems applications.

It is important to have an understanding of the different roles taken on by people involved in a spreadsheet project. The number of people needed to carry out a particular role is mainly dependent on the size and complexity of the spreadsheet model. Read and Batson (Read-99) define various roles in spreadsheet model development and use. The *model sponsor* is the person who requests that the model be built and ensures that the required resources are available. Agreement of the objectives of the model is the responsibility of the model sponsor. The *model developer* translates the sponsor's requirements into the actual spreadsheet model. The model that has been built will have at least one *user*. The sponsor and developer of the model may also be its users. The *reviewer* is the person who tests the spreadsheet (Read-99).

2.3 The Phenomenon of Spreadsheet Errors

Numerous publications have recently demonstrated the seriousness of user-generated spreadsheet errors and their adverse consequences or potential impact on businesses. There is substantial anecdotal evidence suggesting that end-user developed spreadsheets can be considered unreliable, inflexible, unmaintainable, and unmanageable (Benham-93). According to Ray Butler of HM Customs and Excise (United Kingdom), even in a domain such as indirect taxation, which involves relatively simple calculations and well-documented calculation rules, spreadsheet models are prone to errors, despite relatively high domain knowledge by developers (Chadwick-00b).

According to Ronen et al (Ronen-89), spreadsheet packages have extended computing to vast numbers of individuals. They argue that for many users, the spreadsheet program represents their first experience with programming and documentation. Ronen et al (Ronen-89) state that in general, these users have not been trained in systems analysis and tend to overlook the concerns of the professional systems analyst in designing a system. The practitioner literature has discussed a number of problems with spreadsheet construction (Ronen-89).

The phenomenon and magnitude of spreadsheet errors can be viewed from three different perspectives (Rajalingham-99). They are as follows:

- frequency of the errors
- impact and real-life consequences of spreadsheet errors
- types and classes of specific errors

The first two aspects of the problem of spreadsheet errors are discussed in this chapter while the third is analysed and presented in the next chapter, *Chapter 3: Analysis and Classification of Spreadsheet Errors*.

2.3.1 Overview of Trends in Spreadsheet Errors

There is more than sufficient evidence from various reliable sources that the problem of spreadsheet errors has been experienced for decades. This also appears to be the situation today despite the advent of various tools and techniques for controlling the integrity of spreadsheet models.

In 1998, research carried out by Pricewaterhouse Coopers revealed that there was a trend of increasing spreadsheet model size and complexity (Whittaker-99). Whittaker argues that the trend towards larger model size and complexity is clear, and there is every possibility that this trend will continue in future. A conclusion that can be drawn from this statement is that the frequency of spreadsheet errors is steadily increasing as in general, the number of errors is proportionate to the spreadsheet model size and complexity.

Another factor that influences the escalating frequency of spreadsheet errors is the speed and simplicity of building spreadsheet models. Howitt (Howitt-85) believes that spreadsheets create the opportunity to make more mistakes and multiply them rapidly due to the speed and simplicity of spreadsheet application development. This indicates that with the increasing use of spreadsheets over the years, users have been making more errors and quickly multiplying them.

There is extensive material clearly indicating an increasing use of spreadsheets, resulting in a proportional increase in the frequency of spreadsheet errors. According to Carlsson (Carlsson-89), in business, spreadsheet programs have become one of the most frequently purchased and used personal computer programs. Isakowitz et al (Isakowitz-95) state that there has been increasing sophistication and power of commercial spreadsheet packages. They believe that spreadsheet programs have transformed the concept of end-user computing, creating a new computational paradigm that offers a unique combination of ease of use and unprecedented modelling power. This has encouraged the widespread use of spreadsheets in business and resulted in spreadsheet programs becoming the most popular decision support tool in modern business (Isakowitz-95).

Ray Butler of HM Customs and Excise, United Kingdom (Butler-97) states that spreadsheets are among the most dangerous and error-prone development platforms. The figures on the frequency of user-generated spreadsheet errors are truly astounding and indicate a high probability of imminent disaster scenarios around the world (Chadwick-00b). An important conclusion that can be drawn on the trends in spreadsheet errors is that with the profound increase in the production and use of spreadsheet models over the years, the frequency and impact of the errors have also steadily increased.

2.3.2 Frequency of User-generated Spreadsheet Errors

There have been various publications containing information on the frequency of spreadsheet errors. Despite the widespread use of spreadsheets, there has been extensive anecdotal and experimental evidence that electronic spreadsheets are highly susceptible to user-generated errors (Brown-87). Although electronic spreadsheets are immensely beneficial to accountants and financial analysts, they may have a disastrous impact on critical business decisions (Hayen-89). After a thorough review of relevant literature, various cases have been selected and presented in this section to demonstrate the appalling frequency of user-generated spreadsheet errors.

Based on the results of an experiment, Brown and Gould (Brown-87) concluded that even a substantial percentage of spreadsheets created by experienced spreadsheet users contained one or more errors. According to Freeman (Freeman-96), Coopers and Lybrand (London), reported that over 90% of all spreadsheets they had examined, with more than 150 rows, contained at least one significant formula error. This is an extremely high figure and if the errors had gone undetected, they could have had a devastating effect on the business.

An article in *New Scientist* (Ward-97) has reported that a decade's worth of research findings of Professor Raymond Panko at the University of Hawaii revealed that spreadsheets had a dangerously high rate of errors. It appears that on average, 30% of spreadsheets contain errors, many of which are serious. According to Professor Panko, the problem is that spreadsheets demand a level of accuracy that people find difficult to manage.

A financial model review by KPMG Management Consulting, London (KPMG-97) stated that in 95% of the financial models audited, at least 5 errors had been found. The review also revealed alarming statistics concerning defects and flaws in the spreadsheet development process, addressing the project management, technical and analysis aspects. An audit of spreadsheets from over 21 major UK banking and financial organisations revealed that 92% of the spreadsheets dealing with tax issues had significant errors while 75% had significant accounting errors (KPMG-98b).

An excellent compilation of studies on the frequency of spreadsheet errors has been produced by Panko and Halverson (Panko-96,98,00). The findings are presented in *Appendix A*.

There is also substantial anecdotal evidence from the commercial sector, of the high frequency of user-generated errors in spreadsheet models. A selection of the relevant cases is presented below in chronological order of publication.

- Creeth (Creeth-85) has stated that according to industry experts, one out of every three spreadsheet printouts contains errors.
- An article from *Personal Computing* (Ditlea-87) reported that a Houston consultant with Price Waterhouse had found 128 errors in 4 spreadsheet models that had already been in use for months.
- Estimates from the trade press on the number of spreadsheets that contain errors range from 20 to 40 percent (Brown-87).
- According to Davies & Ikin (Davies-87), out of 19 worksheets (from 10 different firms) audited, 4 (21%) had serious errors, while 13 were considered to have inadequate documentation, and 10 did not use cell protection.
- Roberts (Roberts-88) found one or more errors in 80% of spreadsheet models audited.
- In an inspection of 20 operational models of 10 firms, errors were found in at least 25% of the models. Apart from that, other problems were also found (Cragg-93).
- In an Australian mining firm, an audit found that 30% of the spreadsheets audited had been corrupted because cell protection had not been used, and users typed numbers into formula cells (Dent-95).

2.3.3 Impact and Consequences of User-generated Errors

Spreadsheet errors can be devastating because the data is often the foundation on which many organisations make critical decisions (Freeman-96). It is important to examine the adverse consequences of the problem of spreadsheet errors in real life. This enables a distinct comprehension of the magnitude of the problem and an assessment of the seriousness of the situation.

The information presented in this section has been obtained from numerous publications. It must however be noted that these are based only on reported cases. It is believed that there are many other similar cases that have not been brought to public attention due to fear that it might adversely affect the reputation of the organisation involved.

There are publications from more than a decade ago with clear indications that user-generated spreadsheet errors have caused serious disruption of business. Although these cases are not based on formal research, they do show that spreadsheet errors were considered important enough to be reported in the general business and computing press.

A subset of significant reported cases is provided below in chronological order of publication.

- According to an article in *Business Week* (Business Week-84), a Midwestern firm's estimated taxes had been $5,000 off due to an incorrect formula for assessing salvage value in the spreadsheet.

- The article (Business Week-84) has also stated that in the forecast for a new product, the forecast sales was $8 million over. Fortunately, it was detected in time to prevent any serious damage.

- In another case (Business Week-84), a person ordered 30,000 units at $4 each, but the plan had changed and the company only needed 1500. Quite a lot of money was therefore tied up in excess stock.

- Two spreadsheets with 15,000 cells were used to project the market for CAD equipment. The numbers were rounded off to whole dollars and even the inflation multiplier, which should have been 1.06 was rounded off to 1. Consequently, the market was underestimated by $36 million (Business Week-84).

- A Dallas-based oil and gas company fired several executives for spreadsheet model oversights that cost the company millions of dollars (Freeman-86).

- Work by Ditlea (Ditlea-87) published in Personal Computing, offer several cases showing the adverse impact of spreadsheet errors on businesses. The controller of James A. Cummings, Inc., a Florida construction company, was putting together a Symphony spreadsheet model to bid on a $3 million office complex. His formula to calculate the bid did not include a figure of $254,000 for overhead costs that he had later inserted at the top of a column of figures. This entry fell outside the range of numbers to be added by the @SUM (=SUM in MS Excel) function in his formula. The undetected error resulted in a loss for the company when the bid was won (Simkin-87).

- In another case (Simkin-87), a consultant called Larry Nipon found an error that would have cost $1.5 million had it gone unchecked. The error was actually identified by *Cambridge Spreadsheet Analyst*, a spreadsheet auditing program.

- Davies and Ikin (Davies-87) have found that out of 19 operational models audited from 10 different firms, 4 (21%) had serious errors, including a $7 million error in interdivisional transfers, different exchange rates for Australian dollars in the same time period, and a negative balance for stock on hand. The effect errors like these can have on the company is simply unimaginable.

- According to Woodbury G G (Woodbury-89), in a North Carolina election, results of the election were about to be incorrectly posted. Mr Woodbury, using a calculator, detected an inconsistency. Examination found an incorrect cross-tabulation in the spreadsheet being used to post the results.

The following are three of the more recently reported cases:

- Dhebar (Dhebar-93) reported that a firm called Fortune 500 used discounted cash flows to evaluate investment proposals and an important figure was not updated for 8 years. The formula and discount rate had apparently been established long ago, were never documented and made by a person who had left the company. Although the prime rate rose from 8% to over 20% between 1973 and 1981, the spreadsheet was kept at 8%. This is potentially detrimental to the business.

- At Fidelity, a spreadsheet was used to report distributions for various funds. For the huge Magellan fund, a $4.32 per share capital gains distributions was forecast in November, and investors were notified. However in December the company announced there would be no distribution. A clerical worker put the wrong sign in front of a $1.2 billion ledger entry. This "created" a $2.3 billion gain in place of the real $0.1 billion loss. This may have affected buyers, some of whom may have sold to avoid the distribution and missed a price rise, others of whom may have waited to buy to avoid the distribution and also missed the price rise (Savitz-94).

- According to an article in *New Scientist* (Ward-97), a study by the Computer Audit Unit of HM Customs and Excise (UK) found that as a result of errors, spreadsheets were out by amounts ranging from a few hundred pounds to millions of pounds. These errors were made by people when filling in computer spreadsheets used by companies to keep track of their cash.

These reports demonstrate that the occurrence of user-generated spreadsheet errors is indeed a critical problem for businesses and requires immediate attention. If this situation prevails, organisations will, inevitably, be suffering great financial losses as a result of incorrect decisions made based on their erroneous and unreliable spreadsheet models.

2.4 Need for a Disciplined and Structured Approach

Spreadsheet models are increasingly being used in decision-making within organisations (Cragg-93). However, much past research and published reports have firmly established that there is no unified approach to spreadsheet development in industry. Spreadsheet development can, in many ways, be compared to the days of main-line software development before the advances due to structured programming, analysis and design. Isakowitz et al (Isakowitz-95) state that in spite of the increasing sophistication and power of commercial spreadsheet packages, there is still a lack of a formal theory or methodology to support the development and maintenance of spreadsheet models.

Findings from research carried out over several years have revealed the need for a new approach or discipline for spreadsheet development. This is evident from the constant call for a new structured approach, in many recent publications. Studies have also discovered a general lack of policies on spreadsheet development. A collection of these studies have been organised and presented by Panko and Halverson (Panko-96). This can be found in *Appendix B*. Hall (Hall-96) argues that with the high probability of the occurrence of spreadsheet errors, there is an obvious need for some formalised control policy in the spreadsheet development process.

Panko and Halverson (Panko-96) state that surveys of spreadsheet development have revealed that strict development disciplines have not been followed in spreadsheet development, as they are in conventional programming. They also indicate that the process of building spreadsheet models has been largely informal and emphasise on the need to adopt programming disciplines in order to deal with complex spreadsheets. Panko and Halverson also point out the fact that there is an obvious need to adopt traditional programming disciplines due to the similarity between spreadsheet and programming errors.

Spreadsheet applications are more vulnerable to poor design and errors compared to conventional programs, as many spreadsheet users have not been trained in systems analysis and software engineering (Davis-96). Benham et al (Benham-93) propose the adoption of the techniques of structured analysis, design and programming to spreadsheets, in order to enhance the quality of the applications. Their reason is that such structured techniques were developed to address the shortcomings of early data processing systems. Howitt (Howitt-85) states that users' failure to employ a consistent and thorough design methodology is due to the speed and simplicity of spreadsheet model development.

According to the publications by Davies and Ikin (Davies-87) and Cragg and King (Cragg-93), spreadsheet development, in most cases, has been found to be very informal and lacking in the use of important development disciplines. David Finch, Head of Internal Audit at Superdrug plc (United Kingdom) believes that there is often inadequate control and standardisation in the process of spreadsheet development by end-users in different departments (Chadwick-00b). Creeth (Creeth-85) has called for quality control over the use of spreadsheet models.

An investigation carried out into the spreadsheet practices in ten firms revealed that spreadsheet models were usually built in an informal, iterative manner, by people with very little training (Cragg-93). This created an awareness of the need for increased training as well as setting and enforcing organisational spreadsheet standards (Cragg-93). According to Ray Butler (Butler-97), the problem with spreadsheet building is that users do not regard spreadsheet models as computer programs requiring specification, testing and documentation. Ray Butler believes that a reduction in the risk of errors can be achieved by using a more formalised development and testing methodology for spreadsheet applications (Chadwick-00b).

Hendry and Green (Hendry-94) have pointed out that the great disadvantage of spreadsheets is that it is so easy. They suggest that instead of creating the whole spreadsheet first and then checking for errors, errors ought to be checked for at various stages of the development process. They believe that this would enable the detection and correction of errors without missing many. This strategy of stage-by-stage component testing is a software engineering-based technique.

Ronen et al (Ronen-89) express concern over the lack of formal analysis or documentation in spreadsheet development. They state that a structured approach to spreadsheet design can help reduce the occurrence and seriousness of problems with spreadsheets. According to Isakowitz et al (Isakowitz-95), a decrease in spreadsheet errors can be achieved by adopting principles of structured methods from software/system engineering. Kavanagh (Kavanagh-97) states that end-users are putting their companies at risk by building spreadsheets without realising that this demands the discipline of traditional programming.

Based on these studies and published reports, we can arrive at the firm conclusion that the application of structured methods and the adoption of a disciplined approach based on programming (or software engineering) principles in spreadsheet development, is indeed imperative. This research programme investigates the possibility of applying such methods in order to effectively address the phenomenon of user-generated spreadsheet errors and enhance the integrity of spreadsheet models.

2.5 Summary

Spreadsheet programs have been in widespread use from the development of the first electronic spreadsheet package, *VisiCalc*, in 1979, to the current windows-based *Microsoft Excel*. The different roles in spreadsheet modelling include the *model sponsor*, the *model developer*, the *user* and the *reviewer*. There are three important perspectives to the phenomenon of spreadsheet errors. They are the *frequency of the errors*, the *real-life consequences of spreadsheet errors* and the *types and classes of specific errors*.

An important conclusion that can be drawn on the trends in spreadsheet errors is that with the profound increase in the production and use of spreadsheet models over the years, the frequency and impact of the errors have also steadily increased. Users have been making more errors and quickly multiplying them.

It is evident from numerous publications that the frequency of user-generated spreadsheet errors is indeed appallingly high. These publications contain extensive anecdotal and experimental evidence of the vulnerability of spreadsheet models, from both business and academia sources. This is further corroborated by research findings.

Numerous studies and audits have been carried out on the impact of user-generated spreadsheet errors. These along with a huge collection of reported cases over two decades, have clearly revealed the extent of damage that has been caused to businesses, as well as potential future disruption.

Researchers on the problem of spreadsheet errors and authors of numerous relevant publications have relentlessly stressed on the need for a new approach to spreadsheet modelling. They have constantly recommended a structured and disciplined approach to spreadsheet model development based on software engineering methods and techniques.

CHAPTER 3
ANALYSIS AND CLASSIFICATION OF SPREADSHEET ERRORS

3.1 Introduction

The previous chapter, *Chapter 2*, presented an insight into spreadsheets and described the problem of user-generated spreadsheet errors in terms of their frequency and impact. The importance of applying software engineering and structured methods to spreadsheet development was also discussed. As mentioned in *Chapter 2*, the phenomenon and magnitude of spreadsheet errors can be viewed from three distinct perspectives. The first two perspectives were addressed in *Chapter 2* by investigating the frequency and real-life consequences of spreadsheet errors. This chapter focuses on the third perspective, the types and classes of specific errors.

A thorough review of literature concerning spreadsheet development and the relevant integrity issues, has revealed a significant deficiency. Very little research has been devoted to the study and examination of specific errors that occur in spreadsheet models. Therefore, an analysis of specific types of errors has been conducted as a precursor to the development of strategies and solutions to deal with the problem effectively.

There are numerous types of user-generated spreadsheet errors, with different characteristics and attributes. As such, an essential and integral part of the analysis of specific types of spreadsheet errors would be to develop a classification of these errors. This chapter presents a more comprehensive classification or taxonomy of spreadsheet errors than ever presented or published before, following a meticulous analysis of specific types of user-generated spreadsheet errors from a wide variety of sources. The classification is based on a rational taxonomic scheme and is supported by a selection of generic and specific examples. The spreadsheet error taxonomy is produced by analysing the nature and characteristics of the different types and categories of specific errors. Earlier versions of the taxonomy have been published (Rajalingham-98, 99, 99a, 00, 00a, 00b). The classification facilitates more effective comprehension of the different types of spreadsheet errors.

3.2 The Concept of *Taxonomy* or Classification

In a broad sense, taxonomy is the science of classification, though more strictly, it refers to the classification of living and extinct organisms. The term is derived from the Greek *taxis* ("arrangement") and *nomos* ("law"). It is important to note, however, that there is no special theory which lies behind modern taxonomic methods. In attempting to define *taxonomy* within the context of spreadsheet errors, it would be appropriate to investigate the definition of this term in other fields of study. In biology, *taxonomy* refers to the establishment of a hierarchical system of categories on the basis of presumed natural relationships among organisms. The goal of classifying is to place an organism into an already existing group or to create a new group for it, based on its resemblances to and differences from known forms. To this end, a hierarchy of categories is recognised (Britannica.com-99-00).

Based on the definitions borrowed from other disciplines, we can extend the concept of taxonomy to the classification of spreadsheet errors. For our purposes, the *spreadsheet error taxonomy* can be defined as a hierarchical system of classes of spreadsheet errors on the basis of common characteristics and relationships.

3.3 Rationale for the Classification of Spreadsheet Errors

There are various reasons for developing a classification of spreadsheet errors. The most important purpose of creating a taxonomy is that it is a methodical approach to problem analysis. The analysis of the different types of errors based on this approach is likely to improve comprehensive testing of a spreadsheet development methodology. The development of a taxonomy of spreadsheet errors also forces us to gain a deeper understanding of the characteristics of an error as well as the nature of its occurrence. A comparison can also be made with other related errors belonging to the same category.

An insight into the features and nature of an error is of paramount importance, in order to prevent the occurrence of the error or develop a method of detecting its presence. The classification of spreadsheet errors would inevitably involve an identification of similar characteristics and properties between certain errors. This can be used as a basis for developing similar approaches to address spreadsheet errors within the same category or taxonomic group. Knowledge of the characteristics of an error also enables analysis of its potential impact and frequency. It is highly probable that other errors in the same category would have the same degree of seriousness.

3.4 Derivation of the Taxonomic Scheme

This section discusses the factors and approaches that have been considered in the development of the taxonomy. As indicated earlier, there is no special theory which lies behind modern taxonomic methods. As such, an investigation had to be carried out into the taxonomic methods used in other fields. These methods of classification have been widely employed in the fields of *zoology* and *botany*.

Based on the principles of classification adopted in *zoology* and *botany* (Britannica.com-99-00), spreadsheet errors can be classified using a similar taxonomic scheme. The process of classification consists of the following steps:

- A specific type and example of a spreadsheet error is obtained.
- The error is compared with the known range of variation of spreadsheet errors.
- The error is correctly identified if it has been described, or a description showing similarities to and differences from known categories, is prepared. If the error is of a new type, it is assigned to a new category or class.

In order to address these limitations, the alternative *binary* approach was considered and assessed. Like the bushy structure, this method is also based on a top-down approach, resulting in a hierarchical taxonomy. However, at each stage of the taxonomy, the binary approach uses *dichotomies* or divisions into two mutually exclusive *(non-overlapping)* groups, to classify the errors. This eliminates the possibility of positioning the same type of error in different parts of the taxonomy and causing an overlap of the different categories of spreadsheet errors.

This feature of the binary approach enables a far more straight-forward way of assigning a specific error to a taxonomic class. A simple IF-THEN-ELSE rule or constraint can be used to navigate down the taxonomy tree and position errors in appropriate classes. This is demonstrated in the next section. Furthermore, as a rule, at each stage where a dichotomy is produced, only a single factor, representing a distinct aspect of the error is used. This reduces ambiguity of class definition at each rank.

To this end, the following aspects of a particular type of spreadsheet error are analysed:

(i) Manifestation of the error
(ii) Cause of the error
(iii) The role of the person responsible for the error
(iv) The cognitive state of the person responsible for the error
(v) The stage of the spreadsheet building life cycle where the error occurs
(vi) The relevant view of the spreadsheet model system

In view of the advantages of the *binary* method compared to the *bushy* method, the binary approach has been adopted as the basis of a rational taxonomic scheme for classifying spreadsheet errors. The taxonomic scheme also involves the conventional process of classification (as used in *zoology* and *botany*) and an analysis of the nature, properties and characteristics of spreadsheet errors.

3.5 The Classification of Spreadsheet Errors

An important point to be clarified at this stage is that the classification is confined to only *user-generated spreadsheet errors*, as opposed to system or software-generated errors. The issue of detecting or correcting flaws in the spreadsheet software is beyond the scope of this research. User-generated errors can be defined as errors (or potential errors) produced or caused by the developer(s) or end-users of the spreadsheet model and can therefore be controlled or prevented by them.

Whenever, the term *error* is used in this thesis, it should be noted that it has a broader definition encompassing both *actual errors* and *potential errors*. The errors include *flaws*, *slips* and *mistakes*. Slips are errors that occur when the intention to act fits the intended goal but the action is not carried out according to plan. Mistakes, on the other hand, are errors that occur when an action is carried out as intended but the action itself is not appropriate to the task (Chadwick-97).

It is also appropriate to state at this juncture that in the process of classifying certain specific errors, assumptions had to be made about the precise cause of the errors, where this is not clearly indicated by the source. It is possible for the same error to be assigned to a different category, should the actual cause not match the assumed cause.

Figure 3.2 displays a comprehensive classification of user-generated spreadsheet errors. At the highest level, spreadsheet errors can be divided into two major categories, namely *qualitative errors* and *quantitative errors*. The classification factor used at this stage is the manifestation of the error. Panko and Halverson (Panko-96) have also broadly classified spreadsheet errors as being either quantitative or qualitative.

By examining the manifestation of a specific type of spreadsheet error, it can be clearly determined whether it is quantitative or qualitative, but not both. Any error or flaw which is not quantitative has to be qualitative. Therefore, spreadsheet errors can be divided into two non-overlapping categories of *quantitative* and *qualitative* errors. This can be expressed in a form identical to a structured program.

```
For all user-generated spreadsheet errors,

IF      numerical error causing incorrect bottom-line value
THEN    quantitative error
ELSE    NOT quantitative error (i.e. qualitative error)
```

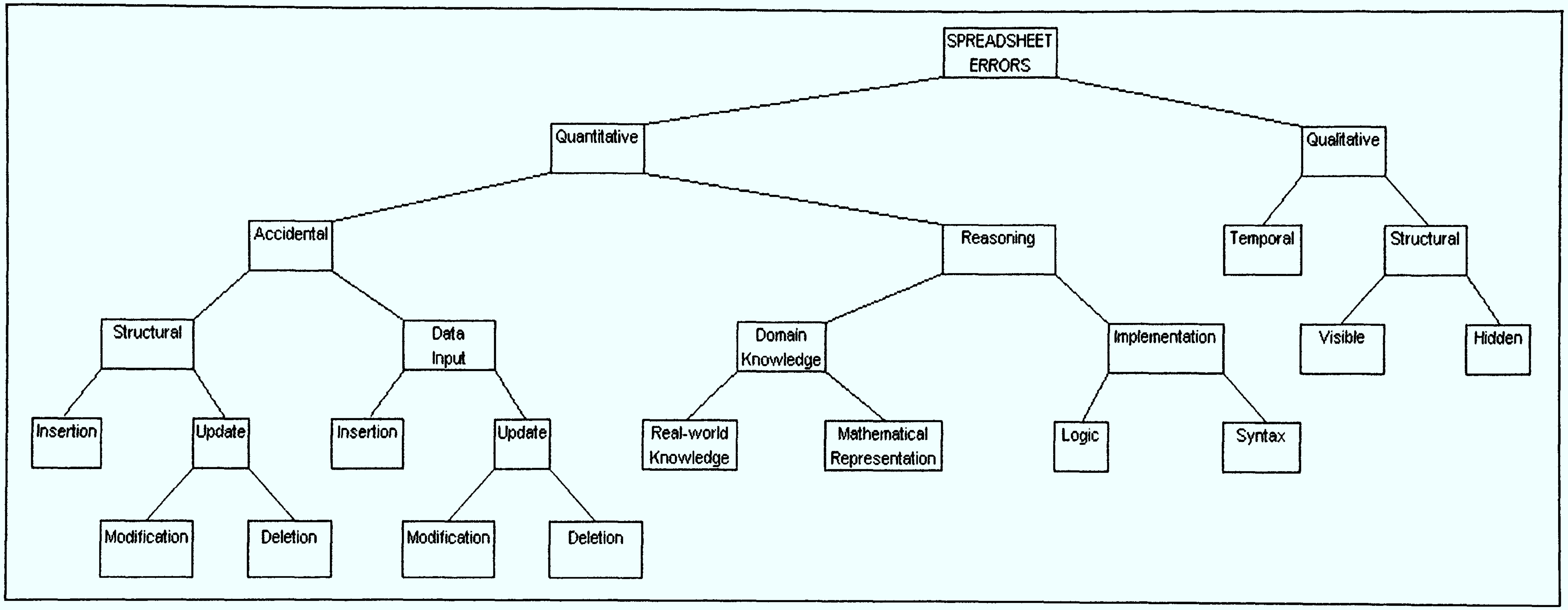


Figure 3.2: Taxonomy of User-generated Spreadsheet Errors

3.5.1 Quantitative Errors

Quantitative errors are numerical errors that lead to incorrect bottom-line values (Panko-96). They simply produce wrong data in the spreadsheet model. Based on an analysis of the cause of the error, a dichotomy of *accidental* and *reasoning errors* can be used to capture the different types of quantitative errors.

Any error or flaw which is quantitative and not accidental must have been produced as a result of a mistake in reasoning and can therefore be considered to be a reasoning error. Common sense would dictate that an error cannot be both accidental and caused by a mistake in reasoning. Therefore, quantitative errors can be divided into two non-overlapping categories of *accidental* and *reasoning* errors.

For all *quantitative* errors,

IF error is caused by negligence or carelessness
THEN ***accidental*** error
ELSE *NOT accidental* error (i.e. ***reasoning*** error)

It is important to state at this juncture that the dimension of fraud is not taken into account when developing the classification framework for quantitative errors. This is because any error can be deliberately produced with fraudulent or malicious intent and disguised as an accidental or reasoning error, unless of course the criminal motive is blatantly obvious as in this example:

A user rewrites a payroll equation as follows (Stang-87):

```
IF EMPLOYEEID = MINE
THEN PAYCHEQUEAMT = HOURS X RATE X 1.03
ELSE PAYCHEQUEAMT = HOURS X RATE.
```

1. Accidental Errors

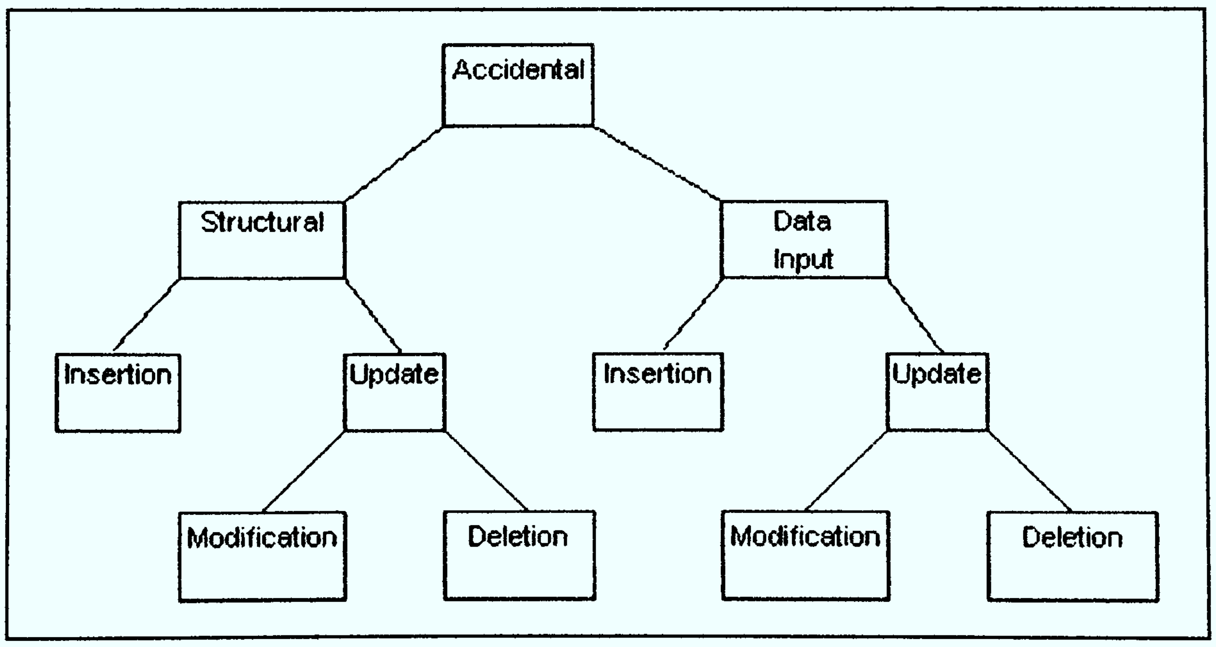


Figure 3.3: Accidental Errors

Accidental errors are mistakes and slips caused by negligence, such as typographical or pointing errors. Though quite frequently occurring, they have a high chance of being spotted and corrected immediately by the person committing the error. Some, however, do go undetected and could lead to incorrect values in the spreadsheet model. After a close examination of various types of accidental errors, it has been found that they can be further divided into two distinct categories. The taxonomic factor used to achieve this is the user role responsible for the error. As such, an accidental error can either be a *structural error* or a *data input error*.

Any user-generated error or flaw which is not produced by the model developer could only have been caused by the end-user(s) of the model. Errors caused by end-users are defined as *data input errors* as these errors occur when end-users insert, alter or remove data in the models. The structures or templates of these models would have already been constructed by the model developer. Based on this understanding of the two distinct user roles, accidental errors can be divided into two non-overlapping categories of *structural* and *data input* errors.

For all *accidental* errors,

IF error is caused by the model developer
THEN ***structural*** error
ELSE *NOT structural* error (i.e. ***data input***)

(a) Structural Errors

Structural errors are errors produced by the developer of the spreadsheet model. These errors are produced when creating or altering the structural or programmed component of the spreadsheet model. Therefore, these errors can again be segregated into two categories, namely, *insertion* and *update* errors. Though the structural component of a spreadsheet model consists of schema and editorial sub-components (described elaborately in *Chapter 5*), these errors primarily concern the schema of the model. As the editorial parts of the model are mainly textual and not referenced by any formulae, they do not produce numeric or bottom-line errors. As such they are not classed as quantitative errors. They are in fact qualitative errors as these editorial errors can degrade the quality of the model and distort its semantics.

Any developer-generated accidental error or flaw not produced while creating the structural aspects of the spreadsheet model must have occurred while they are being altered. This enables the disjointed division of accidental structural errors into *insertion* and *update* errors.

For all *structural* errors,

```
IF      error is produced when creating the structural aspects of the
        spreadsheet model
THEN    insertion error
ELSE    NOT insertion error (i.e. update error)
```

(i) Insertion Errors

These errors occur while the developer is creating the structures of the spreadsheet model. The model at this stage would be prone to accidental errors such as typographical errors, pointing errors, duplication and omissions. As the activity is carried out by the model developer, the cells affected would usually be formula cells.

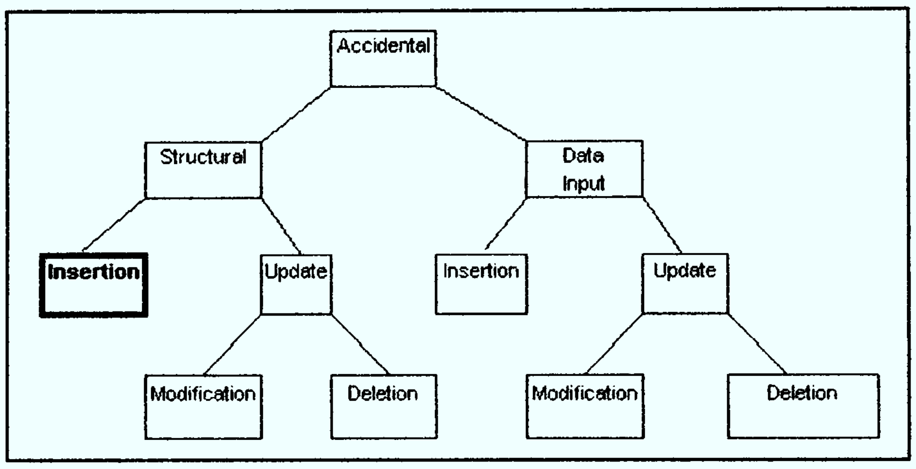


Figure 3.4: Insertion Errors (Structural)

Example 1: Omissions

Omissions are key factors or variables that are left out of the model (Cragg-93), that should be there. They often result from a misinterpretation of the situation. Human factors research has shown that omission errors are especially dangerous, because they have low detection rates (Panko-96). This is a problem which is at the heart of any modelling exercise. KPMG (KPMG-98) reported that references were made to worksheets that does not exist (Cragg-93).

Example 2: Pointing Errors

Pointing errors refer to errors caused by references being made to wrong cells or cells in the wrong location. The model developer types the wrong cell coordinates in composing the formula (Brown-87). As a result of carelessly entering incorrect cell or range addresses into formulae, the formulae themselves produce incorrect results. Pointing errors could therefore also manifest themselves in the form of references to blank cells and non-numeric cells or cause the presence of figures that are not used.

Therefore, reasoning errors can be exclusively divided into two categories: *domain knowledge* and *implementation* errors. Research into the relative frequencies and real-life impact of the different types of reasoning errors have shown that implementation errors are far more common than domain knowledge errors. Domain knowledge errors are, however, generally more serious than implementation errors.

For all *reasoning* errors,

IF error occurs owing to a lack of understanding of the underlying problem or function to be modelled
THEN ***domain knowledge*** error
ELSE *NOT domain knowledge* error (i.e. ***implementation*** error)

(a) Domain Knowledge Errors

Domain knowledge errors are specifically caused by inadequate awareness or knowledge required to identify, analyse and understand the business function or problem underlying the spreadsheet model. This knowledge is essential for modelling the problem and designing the corresponding conceptual or logical data model.

Domain knowledge errors, however, do not concern the specific features and capabilities of any particular spreadsheet package. The matrix of data and formulae that constitute the recognised spreadsheet model is an electronic representation of a business function in the real world.

This category of errors consists of two distinct classes, namely *real-world knowledge* and *mathematical representation* based errors. Any reasoning domain-knowledge error which occurs despite selection of the right algorithm must have been caused by a lack of understanding of how the algorithm is to be mathematically represented. It would therefore seem appropriate to term these sorts of errors as *mathematical representation* errors.

For all *domain-knowledge* errors,

IF error caused as a consequence of a lack of knowledge on the underlying algorithm of a calculation or function
THEN ***real-world knowledge*** error
ELSE *NOT real-world knowledge* error
(i.e. ***mathematical representation*** error)

Example 1: RELATIVE and ABSOLUTE Copy Problem

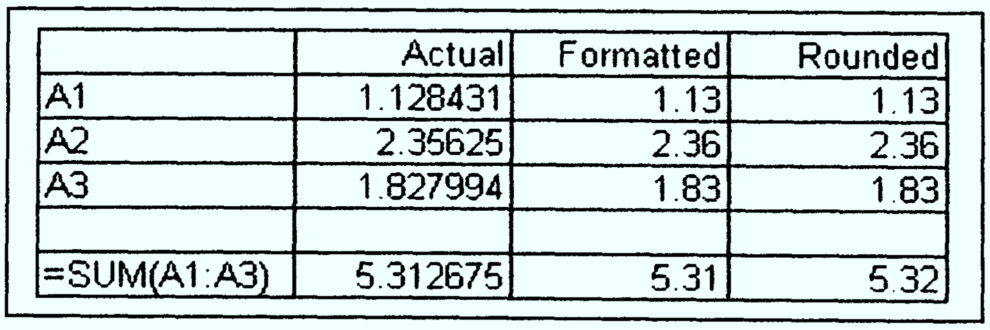
The relative copy causes cell references in a copied formula to alter row and column references relative to the original cell copied. People often make the false assumption that the software will automatically adapt the cell references wherever they happen to copy (Chadwick-97). On other occasions, the error is caused by the user copying a formula hidden underneath a cell value, thinking that they are copying the value from the cell (Brown-87). According to Hendry & Green (Hendry-94), novices experience difficulties in learning about relative and absolute cell references, a feature of all spreadsheets.

According to a report by KPMG Management Consulting, London (KPMG-98), in the calculation of vehicle leasing costs, the element of the formula that referred to *directors* had been lacking a $ sign (used for *absolute copying* instead of the default *relative copying* of formulae), resulting in incorrect cell references when the formula was copied from the original cell. This resulted in an understatement of the costs (e.g. by $432k in 2006).

Example 2: Rounding Error

When writing any spreadsheet the problem of rounding must be considered. Rounding can and should always be controlled. The best approach is to produce rounded numbers, and perform all operations on them, so that one works with numbers that are displayed, not with "hidden" values.

Based on *Figure 3.18* (Batson-91), it can be seen that the "formatted" column does not add up. The difference is small and can be attributed to rounding, but it affects the credibility of the model. It is therefore vital that a spreadsheet modeller understands what is occurring and takes measures to ensure that the rounding is controlled.



	Actual	Formatted	Rounded
A1	1.128431	1.13	1.13
A2	2.35625	2.36	2.36
A3	1.827994	1.83	1.83
=SUM(A1:A3)	5.312675	5.31	5.32

Figure 3.18: Rounding Error

In example shown in *Figure 3.18*, the "actual" column refers to how the number is stored within the spreadsheet (often up to 15 significant figures). The "formatted" column shows what appears on the screen if the column is formatted to two decimal places; the numbers themselves, however, are still held in the spreadsheet to 15 significant figures, and it is "hidden" values which are used in subsequent calculations. The "rounded" column shows what happens when each value is rounded so that the spreadsheet holds the values to two decimal places only, in which case, as shown, the column adds up correctly (Batson-91).

Stang (Stang-87) also provides an example of a rounding error. If users format to one digit to the right of the decimal, and then enter values having greater precision, the spreadsheet will round off the numbers. Thus **1.44** will round off to **1.4**; the sum of **1.44** and **1.44** will round to **2.9** from **2.88**. Such additions would appear to be incorrect.

Example 3: Circular Reference

Circular references in formulae often indicate that there is an error in the logic of the model and should therefore be avoided. Such references should be eliminated at the specification stage (Batson-91). This error frequently occurs in totals where the formula uses its own value in its calculation. This error will give a run-time error message and so probably occurs infrequently (Chadwick-97). A common example of a circular reference arises when calculating bank overdraft interest (Batson-86,91). This is shown in *Figure 3.19 (a)* (Batson-91).

Cashflow	£
Opening bank balance (overdrawn)	(x)
Add: Receipts	x
Less: Payments	(x)
Less: Overdraft interest based on closing balance	(x)
Closing bank balance	(x)

Figure 3.19 (a): Circular Reference

Each time the spreadsheet is recalculated the overdraft interest will change and update the closing bank balance ad infinitum. The error can be corrected by removing the circular reference. The correct way is shown in *Figure 3.19 (b)* (Batson-91).

Cashflow	£
Opening bank balance (overdrawn)	(x)
Add: Receipts	x
Less: Payments	(x)
Balance before overdraft interest	(x)
Less: Overdraft interest on balance before interest	(x)
Closing bank balance	(x)

Figure 3.19 (b): Circular Reference Resolved

According to Ditlea (Ditlea-87), a circular reference was adding the *11-month total* for a *region* to itself. As a result, the spreadsheet was mistakenly doubling a $10 million figure every time it recalculated.

3.5.2 Qualitative Errors

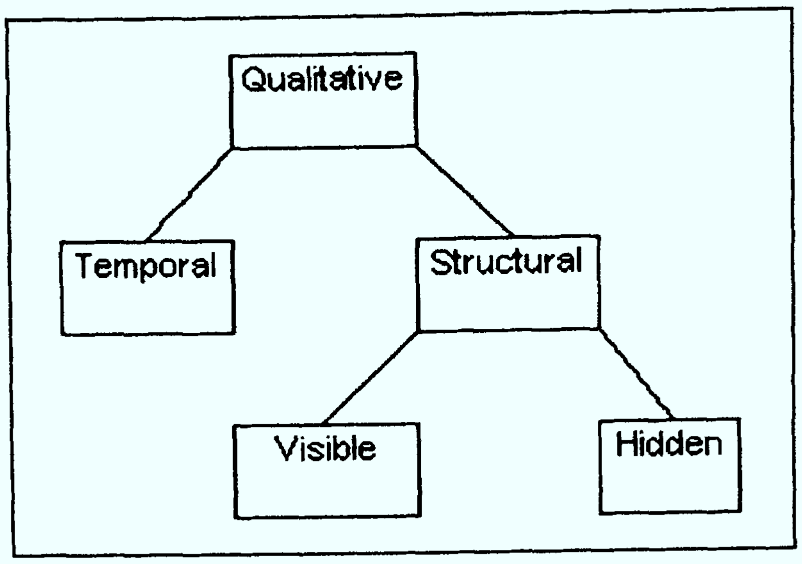


Figure 3.21: Qualitative Errors

Qualitative errors are errors that do not immediately produce incorrect numeric values but degrade the quality of the model. The model also becomes more prone to misinterpretation on the part of the user. As a result, it also becomes more difficult to update and maintain the model. A more detailed investigation into qualitative errors reveals that they can be generally divided into two different types, namely, *temporal errors* and *structural errors*.

This dichotomy is obtained mainly based on an analysis of the three views of an information system. It has been previously established that a spreadsheet system is also a type of information system.

The three views of an information system: *data*, *processing* and *behaviour*, are also applicable to spreadsheet models. Within the context of spreadsheet models, the *processing view* of a model is the network of formulae used to perform calculations on data and produce the computation results. This is also the schema of the model. The *data view* represents the various input data required for the calculations of formulae. The *processing* and *data views* are rather snapshot in nature. The *behavioural* or *temporal view* represents the effects of time and real world events on the spreadsheet model. Unlike the *data* and *processing views*, this is a dynamic view of the spreadsheet model.

A qualitative error which is not temporal in nature can be considered a structural error. This encompasses all forms of non-temporal factors or structural flaws which degrade the quality of the spreadsheet model. The structural aspect of the model in this context represents the binding of the model schema (formula network) and data.

For all *qualitative* errors,

IF error is caused by an elapse of time, which invalidates data
THEN ***temporal*** error
ELSE *NOT temporal* error (i.e. ***structural*** error)

Example 2: Complexity of Formulae

The calculation of distances between transit and non-neighbouring areas is apparently based on a total area of **78,864 sqkm** divided into **163** transit or **15** non-neighbouring areas. The distance is taken as the diameter of a circle of such an area. The formula could have been written more concisely using the **PI** function (KPMG-98). Stang (Stang-87) suggests that any equation longer than 80 characters uses logic that is difficult to follow (Stang-87). Ray Butler (Butler-97) identified that addition and subtraction of numbers within single spreadsheet cells were done without thought for the audit trail or auditability.

3.6 Summary

There has been inadequate research and examination of specific errors in spreadsheet modelling. An analysis and classification of specific types of spreadsheet errors has been carried out as a precursor to the development of approaches to effectively address the problem. This chapter has presented a more comprehensive taxonomy of spreadsheet errors than ever presented or published before, based on a rational taxonomic scheme.

The main reasons for developing a classification of spreadsheet errors are as follows:

- It is a methodical approach to problem analysis.
- It has greater potential for improving comprehensive testing of a spreadsheet development methodology.
- It provides a deeper insight into the nature and characteristics of the errors.

It is evident that there are no standard methods for producing a taxonomy. The conventional generic process of classification widely used in *zoology* and *botany* has been adopted in producing the spreadsheet error taxonomy.

The *binary* structure for an error taxonomy has been found to be more beneficial compared to the previously adopted *bushy* method. The current taxonomy of spreadsheet errors is based on a binary approach that uses *dichotomies* or *IF-THEN-ELSE* rules to classify errors. Therefore, the taxonomy can be expressed in a structured form. A summary of the entire classification in this form is presented in *Figure 3.27.*

CHAPTER 4
PAST WORK AND EXISTING DEVELOPMENTS

4.1 Introduction

Chapter 2 mainly presented an insight into the problem of user-generated spreadsheet errors in terms of their frequency and impact, while the previous chapter, *Chapter 3*, concentrated on the analysis and classification of specific user-generated spreadsheet errors.

This chapter presents a discussion of a spectrum of existing tools and techniques for integrity control of spreadsheet models and the different life cycles and methodologies proposed for their development. An analysis of the effectiveness and limitations of the tools and techniques is also conducted along with a critical evaluation of the various life cycles and methodologies proposed for the development of spreadsheet models.

Numerous *software tools* have been developed and marketed for the auditing and integrity control of spreadsheet models. Various *techniques* have also been proposed to enhance the quality the models. Apart from these tools and techniques, over the years, several *life cycles* and *methodologies* for the development of spreadsheet models have been proposed and presented in a host of publications.

4.2 Existing Tools and Techniques

4.2.1 Tools

Software audit tools have been around for almost as long as spreadsheets themselves (Butler-97). The following are among the most popular computer-based tools that have been developed to help combat the problem of spreadsheet errors. Not all of them are in widespread use today.

- *Spreadsheet Auditor*
- *Cambridge Spreadsheet Analyst*
- *Microsoft Excel*'s Built-in Auditing Functions
- *The Excel Auditor*
- *Spreadsheet Professional* Audit Tool for *Microsoft Excel*
- *Spreadsheet Detective*
- *The Operis Analysis Kit (OAK)*
- *Spreadsheet Auditing for Customs and Excise (SpACE)*

The objective of this section is to only briefly introduce some of the main tools that have been available. As such a detailed description of each tool is not given.

Spreadsheet Detective

The *Spreadsheet Detective* is also an Excel add-in, produced by Southern Cross Software. Nixon (Nixon-01) states that there are two fundamental ways in which the software attempts to assist users in the auditing of spreadsheets. The first is the identification of formula schema while the second is the listing of potential problems such as references to non-numeric cells or unprotected schema.

The Spreadsheet Detective's key patented features are the *shading*, which provides a proper formula map over the existing cells, and the *AutoNames*. While the Spreadsheet Detective's *AutoNames* make the use of Named Ranges largely redundant, this is a useful feature for people who do still use Named Ranges. Spreadsheet Detective can produce a report of all Named Ranges, including for which sheet they have been defined and the range to which they refer. They are integrated with the annotations or Formula report, and the report correlates them with cell labels or AutoNames.

The Detective tends to produce reports of dubious formulae rather than selecting cells, with the exception of some of its year 2000 analysis. The Spreadsheet Detective can also compare different versions of a spreadsheet, which is very important to verify that only specific changes have been made. The Detective can align both rows and columns.

The Spreadsheet Detective's advanced features are as follows:
- AutoNames
- full annotations
- useful Named range definition reports
- Year 2000 analysis
- 3D formula indication
- workbook precedent report

The Operis Analysis Kit (OAK)

OAK provides the basic map and formula report required for any spreadsheet audit. This tool has been produced by Operis Business Engineering Limited, London and takes the form of an add-in for Microsoft Excel. OAK provides the following features:
- Basic Formula Map
- Workbook Summaries, Formula Report
- Named Range analysis
- Selection of different types of cells
- Spreadsheet Comparison
- Insert/Delete Row/Column
- Development History spreadsheet

The formula map essentially copies the original spreadsheet, and then replaces all formulae in the original spreadsheet with symbols to indicate whether they are copies of other formulae above or to their left. OAK can also shade the original spreadsheet to show which cells have formulae. This is a much better option than producing a separate map because one can see the shading and the formula results at the same time, as well as being able to manipulate the formulae. However, the OAK shading gives no indication of how formulae have been copied. It also uses cell colour rather than patterns, which can corrupt existing formatting.

The workbook summaries provide a list of all the worksheets in a book and some basic statistics about the size of each worksheet. More importantly, it provides a list of all unique formulae. OAK provides some excellent facilities to be able to rename Named Ranges and automatically update the formulae that use them. OAK can also produce a report of all Named Ranges, including for which sheet they have been defined and the range to which they refer. OAK can also automatically select cells based on different criteria. For example, it can select functions with hardwired constants or that refer to blank cells. It can also compare different versions of a spreadsheet.

Spreadsheet Auditing for Customs and Excise (SpACE)

SpACE has been developed by the HM Customs and Excise, United Kingdom. It is mainly used by VAT inspectors in auditing client spreadsheets. However, it is also available to the public. SpACE works by using a combination of search facilities, overlaid mapping options and the identification of unique formula, to highlight potential errors in a spreadsheet. It also has more in-depth auditing functions such as the ability to check lists of data for duplicates (Nixon-01).

4.2.2 Techniques

Apart from software tools developed to help control the integrity of spreadsheet models, various techniques have also been proposed. The objective of these techniques is to enhance the quality of spreadsheet models. The following list captures a selection of significant techniques described in spreadsheet literature:

- Benham's (Benham-93) Structured Techniques for Spreadsheet Development
- Kee's (Kee-88) Standard Spreadsheet Design Format
- Ronen et al's (Ronen-89) Recommended Spreadsheet Structure
- Ronen et al's (Ronen-89) *Spreadsheet Flow Diagrams (SFD)*

Benham's (Benham-93) Structured Techniques for Spreadsheet Development

Benham (Benham-93) proposes the arrangement of the spreadsheet into blocks or sections along the spreadsheet's diagonal. As a minimum, the spreadsheet should have the following sections:

- Introductory Section
- Data and Assumption Section
- Model Section (work performed by the spreadsheet)
- Analysis Section (required outcomes or results)
- Macro Section

Ronen et al's (Ronen-89) Recommended Spreadsheet Structure

Figure 4.6 presents Ronen et al's recommended structure for a spreadsheet. The purpose of the structure is to separate parts of a spreadsheet into blocks to reduce the potential for errors. *Figure 4.6* contains a number of blocks which, when taken together, form the spreadsheet model.

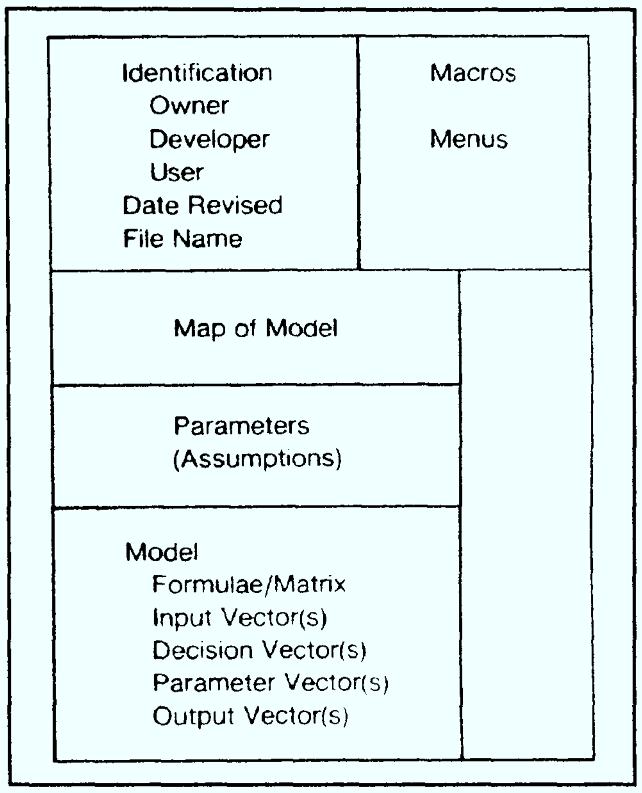


Figure 4.6: Ronen et al's Spreadsheet Structure

The **identification** block presents the name of the developer, user, and model. It also contains a list of revision dates and the name of the spreadsheet file. To the right of the identification block is the **macros/menus block**. Immediately below the identification block is a **map** or index to the spreadsheet. It contains a description of where the various blocks may be found and acts as a table of contents for the model (Ronen-89).

The large **documentation** block allows the spreadsheet developer to describe in general terms how the model works and to annotate various rows in the model. The **parameter** block contains variables that are used in the formulae. The final block in the spreadsheet is the **model** itself (Ronen-89).

Ronen et al's (Ronen-89) Spreadsheet Flow Diagrams (SFD)

Ronen et al (Ronen-89) endeavour to apply the notion of *Data Flow Modelling* in spreadsheet development. This is due to its popularity in traditional systems analysis and design as a way to promote structured, top-down design and to reduce complexity. The proposed *Spreadsheet Flow Diagrams (SFD)* are used for the same purpose.

Figure 4.7 shows the basic symbols of Ronen et al's *SFD*. A simple rectangle is used to represent input vectors, output vectors, decision vectors, and parameters. According to Ronen et al (Ronen-89), the advantage of using a structured notation for spreadsheets is the same as the merits of such notations used in *Data Flow Diagrams*.

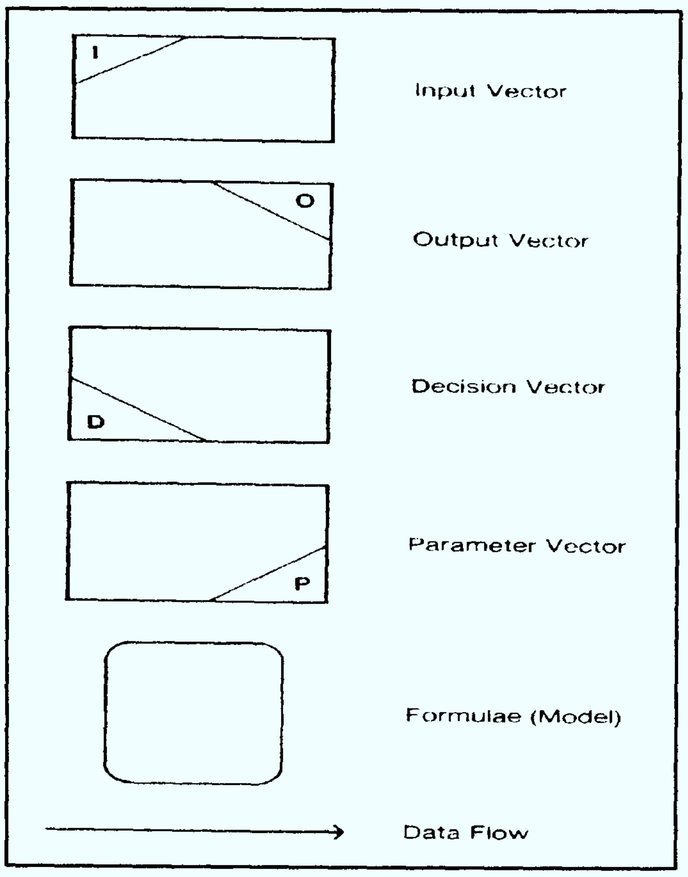


Figure 4.7: Notations of Ronen et al's *SFD*

4.2.3 Effectiveness and Limitations of the Tools and Techniques

This section presents a discussion of the effectiveness and limitations of the eight tools and four techniques described in *Sub-sections 4.2.1* and *4.2.2*.

All the software tools described in *Section 4.2.1* are primarily aimed at facilitating auditing and error detection in spreadsheet models. Though these developments have to an extent reduced errors in spreadsheets, they have not been entirely successful as the phenomenon still persists. The main reason for the lack of success of the tools is the fact that they concentrate on detecting errors rather than preventing the incidence of the errors.

There are two criteria that can be used to assess the effectiveness of a software tool:

- Its capacity to detect existing errors
- Its capacity to caution the user on potential errors, flaws and problems

The *Spreadsheet Auditor* and *Cambridge Spreadsheet Analyst* have become obsolete following the termination of their development. These tools were created to help audit *Lotus 1-2-3* file formats are would be not be very useful today with the more widespread use *MS Excel* in the Windows platform. As the tools were produced in the mid-80s, they lack the more advanced and sophisticated features of the other more recently developed tools.

The *Spreadsheet Detective* is the most effective among the eight tools assessed. It possesses an excellent capacity to detect existing errors and notify users of any potential flaws or errors. The *Spreadsheet Detective* provides an overlay to a worksheet with different types and colours of shading along with text descriptions. This easily reveals errors such as overwritten formulae. It also produces reports of *named ranges* and *formulae*, which can be used to effectively identify dubious and potentially erroneous cells.

Among the tools evaluated (apart from *Spreadsheet Auditor* and *Cambridge Spreadsheet Analyst*), the *Excel Auditor* is the least satisfactory. Though the *Excel Auditor* offers various functions outside the usual scope of auditing software, it is neither as effective as the other tools in detecting existing errors nor identifying any potentially unsafe or problematic cells. A major limitation of the *Excel Auditor* is that it performs a laborious cell-by-cell inspection rather than using more visual techniques. However, it can be useful as a documentation tool.

Spreadsheet Auditing for Customs and Excise (SpACE) can be regarded as a very good tool for both detecting existing errors and identifying potentially problematic cells in a spreadsheet. Its effectiveness in accomplishing these is comparable to that of the Spreadsheet Detective. SpACE has very good auditing tools but lacks the ability to produce a formula description in natural language like the *Spreadsheet Detective*.

The *Operis Analysis Kit (OAK)* is highly effective in the detection of existing errors in a spreadsheet model. This is attributable to *OAK*'s ability to produce a basic formula map and shading of the original spreadsheet. A disadvantage is that this can sometimes corrupt existing formatting. *OAK* does not fare as well as the *Spreadsheet Detective* or *SpACE* on the second criterion. *OAK* is relatively less effective in identifying potential problems, such as unprotected cells.

Spreadsheet Professional is satisfactory in both the detection of existing errors and the identification of potentially unsafe or erroneous cells. The detection of existing errors is mainly done with the help of the *Cell Translation* feature which enables quick verification of the logic of formulae. The *Spreadsheet Professional* also provides useful reports of potential problems or flaws such as unused operands of a formula, hard-coded formulae and the referencing of blank or non-numeric cells. The main limitation of this tool is that it does not offer more advanced features for error detection like the *Spreadsheet Detective*, *SpACE* or *OAK*.

Microsoft Excel's Built-in Auditing Functions do have a reasonable capacity to detect existing errors in a spreadsheet by tracing the *precedents* and *dependants* of a cell. However, the functions are not effective in identifying potential errors or potentially unsafe cells, for instance, unprotected and hard-coded formulae. Like the *Excel Auditor*, *MS Excel's built-in auditing functions* also have the disadvantage of concentrating on cell-by-cell inspection.

While most of the software tools focus on error detection, the techniques described in *Section 4.2.2* represent efforts to reduce, if not prevent, the occurrence of errors. The advent of these techniques indicate an increased awareness of the importance of adopting more structured or systematic approaches to the development of spreadsheet models. All the techniques discussed in Section *4.2.2* have their advantages and disadvantages or limitations.

There is a significant difference between the first three techniques (*Benham's Structured Techniques*, *Kee's Standard Spreadsheet Design Format* and *Ronen et al's Recommended Spreadsheet Structure*) and the fourth technique (*Ronen et al's Spreadsheet Flow Diagrams*). The first three techniques are based on developing a standard generic structure for the entire spreadsheet model, while the fourth technique employs an established method within structured systems analysis to specifically model the workings or calculations part of the spreadsheet. The main limitation of the fourth technique (*Ronen et al's Spreadsheet Flow Diagrams*) in this respect is that it does not address the other important aspects of the spreadsheet model. Therefore, it is recommended that this technique be applied within one of the first three techniques discussed in *Section 4.2.2*.

A comparison of the first three techniques would immediately reveal a fundamental difference between the first technique (*Benham's Structured Techniques for Spreadsheet Development*) and the next two techniques (*Kee's Standard Spreadsheet Design Format* and *Ronen et al's Recommended Spreadsheet Structure*). The first technique, *Benham's method*, is based on a block diagonal structure while the other two techniques are not. The advantage of this layout is that each section or module of the spreadsheet model is not adversely affected by row or column insertions or deletions in any other parts of the model.

There are certain important similarities among the first three techniques discussed in *Section 4.2.2*. They all attempt to adopt a standard, structured and disciplined approach to spreadsheet development. Apart from that, there is also an emphasis on the division of the model into distinct modules or components. Applying a modular structure to spreadsheet models makes them appear more organised and enhances their comprehensibility. This can also reduce the potential for errors. An examination of the proposed components or modules within each of the three techniques also shows certain similarities. *Benham's method* and *Kee's spreadsheet format* explicitly separate the input, workings and output components of the spreadsheet model. *Ronen et al's spreadsheet structure* performs this segregation within the *model* component. The proposed spreadsheet layout of all three techniques contains a section that clearly describes the spreadsheet model.

Based on the assessment of the advantages and limitations of the four techniques described in *Section 4.2.2*, it is recommended that the most effective approach would involve the use of *Benham's method* combined with *Ronen et al's Spreadsheet Flow Diagrams* to model the *data*, *model (workings)* and *analysis* sections.

Stage 2: Specify

The key business risks which define the requirements for the model are identified. A specification document is subsequently prepared. It contains an *overview* of the model, *outputs*, *inputs* and *calculations* required.

Stage 3: Build

This stage involves three activities: *model development*, *documentation* and *testing*.

Stage 4: Review

The review may be either the core of a model review engagement, in which case the scope of the review will be stated explicitly in the proposal document, or an independent review following the *Build* stage of a model development engagement.

Stage 5: Implement

The content of the implementation stage will depend very much on whether the model is a one-off project model or an ongoing management model.

Hayen and Peters' (Hayen-89) Spreadsheet Development Life Cycle

The following steps form the *Spreadsheet Development Life Cycle* proposed by Hayen and Peters (Hayen-89):

Step 1: Determine Feasibility

Determine if a spreadsheet is the appropriate tool for analysing the business problem under consideration.

Step 2: Create Paper Model

The paper model can be considered in several different ways. It could be a workpaper created manually or a form selected from a set of standardised forms.

Step 3: Collect and Prepare Data

Collect and prepare the data required by the model.

Step 4: Enter Spreadsheet

Create the worksheets.

Step 5: Verify Spreadsheet Logic

To verify logic, spreadsheet applications should have as many built-in accounting tests as possible. The logic of the spreadsheet application can perform these tests automatically.

Step 6: Enter Application Data

If several different sets of data are to be input, the developer can establish separate areas of the spreadsheet for the input data and the equations.

Step 7: Produce Reports/Graphs

If more than one report or graph is to be produced, creating macros or command files to do the job helps ensure that the correct data are displayed.

Step 8: Review Results

The results should be reviewed for reasonableness before they get final approval.

Step 9: Prepare Documentation

In the development of a spreadsheet, the documentation should evolve. A final step should be to check its completeness.

Step 10: Sign off

After all the reviews, the final result can be signed off. Whenever a revision needs to be made, the process starts over.

Panko & Halverson's (Panko-96) Spreadsheet Development Life Cycle

Spreadsheet models, like programs, go through a series of development stages. These development stages (in order) are identified by Panko and Halverson (Panko-96) to be *requirements*, *design*, *cell entry*, *draft*, *debugging* and *operational use*.

Stage 1: Requirements and Design

As done in programming, it is extremely important to determine the requirements before actual construction of the spreadsheet is begun.

Stage 2: Cell Entry

This is the stage when numbers and formulae are entered in the spreadsheet cells. Many of the mistakes made at this stage are corrected immediately. However, some errors may be more frequent or more difficult to correct than others.

Stage 3: Draft

The draft spreadsheet should be tested with a variety of types of data or inspected cell-by-cell by the developer or an inspection team.

Stage 4: Debugging

In order to further reduce error rates, developers should engage in the debugging stage that involves data testing and code inspection.

Stage 5: Operational Stage

Even during the operational stage, errors are identified and corrected. However, this can be expensive and sometimes produce even more errors. As the models are in operation, extensive damage may have also been done before detection and correction of the errors.

DiAntonio's Method for Spreadsheet Development

DiAntonio (DiAntonio-86) has proposed a structured method consisting of six distinct steps for the construction of spreadsheets.

Step 1:	The problem is understood and defined.
Step 2:	Isolation of facts is done by splitting the spreadsheet into two parts, one for the *facts* and one for the *solution.*
Step 3:	The solution is formatted or designed and it uses data from the *facts* part of the spreadsheet.
Step 4:	The program is tested with sample data.
Step 5:	The program is evaluated in terms of functionality, headings, labels and format.
Step 6:	The program is documented either on the spreadsheet itself or in hard copy.

<u>Ronen et al's (Ronen-89) Spreadsheet Development Life Cycle</u>

Ronen et al's *Spreadsheet Development Life Cycle* is based on the traditional systems development life cycle. It is shown in *Figure 4.10.*

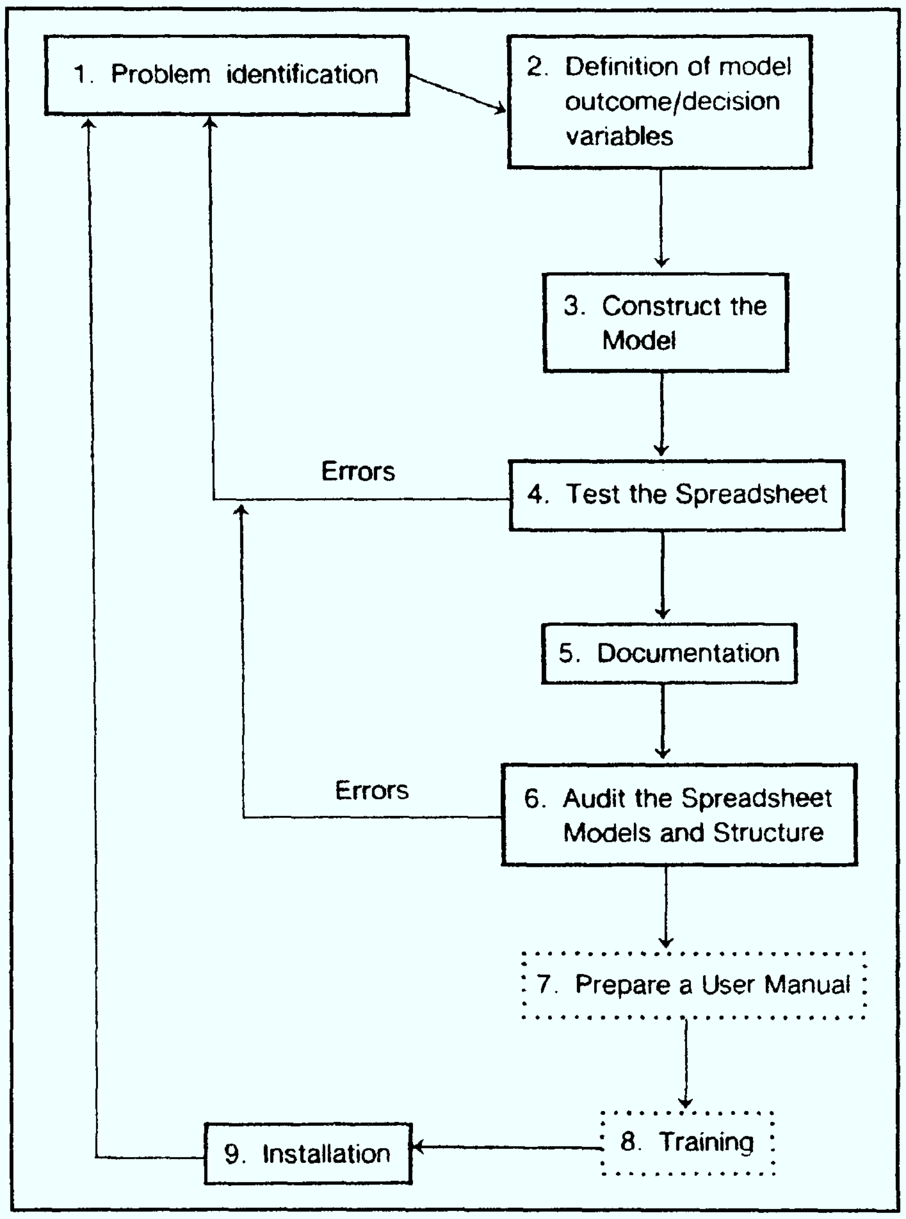


Figure 4.10: Ronen et al's Spreadsheet Development Life Cycle

Step 1: Problem Identification

The designer defines the nature of the problem to be solved.

Step 2: Definition of Model Outcome/Decision Variables

The spreadsheet is usually developed to produce results. The outcome variables need to be defined. An understanding of the outcome is generated is important. This part of the model represents the calculations which are undertaken in the model.

Step 3: Construct the Model

This stage corresponds to the traditional notion of programming. Using the various commands of the spreadsheet language, the model is built.

Step 4: Test

The results of the model are carefully tested. A hard-copy of the model and cell formulae are printed. All calculations are checked independently from the spreadsheet. The spreadsheet is also examined to see if there is an audit trail.

Step 5: Documentation

The spreadsheet model is documented on the spreadsheet itself. This involves inclusion of text on the spreadsheet that explains the model.

Step 6: Audit

The model and its structure are carefully reviewed. The use of audit packages is recommended.

Step 7: Prepare a User Manual (Optional)

For systems designed for others to use, a manual is a necessity. For applications created by the user, a manual is valuable if the application is to be used more than once.

Step 8: Training (Optional)

If the model is to be used by others, they may need to be trained prior to installation.

Step 9: Installation

The spreadsheet is prepared for use, for example, by installing it on a user's computer so that the model loads whenever the spreadsheet program is started.

Chadwick et al's (Chadwick-97) 5-Step Methodology

Chadwick et al (Chadwick-97) have proposed a five-step methodology for spreadsheet auditing, that incorporates the 3A's (appropriateness, accuracy, about-right) approach. An outline of the methodology is presented here.

Step 1: Appropriateness

Checking the appropriateness of the formula applied, from a logical point of view. Appropriateness is the correctness of the formula according to the underlying data model of the business process being modelled. The spreadsheet builder can verify appropriateness by entering the real-world description of the formula in the *cell note* for the cell. An example of this is shown in *Figure 4.11*.

4.3.2 Critical Evaluation of the Life Cycles and Methodologies

The life cycles and methodologies presented in *Section 4.3.1* have various similarities and differences. They mainly vary in terms of level of detail and focus.

Apart from *Chadwick D et al's 5-step Methodology*, all the other life cycles/methodologies cover most of, if not all, the stages of spreadsheet development. *Chadwick D et al's 5-step Methodology* is therefore the least comprehensive approach. Its advantage, however, is that it places more emphasis on spreadsheet auditing compared to the other life cycles or methodologies proposed. It is recommended that this methodology be used within one of the other more comprehensive frameworks.

The most comprehensive life cycles or methodologies proposed are *PWC's Modelling Life Cycle* and the *KPMG Modelling Process*. To a large extent, both these frameworks have common steps or stages. These include *scoping*, *specification*, *design*, *building*, *testing* and *operation*. However, the precise sequence and scope of the constituent stages are different. Within each stage, the frameworks provide a detailed description or specification of the application of the relevant steps to the spreadsheet development process. The depth and comprehensiveness of both these approaches are mainly attributable to the fact that they have been developed by large multinational accounting/auditing firms. Apart from that, both frameworks are also more recently developed compared to the other life cycles/methodologies.

The other four life cycles/methodologies (*Hayen and Peters' life cycle*, *Panko and Halverson's life cycle*, *DiAntonio's method* and *Ronen et al's life cycle*) do not provide a detailed description of each stage of the life cycle. They do however address all stages of the spreadsheet development process. Apart from *Ronen et al's life cycle*, the other life cycles consist of a set of sequential stages. A study of the stages of the four life cycles shows that they are similar to the stages of the traditional systems development life cycle, especially *Ronen et al's life cycle*. The advantage of *DiAntonio's method* over the other frameworks is that it proposes the division of the spreadsheet into a *facts* (*data*) part and a *solutions* (*workings* and *output*) part. This produces a more organised model structure.

Among the life cycles and methodologies proposed for spreadsheet development, the most effective approach would be based on *PWC's Modelling Life Cycle* or the *KPMG modelling process*. In order to further enhance the quality of the framework, *DiAntonio's method* can be applied in the *specification/design* and *building* stages, and *Chadwick D et al's 5-step methodology* can be adopted in the *testing* or *review* stage.

4.4 Summary

This chapter has presented a discussion of a range of existing tools and techniques for improving the quality of spreadsheet models, and various life cycles and methodologies proposed for spreadsheet development. The merits and demerits of the tools and techniques, and a critical assessment of the life cycles and methodologies have also been provided.

Among the principal computer-based tools that have been developed to facilitate auditing and error detection in spreadsheet models are the *Spreadsheet Auditor, Cambridge Spreadsheet Analyst, MS Excel's Built-in Auditing Functions, the Excel Auditor, Spreadsheet Professional Audit Tool for MS Excel, Spreadsheet Detective, the Operis Analysis Kit (OAK)*, and *Spreadsheet Auditing for Customs and Excise (SpACE)*. On the other hand, some of the main *techniques* that have been proposed for the quality control of spreadsheet models include *Benham's Structured Techniques for Spreadsheet Development, Kee's Standard Spreadsheet Design Format, Ronen et al's Recommended Spreadsheet Structure* and *Ronen et al's Spreadsheet Flow Diagrams (SFD)*.

The *Spreadsheet Detective* has been found to be the most effective among the eight tools considered, having an excellent capacity to detect both existing errors and potential flaws. On the other hand, the *Excel Auditor* appeared to be the least satisfactory. Based on an analysis of the four techniques described in this chapter, the most highly recommended approach would involve the use of *Benham's method* combined with *Ronen et al's SFDs* to model the *data*, *workings* and *analysis* sections.

Various life cycles and methodologies have been proposed for spreadsheet development. They include *PricewaterhouseCoopers (PWC's) Modelling Life Cycle*, the *KPMG Modelling Process, Hayen and Peters' Spreadsheet Development Life Cycle, Panko and Halverson's Spreadsheet Development Life Cycle, DiAntonio's Method for Spreadsheet Development, Ronen et al's Spreadsheet Development Life Cycle*, and *Chadwick et al's 5-step Methodology incorporating the 3A's Approach.*

Chadwick et al's 5-step methodology is the least comprehensive approach but has the benefit of placing relatively more emphasis on spreadsheet auditing. It has been found that the most comprehensive life cycles/methodologies are *PWC's Modelling Life Cycle* and the *KPMG Modelling Process*. The most effective methodology would be a hybrid approach based on either *PWC's Modelling Life Cycle* or the *KPMG Modelling Process*, combined with *DiAntonio's method* in the *specification/design* and *building* stages, and *Chadwick et al's 5-step methodology* in the *testing* or *review* stage.

CHAPTER 5
PRELIMINARY INVESTIGATION AND DEVELOPMENTS

5.1 Introduction

In *Chapter 3*, a framework for classifying user-generated spreadsheet errors based on a rational taxonomic scheme was presented, while *Chapter 4* provided a discussion and evaluation of existing tools and techniques for the quality control of spreadsheet models, as well as life cycles and methodologies for spreadsheet development. Both these sets of activities were carried out in parallel.

Having gained an insight into the nature, characteristics and categories of specific types of spreadsheet errors and the existing tools, techniques, life cycles and methodologies, an investigation was carried out into various methods and approaches deemed to have the potential for enhancing the quality of spreadsheet models. This was preceded by an analysis of spreadsheet structure.

This chapter begins with a discussion of spreadsheet structure. The different aspects of spreadsheet structure considered are the components of a spreadsheet model, the structure of formulae and data dependencies. The outcome and findings of the preliminary investigation into the relevant techniques, methods and approaches, are subsequently presented. This is the main part of this chapter and represents the first step in the research programme, towards developing a comprehensive methodology for the integrity control and development of spreadsheet models.

5.2 Analysis of Spreadsheet Structure

5.2.1 Overview

A spreadsheet is a large matrix consisting of rows and columns. Rows are identified by numbers, while columns are identified by letters. The intersection of a particular row and column of a spreadsheet is an individually identifiable cell. A cell address is composed of a column label and a row label, e.g. A7 (column A, row 7). Brown (Brown-87) defines an electronic spreadsheet as a two-dimensional matrix of cells displayed on a computer screen. The contents of the cells can be *text*, *numeric constants*, or *formulae* that reference other cells. The underlying contents of a cell are not readily visible to the user; instead, what is displayed is the numeric result of the computation indicated within the cell. The formula can be viewed by moving the cursor to the cell (Brown-87).

A spreadsheet usually consists of connected components. It has a two-level structure, namely a visible (two-dimensional) surface and a hidden formula network (Saariluoma-91). Therefore, within the context of spreadsheet calculation, there are two levels: one which is visible and concrete, and the other which is more abstract and 'hidden' below the first. According to Saariluoma and Sajaniemi (Saariluoma-91), the surface level of a spreadsheet consists of a set of cells occupied by visible values. At the deep or hidden level, these cells are connected to each other and form a network defined by a set of mathematical formulae in which variables are bound to the numerical contents of specified cells. The surface level displays data and numeric results of the formulae. Knowledge of the surface and deep levels of a spreadsheet is important when making deletions or changes to formulae. This helps in identifying the source of errors produced by the changes (Saariluoma-91).

5.2.2 Components of a Spreadsheet Model

Isakowitz et al (Isakowitz-95) propose two distinct perspectives to view spreadsheet models: *logical* and *physical*. The *logical* perspective consists of a formal and implementation-free description of the model's logic and data structures, while the *physical* level concerns storage, formatting, user interface, and other aspects that affect the model's implementation. From a physical perspective, a spreadsheet model is a collection of addressable cells, arranged in a two-dimensional grid (Isakowitz-95).

Isokowitz et al state that every spreadsheet model embeds an implicit *logical view*, which can be regarded as a set of *functional relations*. A functional relation consists of one or more attributes and of one or more tuples. However, unlike ordinary relations, functional relations have two types of attributes: *data* attributes and *functional* attributes. Data attributes define slots that store constants, whereas functional attributes are bound to functions that are calculated. Isakowitz et al (Isakowitz-95) use the term model's *schema* to refer to the set of functional relation definitions within a particular spreadsheet.

According to Isakowitz et al (Isakowitz-95), there are four principal components that characterise any spreadsheet model: *schema*, *data*, *editorial* and *binding*. The *schema* provides the spreadsheet's skeleton and stores a concise and formal definition of the spreadsheet's underlying logic. The *data* property is the structured collection of constants on which *schema* operates. The *editorial* property can be defined as what is left over in the spreadsheet model after *schema* and *data* have been carved out: titles, column and row headings, and documentation. Finally, the *binding* property is a logical-to-physical mapping that binds *schema*, *data*, and *editorial* to the spreadsheet grid, using cell addresses (Isakowitz-95).

5.2.3 Structure of a Spreadsheet Formula

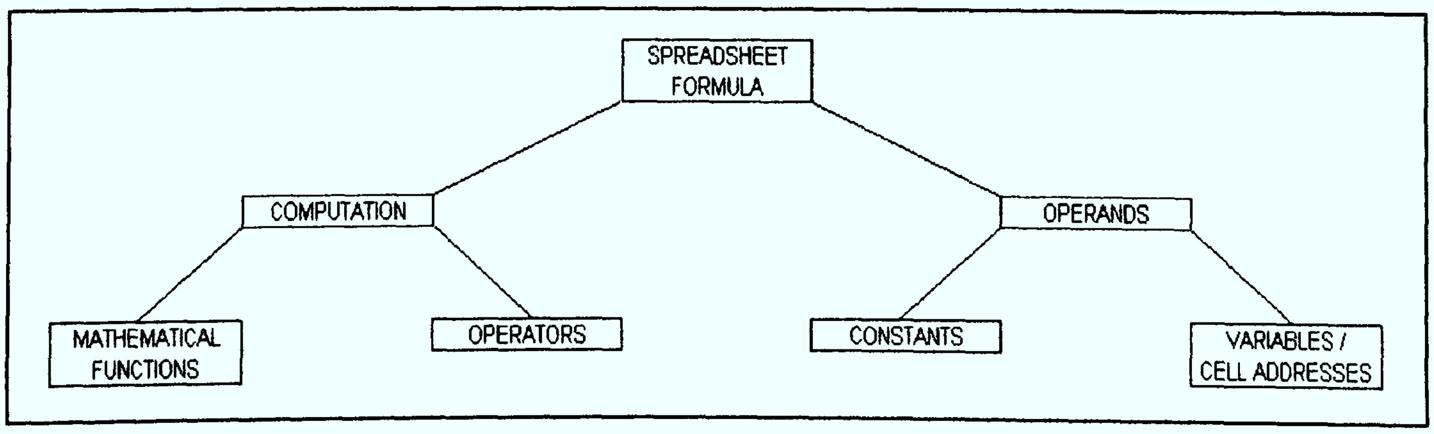


Figure 5.1: Components of a Spreadsheet Formula

Davis (Davis-96) also uses arrows to define data dependencies between cells. Referring to *Figure 5.3* (Davis-96), the formula in cell **H2** is **A4*B4**, which makes **A4** and **B4** are *direct precedents* of **H2**. **H2** is a *direct dependant* of **A4** and of **B4**. This shows that precedence and dependence are inverse relationships. As the formula in **B4** is **C6/100**, **C6** is an *indirect precedent* of cell **H2**.

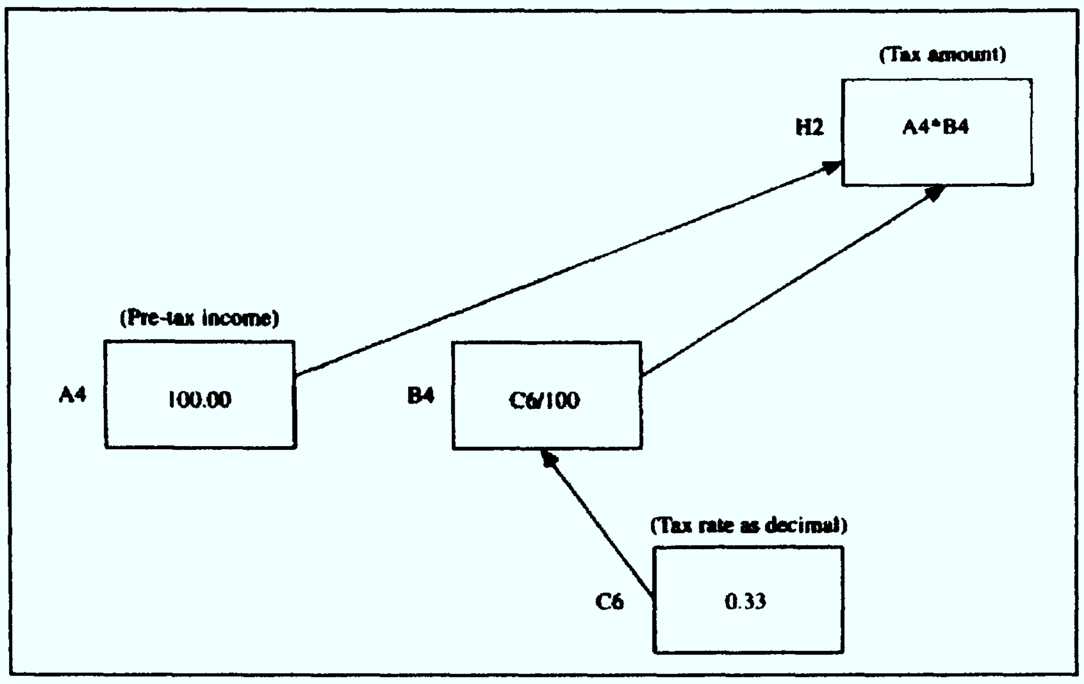


Figure 5.3: Davis' Data Dependency Diagram

5.3 Initial Approaches Explored and Developed

5.3.1 Overview

Prior to the development of the proposed structured spreadsheet modelling methodology presented in *Chapter 7*, various other approaches were explored and analysed. Some of the significant developments preceding the development of the proposed methodology are described in this section.

The approach of this research has been to examine the applicability of main-line software-engineering techniques to the needs of spreadsheet developers. These needs are partly determined by the visual nature of spreadsheets and their heavy reliance on referencing and intermediate data, and partly by the likely acceptance of techniques within the industry.

5.3.2 Modularisation Based on the Concept of an *Extent*

A technique or process of modularisation based on the concept of an *extent* was initially proposed (Rajalingham-98,99). The modular approach employs principles of software engineering such as *modularisation* and *coupling*. Support for the modular approach came from DiAntonio (DiAntonio-86) and Chadwick et al (Chadwick-97) but was weakly defined in both these sources. Within the context of spreadsheet development, *modularisation* refers to the structuring of the spreadsheet model into distinct blocks or modules with data being passed between them. An important justification for this approach is that the human mind finds it difficult to interpret and process large chunks of data. When data is logically and systematically split into smaller parts, it simplifies analysis.

The modular approach dictates the division of the physical model (spreadsheet data) into distinct modules. The fact that the spreadsheet is separated into separate blocks or modules suggests that a modular approach is being taken, based on an analysis of spreadsheet structure. The term given to a distinct module of the spreadsheet is an **extent**. An *extent* can be defined as a matrix representing a logical area or module of the spreadsheet. An extent is a range with special properties. It has various special characteristics. A spreadsheet **model** is defined as a collection of inter-related extents.

The minimum size of an extent is a 2 by 2 range (4 cells). The first column of an extent contains the row headings while the first row of an extent bears the column headings. Every cell within a particular column (except the first column) is associated with the same column heading, which occupies the top cell of that column. Similarly, Every cell within a particular row (except the first row) is associated with the same row heading, which occupies the left-most cell of that row.

Column headings and row headings of an extent must be defined by the user. No two cells can have exactly the same combination of column heading and row heading as there cannot be two or more column headings or row headings with the same name, although a column heading can share the same name with a row heading.

The following steps are taken in defining an *extent* (Rajalingham-98,99):

Step 1

Every value must be placed at the intersection of a particular labelled column and a labelled row, and must be semantically consistent with the meaning the pair has in real life.

Step 2

Every new entry or value for which there already exists both a corresponding column label and a corresponding row label, must be entered in the cell at the intersection of the particular column and row.

Step 3

If a new entry only has either a corresponding column label or a corresponding row label present within the existing structure, then the missing column/row label is added to the extent. If the new entry has column and row labels that do not semantically match any of the existing column and row labels, it must be placed in a different extent. The resulting generic structure of an extent is shown in *Figure 5.4* (Rajalingham-98). The spreadsheet model shown in *Figure 5.5* is an example of an *extent*. The process of modularisation, based on a similar approach, was subsequently presented more elaborately with examples by Chadwick et al (Chadwick-99a).

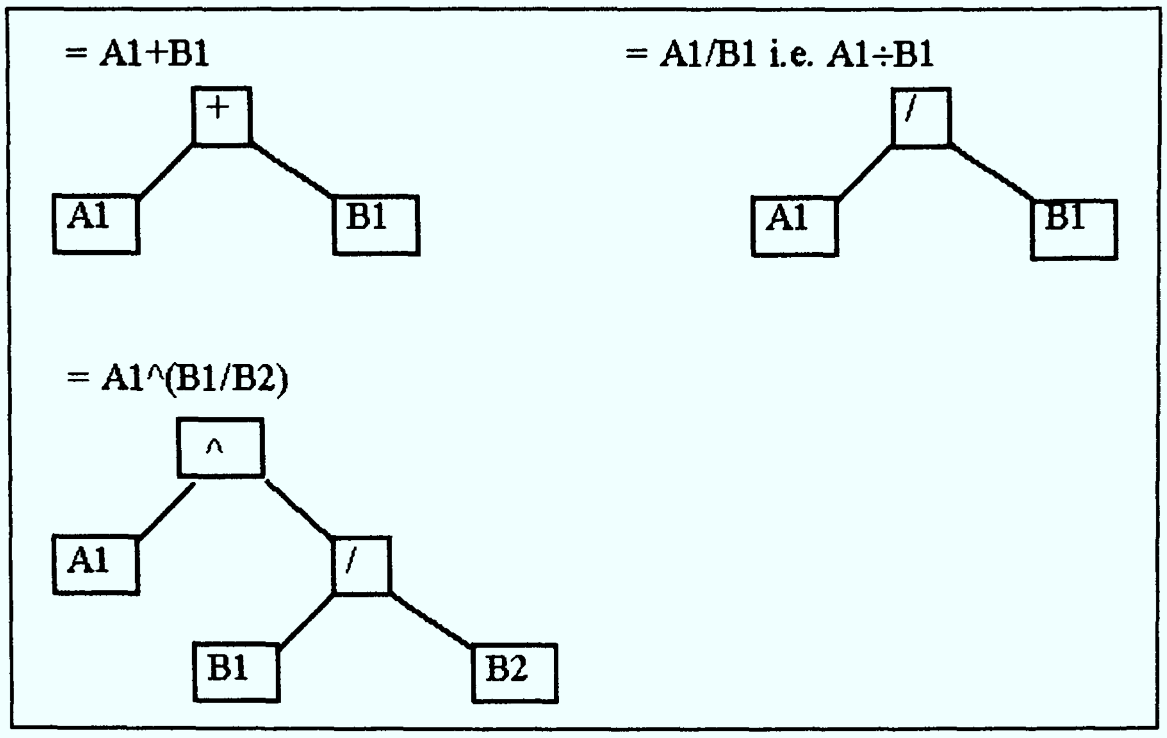


Figure 5.7: Formulae Represented Using Tree Structures

As all functions are of the same form, = **name (argument1, argument2 ...)**, we can represent each in the form of a tree (not necessarily a binary tree). The root would now contain the function name while each argument would form a node. An example is given in *Figure 5.8* (Rajalingham-99,00).

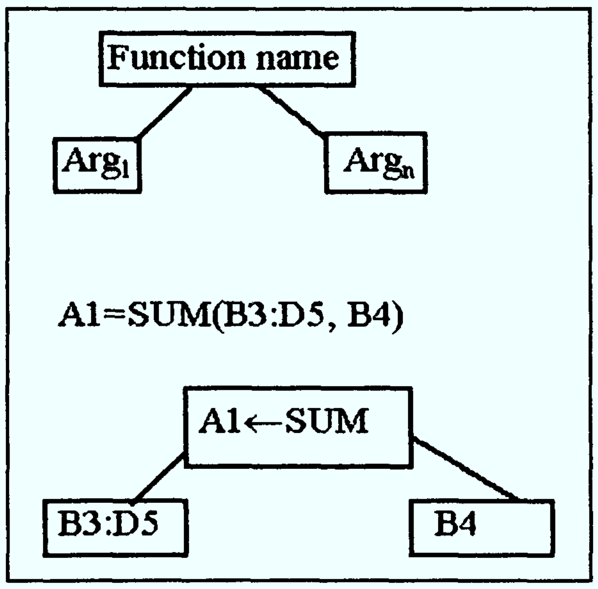


Figure 5.8: Formulae Represented Using Tree Structures

Tree structures can also be used to represent the logical aspect of the formula, independent of physical location. Examples of this are given in *Figure 5.9* (Rajalingham-00). In *Figure 5.9*, *cost of goods sold* is the sum of *opening stock*, *purchases* and *carriage inwards*. Based on *Figures 5.7*, *5.8* and *5.9*, it can be seen how these tree structures can be used to facilitate comprehension, analysis and documentation of formulae. The use of tree structures have been proposed in the analysis and design stages of the *Integrated Spreadsheet Engineering Methodology* presented by Rajalingham et al (Rajalingham-99a). This methodology is mainly based on the classical systems development life cycle by Aktas (Aktas-87).

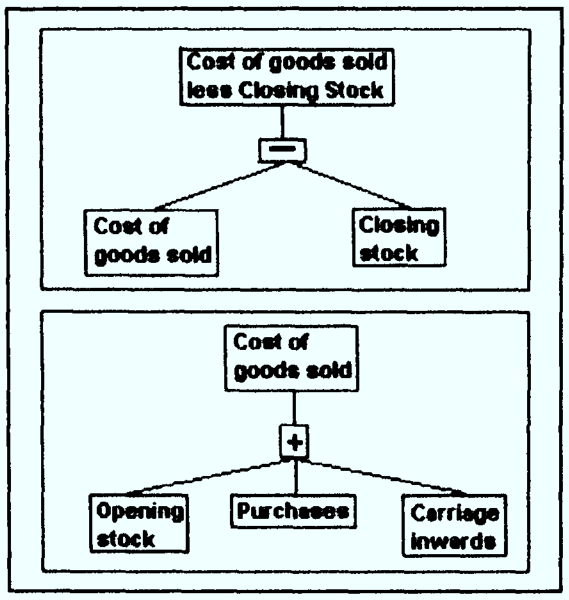


Figure 5.9: Logical Aspect of Formulae

5.4 Summary

A spreadsheet is a two-dimensional matrix of cells that has a two-level structure consisting of a visible surface and a hidden formula network. A spreadsheet model can be viewed from both a logical and physical perspective. It is made up of four main components: *schema*, *data*, *editorial* and *binding*. A spreadsheet performs calculations through formulae. A spreadsheet formula consists of a *computation* component and an *operands* component. If a cell *x* contains a formula that refers to cell *y*, *x* is the *dependant* while *y* is the *precedent*.

An initial software engineering based method developed was a technique of modularisation based on the concept of an *extent*. Using this technique, the physical spreadsheet model is split into distinct but logically related modules (or matrices) with special characteristics, called *extents*. This technique was subsequently enhanced through the *diagonalisation* of the spreadsheet model. This involves placing *extents* diagonally on the spreadsheet to isolate cell entries from row or column insertions or deletions in other parts of the model.

A by-product of the modular approach is a technique for visually representing elements of a spreadsheet formula in a more comprehensible form. This facilitates more effective validation and audit of spreadsheet formulae. Alternative methods of presenting formulae in such a form include *algebraic English*, *fully English* and *Graphic Display*. By combining the techniques of visual modelling and hierarchical decomposition, *tree structures* can be used to model data dependencies during spreadsheet analysis and design. These tree structures can represent both the logical and physical views of a formula. This enables better comprehension, analysis and documentation of spreadsheet formulae.

CHAPTER 6
SOFTWARE ENGINEERING PRINCIPLES AND JACKSON STRUCTURES

6.1 Introduction

The flexibility and freedom offered by a spreadsheet has set it apart from conventional applications and programming languages. However, as discussed in *Chapters 2* and *3*, spreadsheets are more prone to errors compared to conventional programs and applications. Even these conventional programs and applications had numerous errors and flaws that were successfully reduced with the application of structured methods. A natural approach to enhancing the quality of spreadsheets should therefore involve the application of structured methods and software engineering principles.

Chapter 5 presented the outcome and findings of a preliminary investigation into various methods and approaches deemed to have some potential in improving the quality of spreadsheet models. This was followed by a more thorough examination of relevant software engineering principles and structured techniques, and their potential application to the design and development of spreadsheet models.

This chapter discusses related software engineering principles and methods, as well as their application to spreadsheet development. The main techniques and principles underpinning the proposed structured methodology are derived from these methods and techniques. Extensive emphasis is placed on Jackson structural forms as the application of these structures is an essential part of the proposed methodology. A general discussion of software engineering principles and their application to spreadsheet development is first presented. The rationale for the selection of Jackson structural forms is then explained along with the concepts, notations and rules of Jackson structures. This is followed by a discussion of other relevant software engineering principles. In the next chapter, *Chapter 7*, the proposed structured methodology for the development and integrity control of spreadsheet models is elaborately described and presented with illustrative examples.

6.2 Software Engineering Principles

This section presents a general discussion of software engineering principles and their application to spreadsheet development. There is no universally accepted definition of *software engineering* (Jones-90). It has numerous definitions.

Sommerville (Sommerville-01) defines software engineering as an engineering discipline which is concerned with all aspects of software production from the early stages of system specification through to maintaining the system after it has gone into use. The *IEEE Standard Glossary of Software Engineering* defines software engineering as the systematic approach to the development, operation, maintenance, and retirement of software (IEEE-83). Steward (Steward-87) states that the field of software engineering is concerned with all of the activities involved in the solution of problems through the development of computer systems.

These and most of the other definitions offered, clearly establish the scope of and general approach to software engineering. It is a systematic approach that encompasses all aspects, stages and activities involved in the development of software systems. This can be applied to spreadsheet development. Spreadsheet development should adopt a systematic and organised approach that covers all stages and activities of the spreadsheet building process.

There are various principles of software engineering that are applicable to spreadsheet development. Many publications (Bell-00, Sommerville-01, Jones-90) state that software engineering is concerned with the selection and development of the most appropriate methods, tools and techniques used for producing software. According to Sommerville (Sommerville-01), software engineering methods are structured approaches to software development which include system models, notations, rules, design advice and process guidance. Most of the methods and techniques are based on a graphical representation of system models as the basis for system specification or design. This principle can be employed in spreadsheet development. In order to adopt a structured approach, appropriate methods, tools and techniques can be borrowed or developed, and used within the spreadsheet building process.

The investigation of the field of software engineering has revealed that other important principles are also applicable to spreadsheet development. They are as follows:

- an emphasis on finding out and defining the exact requirements of users (Bell-00, Steward-87)
- formal specification of the requirements of a system (Bell-00)
- greater emphasis on quality control and eliminating errors (Bell-00, Jones-90)
- look at the broad picture first, ignoring details, then look at successive smaller parts in greater detail (Steward-87).

The normal stages of the software life cycle (van Vliet-96, Jones-90) are:

- Specification
- (Requirements) Analysis
- Design
- Implementation
- Testing
- Operation and Maintenance

Each software system passes through these stages. A software development process model describes how, and in what order, these stages are organised and carried out. The following are the main software development process models that have been proposed or developed (Jones-90, van Vliet-96, Bell-00):

- (traditional) waterfall
- prototyping
- formal methods
- spiral

6.3 Rationale for Selection of Jackson Structures

This section contains a discussion of why Jackson structural forms are considered to be the most appropriate for the proposed methodology described in the next chapter, *Chapter 7*. A justification of why other approaches have been dismissed, is also provided.

The problem of errors in spreadsheet development can, in many ways, be compared to the days of main-line software development before the advances due to structured programming, analysis and design. Numerous publications (Ronen-89, Benham-93, Isakowitz-95, Panko-96, Kavanagh-97) have proposed the adoption of these techniques to spreadsheet development, in order to overcome the problem.

Several programming and design methodologies originated during the 1960s and 1970s, with goals to systematise the process of software analysis and design, in order to reduce errors and improve quality in the development process. Among the important *data-oriented* methods proposed were M.A. Jackson's *Jackson Structured Programming* (Jackson-75, Cameron-83, Ingevaldsson-86), *Chen's Entity Relationship (E-R) Data Modelling* (Chen-76) and the *Warnier-Orr* methodology (Warnier-81, Orr-81). In the 1980s and 1990s, these methods were supplemented by *object-oriented* methods (Rumbaugh-91, Booch-94). As these methods concentrate primarily on the logical structure of data, it was believed that they could be potentially applied effectively in spreadsheet development.

There are several important reasons for selecting *Jackson Structured Programming* (*JSP*). The principal purpose was for practical reasons. The spreadsheet user community or market is varied and unsophisticated. This rules out more complex methods such as *Chen's E-R Data Modelling* and *Object-oriented Modelling*. A diagrammatic tool is essential for logical modelling. This is a basic software engineering principle.

Among the various methods considered, it was found that the simplest tool in concept is *Jackson Structures* based on *JSP*. This is primarily because it relies only on data dependencies. Data dependencies are very well understood in the spreadsheet community as a result of their familiarity with cell references and the use of auditing tools. Therefore, as a first step, it was quite clear that the use of Jackson structural forms seemed to be the most favoured candidate. This is primarily due to the current state of spreadsheet users' computing knowledge and experience. According to Ingevaldsson L (Ingevaldsson-86), JSP notation can be easily taught to end users. The other methods such as *E-R modelling*, the *Warnier-Orr methodology* and *Object-oriented methods* require relatively high spreadsheet user skills.

Jackson Structured Programming (*JSP*) has been fairly widely promulgated, particularly in Europe, where it has been successful as a standard and in the development of software systems (Cameron-83). Programmers using JSP have found that it results in few, if any, logical errors (Ingevaldsson-86). He also states that the clearly defined step-by-step approach adopted enables different programmers applying JSP to present similar solutions to the same problem.

It appears that there are several possible advantages to the adoption of a structured approach based on Jackson structures. These advantages may be summarised as follows:

- a structured diagrammatic representation of the *logical design* of the spreadsheet model's schema
- a well-defined approach to *modularisation*
- a *top-level overview* of model and module structures
- a structured *indented* format to the layout of the model as a whole and its modules
- the possibility of *automatic structuring* of new spreadsheet models and automatically re-structuring existing spreadsheet models

6.4 Concepts and Notations of Jackson Structures

Jackson structures (Jackson-75) are named after their originator Michael Jackson. The essence of *Jackson Structured Programming (JSP)* is the structure diagram and its relationship to block structure, with its three key constructs of *sequence*, *selection* and *iteration*. Jackson structures offer an elegant diagrammatic way of showing sequence, selection and iteration in program or data structures (Weaver-02).

Figure 6.1 shows a structure diagram, representing a typical block structured module. The repeated parts of the structure are denoted by an asterisk (*) in the top right-hand corner. The structure parts which are selections and therefore mutually exclusive, are denoted by a small circle in the top right-hand corner of the box. The diagram shows that **A** consists of a repeated block **B**, and each **B** is made up of either **C** or **D**. **C** is a sequence of blocks **E** and **F**.

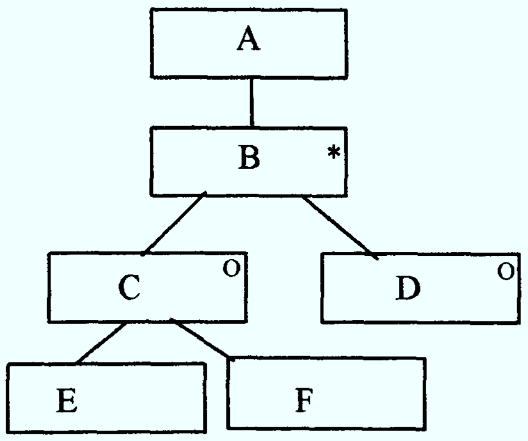


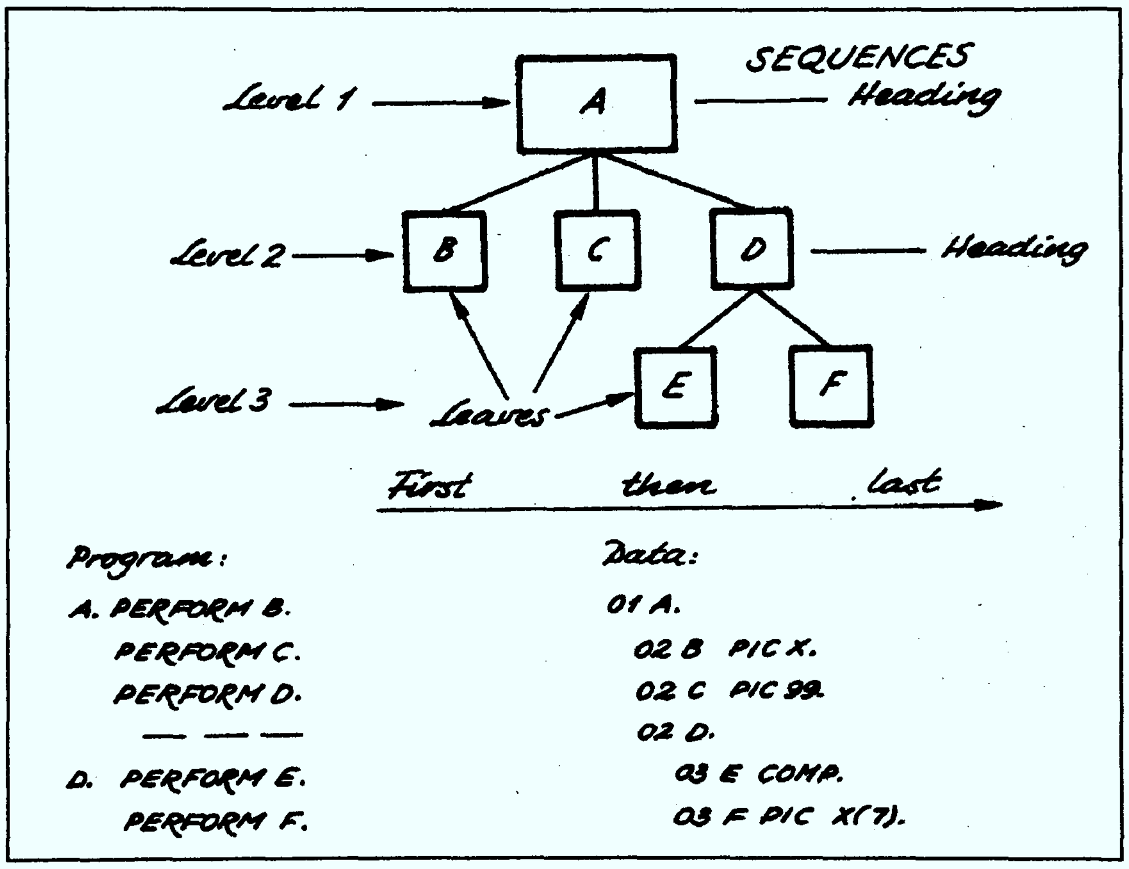
Figure 6.1: An Example Jackson Structure Diagram

The **top box**, **A**, contains the name of the structure. This name describes the contents of the structure. The bottom boxes or '*end leaves*' (i.e. those that have no other boxes below them) are known as **structure elements** (Weaver-98) or **leaves** (Ingevaldsson-86). In *Figure 6.1*, the leaves are **D**, **E** and **F**. **Structure boxes** (**B** and **C**) are all of the intermediate boxes, between the top box and the end-leaves (Weaver-98).

6.4.1 Sequence

A sequence has two or more parts, occurring once each, in order (Jackson-75). The sequence of the blocks or boxes of a Structure Diagram is read from left to right. Based on *Figure 6.2* (Ingevaldsson-86), **A** is a sequence of **B**, **C** and **D**. **D** in turn, is a sequence of **E** and **F**. We refer to the bottom blocks/boxes, **B**, **C**, **E** and **F** as *leaves* (Ingevaldsson-86) or *structure elements* (Weaver-98).

In *Figure 6.3* (Weaver-02), **X** is a sequence of **A**, **B**, **C** and **D**. The diagram is read from lefty to right. Therefore, **A** is followed by **B**, **B** is followed by **C** and so on so forth (Weaver-02). **X** is the *root node* or *top box*. It can also be regarded as the *parent* of **A**, **B**, **C** and **D**. On the other hand, **A**, **B**, **C** and **D** are considered *children* of **X**. There is effectively a *one-to-many* relationship between a *parent* and a *child* with *parent* at the *one-end* of the relationship. Though a *parent* can have one or more *children*, each *child box* must belong to one and only one *parent*. A Jackson structure always has one *root node* (Weaver-02) or *top box*. It appears at the top of the diagram.



Program:

```
A. PERFORM B.
   PERFORM C.
   PERFORM D.
    — — —
D.  PERFORM E.
    PERFORM F.
```

Data:

```
01 A.
  02 B  PIC X.
  02 C  PIC 99.
  02 D.
    03 E  COMP.
    03 F PIC  X(7).
```

Figure 6.2: Sequences

- An iteration must have only a single iterated component in the next lower level (Ingevaldsson-90).

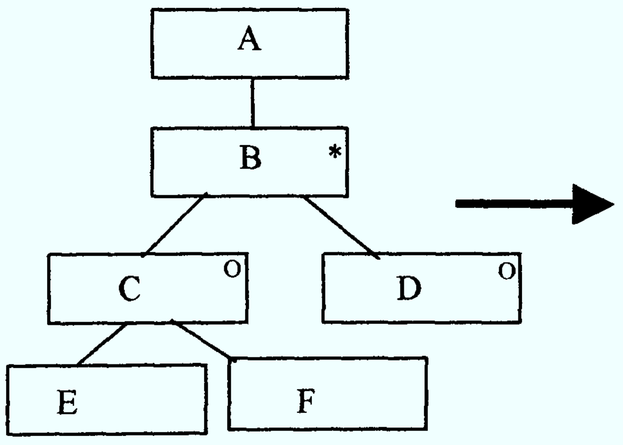
6.6 Other Principles and Techniques

A meticulous study of various other principles and techniques from the fields of software engineering, programming and information systems has revealed that some of these techniques can be employed in the analysis, design and construction of spreadsheet models.

Indentation and Translation of Data Structure into Structured Form

Indentation is an important technique used in structured programming. The philosophy of structured programming, as outlined in (Dahl-72) promotes the indented form for code. This form has led to huge improvements in the comprehension of code, leading to improvements in productivity, auditing and maintenance (Knight-00). Later work (Jackson-75) proposed methods for the translation of data structure into structured form. Jackson proposed that the form of the data structure diagram should be extracted from the natural structure existing in the data to be processed.

Figures 6.9 (a) (Knight-00) and *6.9 (b)* (Ingevaldsson-86) show examples of how the structured form of data is extracted from the data structure. The indented structure on the right of *Figure 6.9 (a)* is the structured programming equivalent of the structure diagram. It can be seen that the indentation is consistent with the levels of data within the Jackson structure.



```
A
REPEAT
  B
  IF ? THEN
    C
      E
      F
  ELSE
    D
  END IF
END REPEAT
```

Figure 6.9 (a): Extraction of Indented Structured Form

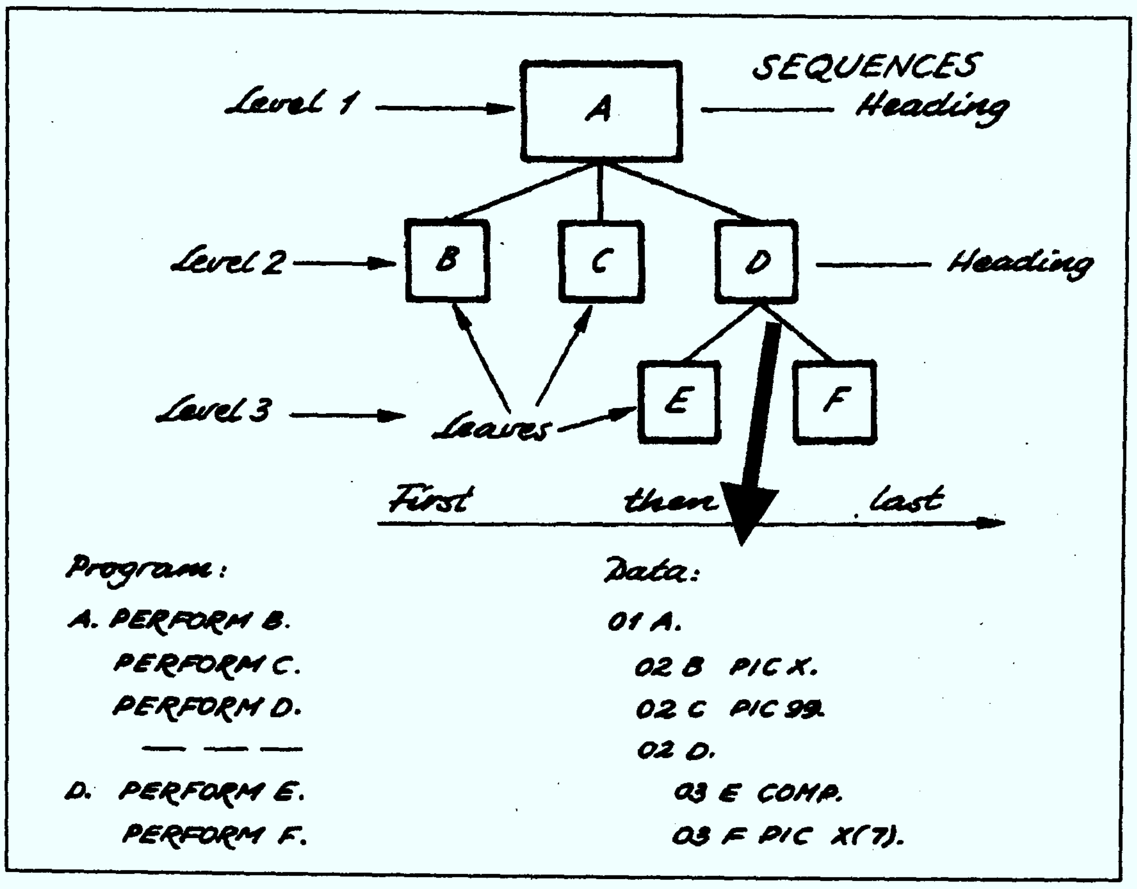


Figure 6.9 (b): Extraction of Indented Structured Form

Virtual Columns

The term 'virtual columns' is used as the multiple physical spreadsheet columns are viewed as a single *logical* column. As such, each row can only contain exactly one function or calculation. The formulae and inputs corresponding to their labels are entered in a set of (virtual) columns consistent with the indentation of the labels. They are located in different *virtual columns*, according to their position in the data structure. When these formulae and inputs appear in different 'virtual columns', the comprehensibility of the model is improved significantly. The precedents of each calculation can be easily identified.

Separation of Inputs, Model Schema (Workings/Calculations) and Outputs

According to Benham (Benham-93), the foundation for this separation is consistent with Sprague and Carlson's (Sprague-82) characterisation of decision support systems as having a data component, model component and user-interface/presentation component. Kee (Kee-88) proposes the use of a central data entry area to make data entry easier and to prevent input errors.

Modularisation

The concept of modularising software lies at the heart of software engineering methodologies. The idea of breaking down a complex piece of software into smaller, relatively isolated sub-components is an appealing one from many points of view. Maintenance, testing and de-bugging, re-use and estimation are all facilitated by modularisation.

Modularisation can be used as a mechanism for segmenting or decomposing a spreadsheet model into smaller parts. Each part is known as a module. Modularisation is the key to successful software engineering, allowing complex systems to be broken down into manageable sub-systems, for ease of comprehension and maintenance. Indeed, the basic principle guiding modularisation can be said to characterise different software engineering methodologies.

Object-oriented software engineering is characterised by Parnas's information hiding principle (Parnas-72), and Stevens, Constantine and Myers' structured approach (Stevens-74) is characterised by the concept of code cohesion. In the proposed structured spreadsheet development methodology, modules are defined by graphical properties of data structure diagrams.

6.7 Summary

Software engineering principles and methods, as well as their application to spreadsheet development, have been discussed in this chapter. This includes a detailed description of Jackson structural forms as the application of these structures is an essential part of the proposed methodology. Although there is no standard definition for *software engineering*, it is widely accepted that software engineering is a systematic approach that encompasses all aspects, stages and activities involved in the development of software systems. Spreadsheet development can also adopt a systematic approach that covers all stages of the spreadsheet building process.

Among the main software engineering principles that can be applied to spreadsheet development include the development of appropriate methods, tools and techniques, precise requirements definition, formal specification of requirements, greater focus on quality control, and adopting a top-down approach. The normal stages of the software life cycle are *specification*, *analysis*, *design*, *implementation*, *testing* and *operation and maintenance*. The main software development process models include the *waterfall* model, *prototyping*, *formal methods* and the *spiral* model.

The adoption of structured systems development techniques has been widely proposed to effectively deal with the problem of spreadsheet errors. In systems development, among the main methods developed include *Jackson Structured Programming*, *Entity Relationship Modelling*, the *Warnier-Orr* method and *Object-oriented* methods. From an investigation of the suitability of these methods to spreadsheet development, *Jackson structural forms* based on *Jackson Structured Programming* has emerged as the most desirable method. This is mainly due to its maturity, simplicity, relevance and practicality. The Jackson method is far more likely to be accepted compared to the other methods, which require relatively high spreadsheet user skills.

The three key constructs of *sequence*, *selection* and *iteration* form the basis of Jackson structural forms based on *Jackson Structured Programming*. There are also certain basic rules that must be followed when developing Jackson structures. Other important principles and techniques that can also be employed in the development of spreadsheet models include *indentation and translation of data structure into structured form*, *virtual columns*, *separation of inputs, workings and outputs*, and *modularisation*.

CHAPTER 7
THE PROPOSED STRUCTURED METHODOLOGY

7.1 Introduction

Chapter 6 provided an understanding of related software engineering concepts and principles, and their potential application to the design and development of spreadsheet models. The principal method focused upon was the use of *Jackson structures*.

Based on the software engineering principles and structured techniques investigated, a comprehensive structured methodology for the construction and integrity control of spreadsheet models has been developed. This chapter presents the proposed methodology in detail. It begins by discussing the development and synthesis of the methodology from the material considered in *Chapter 6*. The various stages of the methodology are described in detail with suitable examples. The methodology's potential for quality improvement is also discussed.

The proposed structured methodology represents a significant development or advance in the research into the development and integrity control of spreadsheet models. Preliminary versions of the methodology are presented by Rajalingham, Chadwick, Knight and Edwards (Rajalingham-01,02; Knight-00; Chadwick-99).

The proposed methodology imposes a strict discipline in the process of spreadsheet development using software engineering principles. This reduces the occurrence of errors as spreadsheet models are designed and constructed in a structured and organised manner. The methodology distinctly describes a technique for modelling the spreadsheet problem and subsequently mapping the design onto the physical spreadsheet according to prescribed rules and a structured algorithm.

7.2 Development and Synthesis of the Proposed Methodology

This section provides an account of the development of the proposed methodology and its synthesis from the material considered in the previous chapter, *Chapter 6*.

7.2.1 General Software Engineering Principles

Based on the discussion of software engineering principles in *Chapter 6*, it has been found that many of these principles are applicable to the development of spreadsheet models. Therefore, these principles have been incorporated into the proposed methodology. It has been established that software engineering is a systematic approach that encompasses all aspects, stages and activities involved in the development of software systems. The proposed methodology adopts a systematic and organised approach that covers all stages and activities of the spreadsheet building process. *Figure 7.1* shows the relationship between the proposed structured methodology and the normal stages of the software development life cycle given in

Chapter 6. The different stages of the proposed methodology are described in detail in the next section, *Section 7.3*.

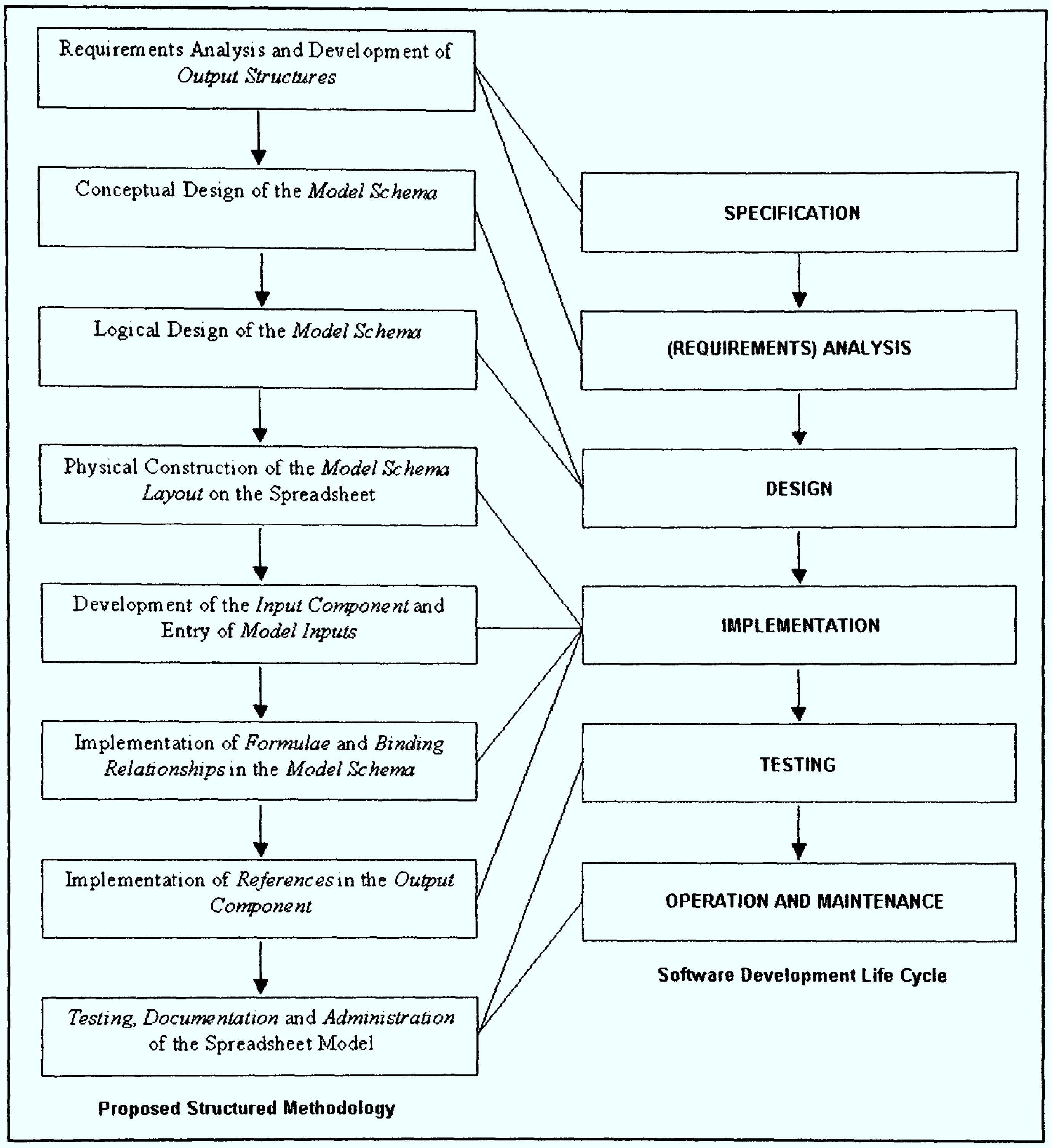

Requirements Analysis and Development of *Output Structures*
Conceptual Design of the *Model Schema*
Logical Design of the *Model Schema*
Physical Construction of the *Model Schema Layout* on the Spreadsheet
Development of the *Input Component* and Entry of *Model Inputs*
Implementation of *Formulae* and *Binding Relationships* in the *Model Schema*
Implementation of *References* in the *Output Component*
Testing, Documentation and *Administration* of the Spreadsheet Model
Proposed Structured Methodology
SPECIFICATION
(REQUIREMENTS) ANALYSIS
DESIGN
IMPLEMENTATION
TESTING
OPERATION AND MAINTENANCE
Software Development Life Cycle

Figure 7.1: The Proposed Methodology and the Software Development Life Cycle

Various other principles of software engineering discussed in the previous chapter have also been used to develop the proposed methodology. Appropriate tools and techniques are used within the methodology as software engineering is concerned with the selection and development of the most appropriate methods, tools and techniques used for producing software. These include *Jackson structural forms, indentation and translation of data structure into structured form, virtual columns, separation of inputs, workings and outputs*, and *modularisation*. The proposed methodology also includes models, notations, rules and design advice. Techniques such as Jackson structures are used to produce a graphical representation of the spreadsheet model as a basis for specification or design.

Among the other important software engineering principles used to develop the proposed methodology are as follows:

- An emphasis on eliciting and defining the exact requirements of users in *Stage 1*.
- Formal specification of the requirements of the spreadsheet system in *Stage 2* and *Stage 3*.
- Focus on a high-level view or broad picture first, followed by a look at successive smaller parts in greater detail in *Stage 1*, *Stage 2* and *Stage 3*.
- Greater emphasis on quality control and eliminating errors in all stages of the methodology.

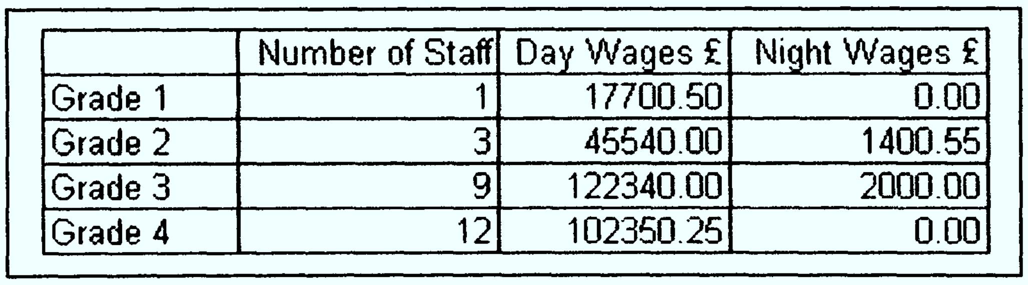
7.2.2 Application of *Jackson Structures*

The suitability of a front-end of the proposed methodology for spreadsheet development, based on the Jackson structural forms (described in *Chapter 6*) has been investigated. It has been found that the conceptual or logical design of spreadsheet models can be represented in a form identical to a *Jackson structure.* This technique is used in *Stages 2* and *3* of the proposed methodology.

When Jackson structures are used to represent the logical design of a spreadsheet model, they can distinctly show all the relationships within the model's schema. As described in *Chapter 6*, Jackson tree structures are based on three key constructs: *sequence*, *selection* and *iteration*. These constructs can show the sequence, optionality and iteration of data items. The three constructs of Jackson structures are also applicable to the design of a spreadsheet model.

<u>Sequence</u>

Referring to *Figure 7.2* (*Staff Budget*) based on Chadwick et al (Chadwick-97), there is a need to calculate the *average staff wages.*



	Number of Staff	Day Wages £	Night Wages £
Grade 1	1	17700.50	0.00
Grade 2	3	45540.00	1400.55
Grade 3	9	122340.00	2000.00
Grade 4	12	102350.25	0.00

Figure 7.2: Inputs for the Staff Budget Model

The formula is:

average staff wages = total wages / total number of staff

Total wages and *total number of staff* are therefore direct precedents of *average staff wages*. *Total wages* being one of the operands of the formula is made up of *total day wages* and *total night wages*. The formula is:

total wages = total day wages + total night wages

Based on this analysis, a partial Jackson structure can be constructed, comprising a set of hierarchical sequences. This is presented in *Figure 7.3*.

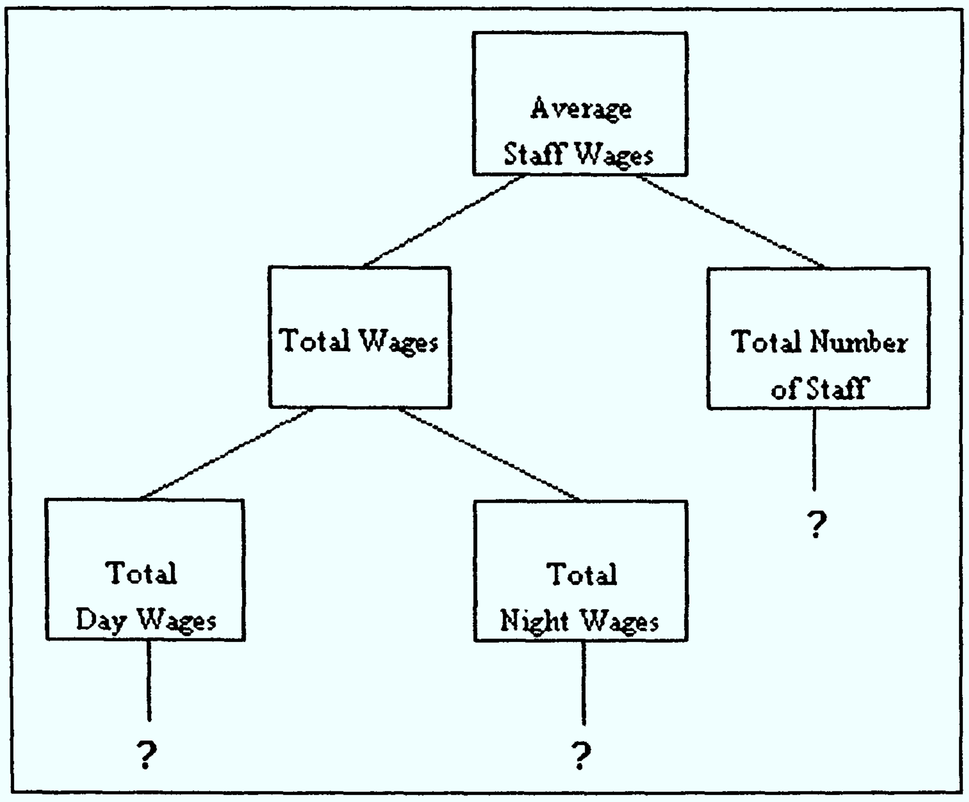


Figure 7.3: Sequences

Selection

This feature of Jackson structures can be used in spreadsheet models to represent mutually exclusive sets of direct precedents for a particular formula. For the purpose of clarity, appropriate conditions can be attached to selection structures.

In the calculation of *tax*, the formula is:

```
IF      taxable profit > 0
THEN    tax = taxable profit * tax rate
ELSE    tax = 0
```

In a spreadsheet cell, the corresponding formula for tax would be written in the form:

```
= IF (taxable profit > 0, taxable profit * tax rate, 0)
```

In either case, *taxable profit* and the constant *zero* would be direct precedents of *tax*. The operands forming the condition within the formula are mandatory precedents. As such they are represented using sequence boxes.

Additionally, depending upon the value of *taxable profit*, *tax* would have either *taxable profit* and *tax rate*, or *zero*, as its direct precedent(s). This part of the formula can be shown using a selection structure. This would be represented in the form of a Jackson structure as displayed in *Figure 7.4*.

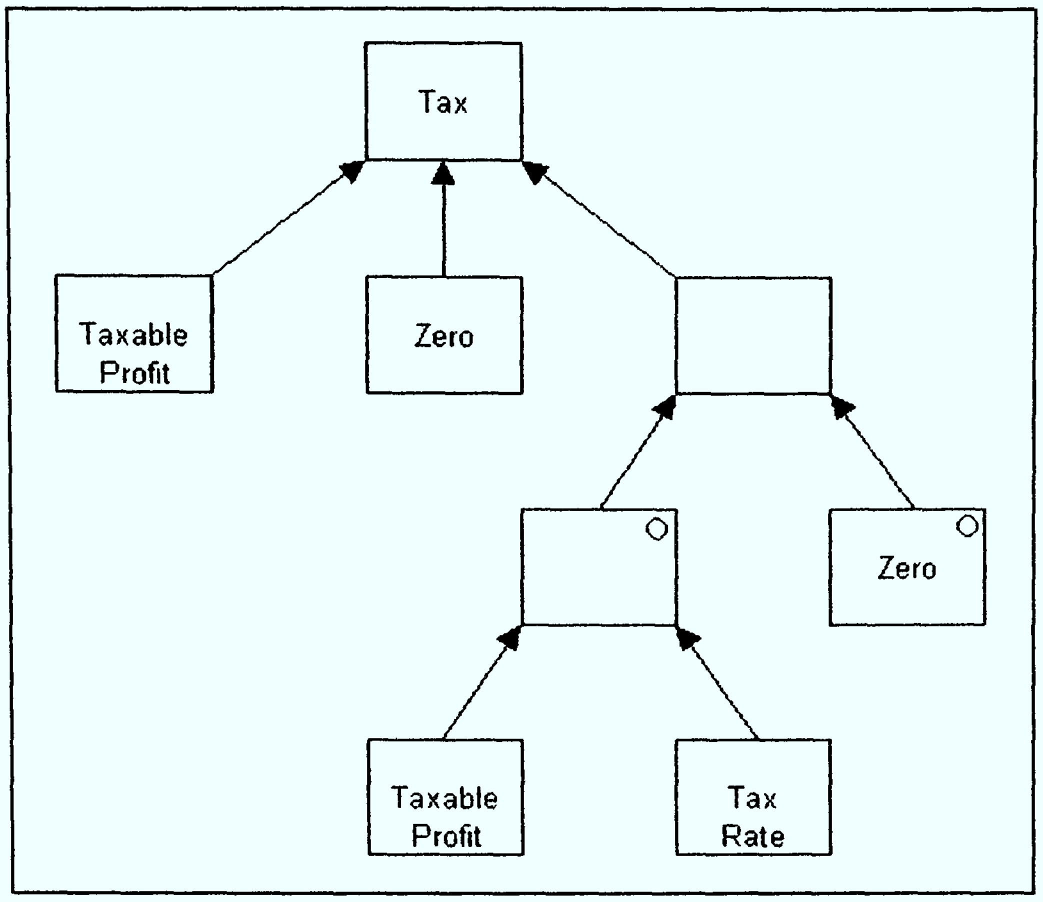


Figure 7.4: Selection

<u>Iteration</u>

Within the context of spreadsheet models, iterations in Jackson structures can be used to show parts of a model that may repeat several times. An iterated component represents multiple instances, where each instance corresponds to a different time period, group, category, etc.

Based on the Staff Budget model example, the average wage for each grade is also required. The formula to calculate this for each grade is exactly the same. This part of the logical design is shown in *Figure 7.5*.

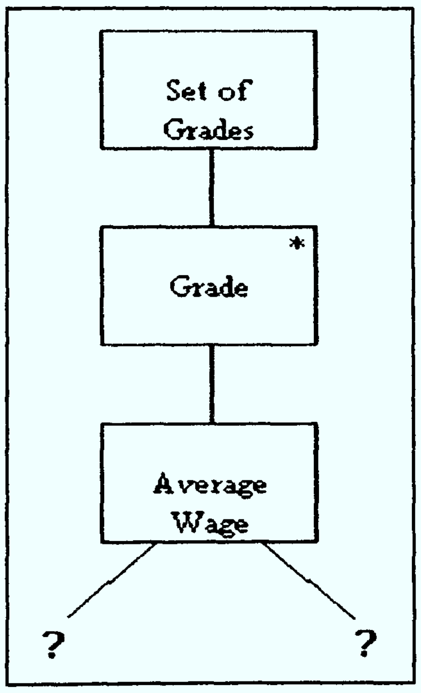


Figure 7.5: Iteration

It has also been identified that *total day wages* is defined as the sum of *day wages for each grade* while *total night wages* is the sum of *day wages for each grade*.

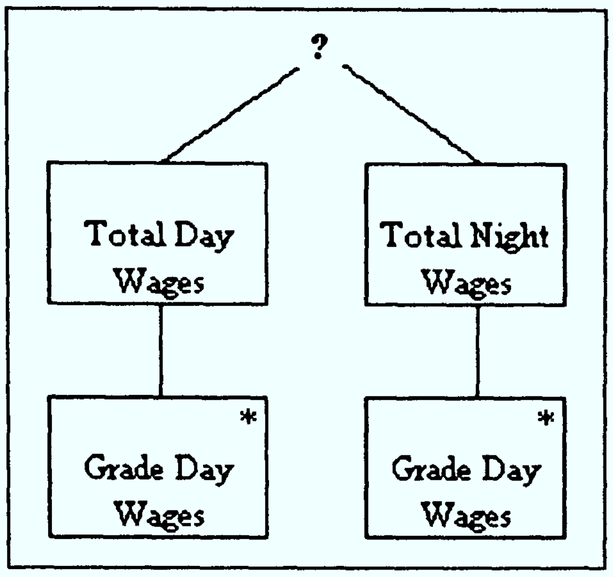


Figure 7.6: Iteration

This part of the model can now be incorporated into the sequence structure shown in *Figure 7.3* and the iteration structure in *Figure 7.5*. The resulting Jackson structure is displayed in *Figure 7.7*. This structure represents the logical design of the entire model.

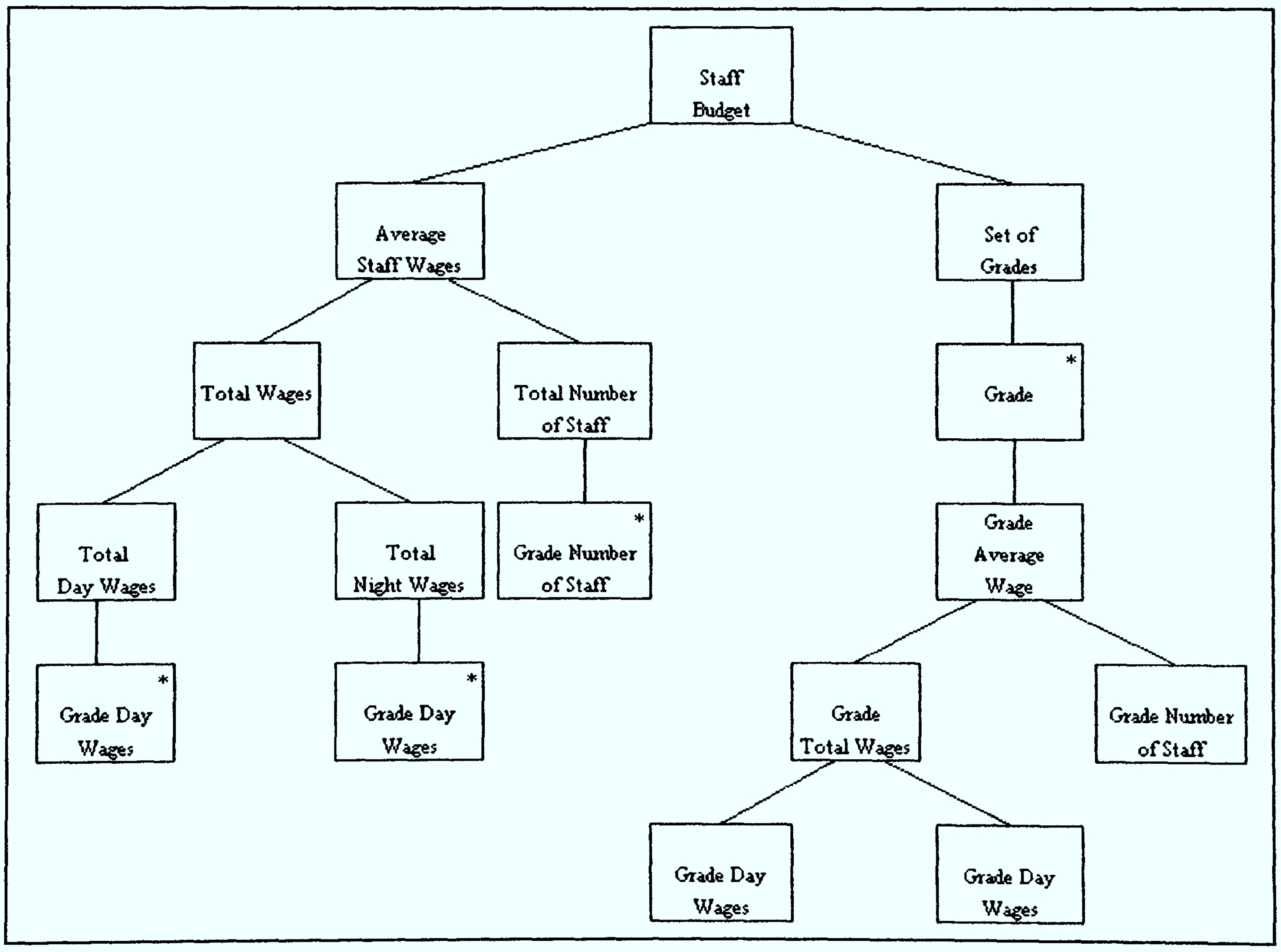


Figure 7.7: Logical Design

7.2.3 Other Principles and Techniques

There are other software engineering and programming principles and techniques described in *Chapter 6*, that have also been used to further develop and enhance the proposed methodology.

<u>Indentation and Translation of Data Structure into Structured Form</u>

Jackson (Jackson-75) has shown that there is direct correspondence between data and program structures, and that *structure diagrams* can be directly mapped onto the corresponding program code. This technique is used in *Stage 4* of the proposed methodology, to translate the logical design represented in the form of a Jackson structure into a structured spreadsheet. This is illustrated using the example of the *Staff Budget* model. *Figure 7.8* shows the extraction of the structured spreadsheet from part of the logical design produced earlier (displayed in *Figure 7.7*). The indented structure on the right of *Figure 7.8* is the structured programming equivalent of the structure diagram.

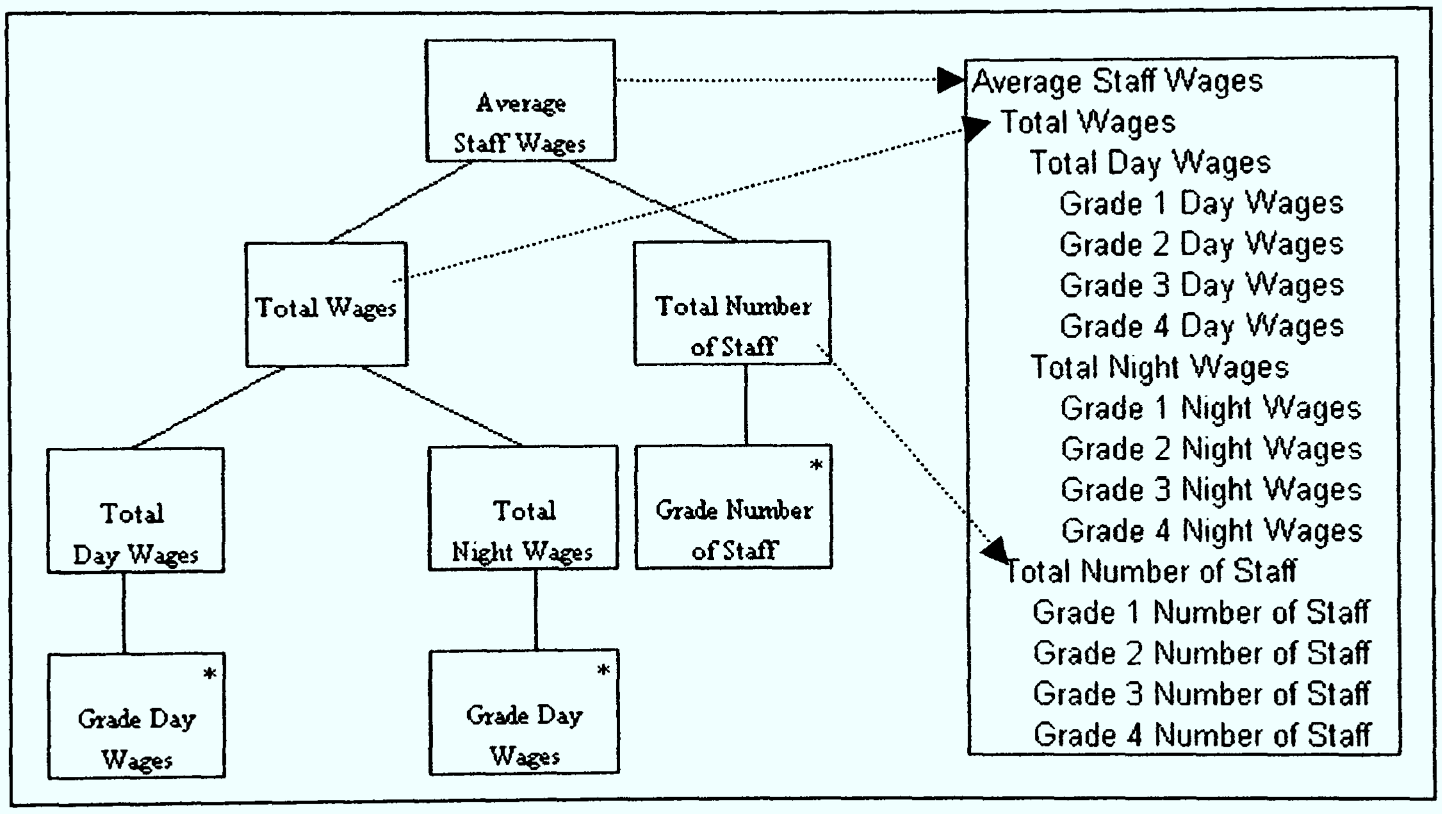
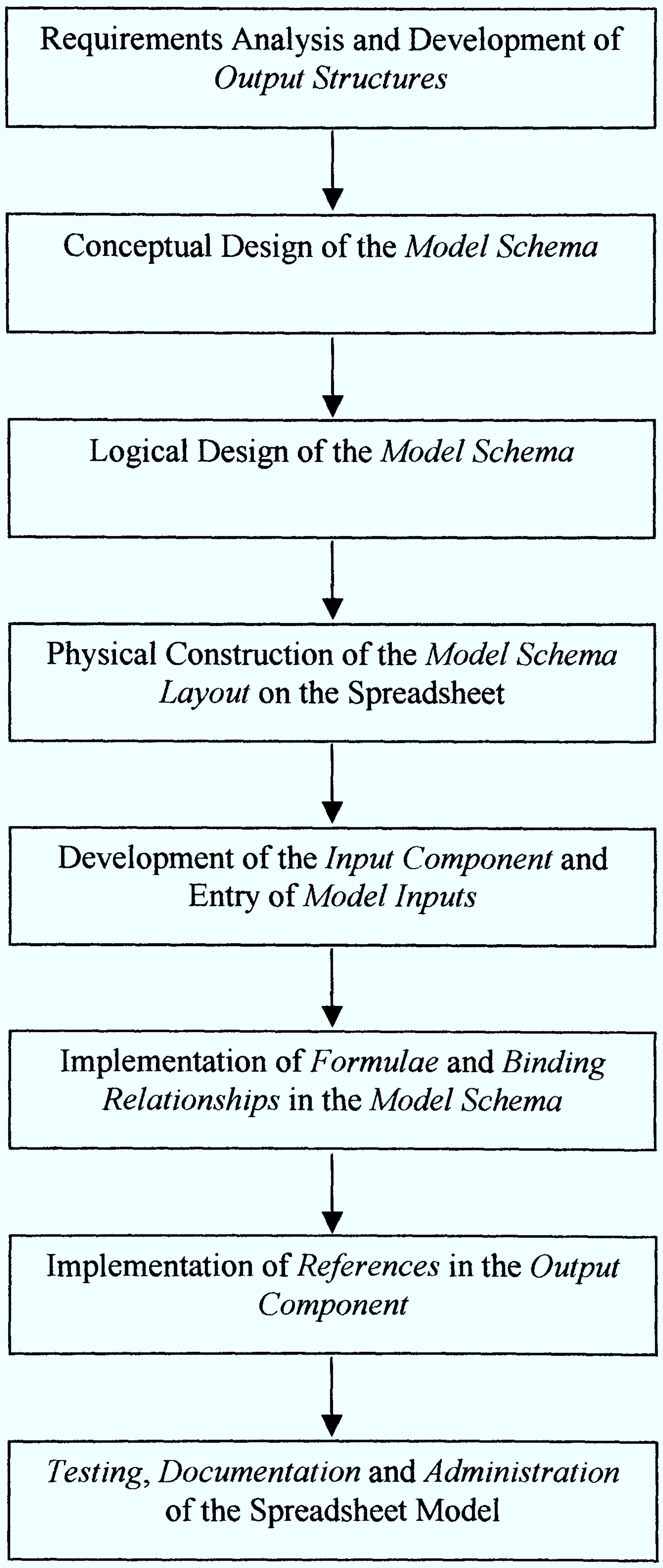


Figure 7.8: Translation of Jackson Structure to Structured Form

7.3 The Proposed Structured Methodology

The methodology consists of eight principal stages:


Requirements Analysis and Development of *Output Structures*
Conceptual Design of the *Model Schema*
Logical Design of the *Model Schema*
Physical Construction of the *Model Schema Layout* on the Spreadsheet
Development of the *Input Component* and Entry of *Model Inputs*
Implementation of *Formulae* and *Binding Relationships* in the *Model Schema*
Implementation of *References* in the *Output Component*
Testing, *Documentation* and *Administration* of the Spreadsheet Model

STAGE 1: *Requirements Analysis and Development of Output Structures*

This stage is carried out from the perspective of the *model sponsor(s)* or *interpreter(s)*. The model sponsor is the person who requests that the model be built and ensures the required resources are available. Agreement of the objectives of the model is the responsibility of the model sponsor (Read-99). The model interpreters are the end-users who interpret or use the output of the spreadsheet model for a particular purpose or to make business decisions.

The first stage comprises two steps:

- **Step 1: Requirements analysis and specification**
- **Step 2: Design of outputs and development of output structures**

In *Step 1*, the requirements of the model sponsors or interpreters are elicited and analysed. The overall objective or purpose of the spreadsheet model is also established. Based on the information gathered, an assessment of the nature, scale and complexity of the model is carried out. Read and Batson (Read-99) have defined a set of tasks under the *scope* stage of their *Spreadsheet Best Practice Methodology*, some of which are appropriate for application in this step. The model developer(s) have to

- decide what needs to be included in the model and what can be omitted;
- understand in outline how the model will work;
- estimate the time and resource required for the model development; and
- agree the above with the key stakeholders.

Step 2 of this stage involves translating the requirements of the model sponsors/interpreters into a set of spreadsheet model outputs. Each spreadsheet model would normally have one or more associated outputs. The methodology insists on the presentation of outputs on one or more separate worksheets. They should neither appear in the worksheet containing the spreadsheet model schema, nor the worksheet containing the model inputs.

The structure of each output is designed and implemented on the physical spreadsheet. Only the editorial aspects of each desired output are implemented at this stage. These include titles, headings and descriptive labels for formula and data. Each desired output of the spreadsheet model is designed from the perspective of the model sponsors/interpreters.

There is a need to distinguish between inputs (or numeric constants) and formulae in the model's output(s). Having determined the various formulae required, the underlying logic of each formula calculation and its domain are defined. This is independent of any particular implementation platform. At the end of the methodology, references to the *model schema* and *model inputs* are added to the output component of the spreadsheet model. No calculations would be present in the outputs. However, there could be multiple outputs presenting the same information at different levels of detail or even in different layouts, to suit a variety of purposes.

The model sponsor/interpreters do not normally make changes to the outputs when the spreadsheet model is in operation. However, they may alter the structure or format of the outputs if deemed necessary. This will not affect the integrity of the underlying spreadsheet model, which is embedded in the *model schema.*

STAGE 2: ***Conceptual Design of the Model Schema***

The *model schema* represents the workings or calculations component of the spreadsheet model. The purpose of constructing the *model schema* is to systematically and methodically perform the interim and final calculations based on the required or desired model output(s). An essential characteristic of the proposed structured methodology is the separation of inputs, calculations and outputs. The model schema, representing the spreadsheet model's underlying logic, is therefore separated from the inputs and outputs. From a physical perspective, the model schema is created on a separate worksheet.

In developing the conceptual model, the first step is to distinguish between inputs and formulae contained within the model output(s). An analysis of all formulae is carried out in order to construct the conceptual model.

The main steps involved in this stage are as follows:

- **Step 1: Determine the operands of each output formula**
- **Step 2: Establish relationships between formulae at a logical level**
- **Step 3: Identify root formulae or formulae with no dependants**
- **Step 4: Use a Jackson structure to represent the direct and indirect precedents of each root formula**
- **Step 5: Merge the structures of all the root formulae**

The first step involves determining the operands of each output formula. This step is carried out as a means of determining all root formulae appearing in the outputs. A root formula is defined as a formula that has neither direct nor indirect dependants. They are therefore not referenced by any other formula within the spreadsheet model.

The conceptual design of each root formula is represented in the form of a *Jackson* structure (Jackson-75). In a large number of spreadsheet models, it is highly possible that there is just one root formula.

Each node of a sequence or selection (depending on its position in the Jackson structure) represents either a formula or a piece of data. If the node is a *structure element* or *leaf* (or *end-leaf*), it represents data (numeric constant) or input. An iterated component that is not a leaf represents a structure (or sub-structure) that can occur zero or more times. Such iterated components have special properties, which will be discussed later. If an iterated component is shown as an end-leaf in the Jackson structure, it represents a set or range of inputs that is always manipulated or operated as a group rather than individually.

The root formulae are placed at the top of the Jackson structure, hanging from a box containing the title of the spreadsheet model. The direct precedents of each root formula are then positioned immediately below it, adjacent to each other. Each node is decomposed step by step, until every end-leaf or bottom node has been identified and represented. The conceptual design of the entire model schema is the combination of the structures of all root formulae into a single Jackson structure with its root node containing the title of the spreadsheet model.

When a top-down approach is adopted without showing duplication of nodes, the structure of the model schema could take the form of a graph instead of the desired tree structure. The purpose of this is to distinctly show instances of multiple dependants of a particular formula of the model schema. This potentially results in a structure as shown in *Figure 7.11*.

From the structure in *Figure 7.11*, we can observe the following points:

- **A** is a *root formula*. It therefore represents a formula with no dependants.
- **D** and **E** are mutually exclusive (due to the *selection* constraint) precedents of **A**.
- The direct precedents of **D** are a *sequence* of **F** and **G**.
- The direct precedents of **K** are a *sequence* of **L** and **M**.
- **M** is a function of zero or more *iterations* of **N**.
- **N** is a range of zero or more related inputs (constants).
- **B**, **C**, **F**, **H**, **J** and **L** are *leaves* as they do not have any precedents. This shows that they are inputs (or constants). **B**, **C**, **F**, **H**, **J** and **L** are therefore read or referenced from the *input component*, which will be constructed later.
- **G** has two dependants, **D** and **E**, and therefore forms a graph.
- **K** also has multiple dependants, **E** and **I**; another graph is formed.

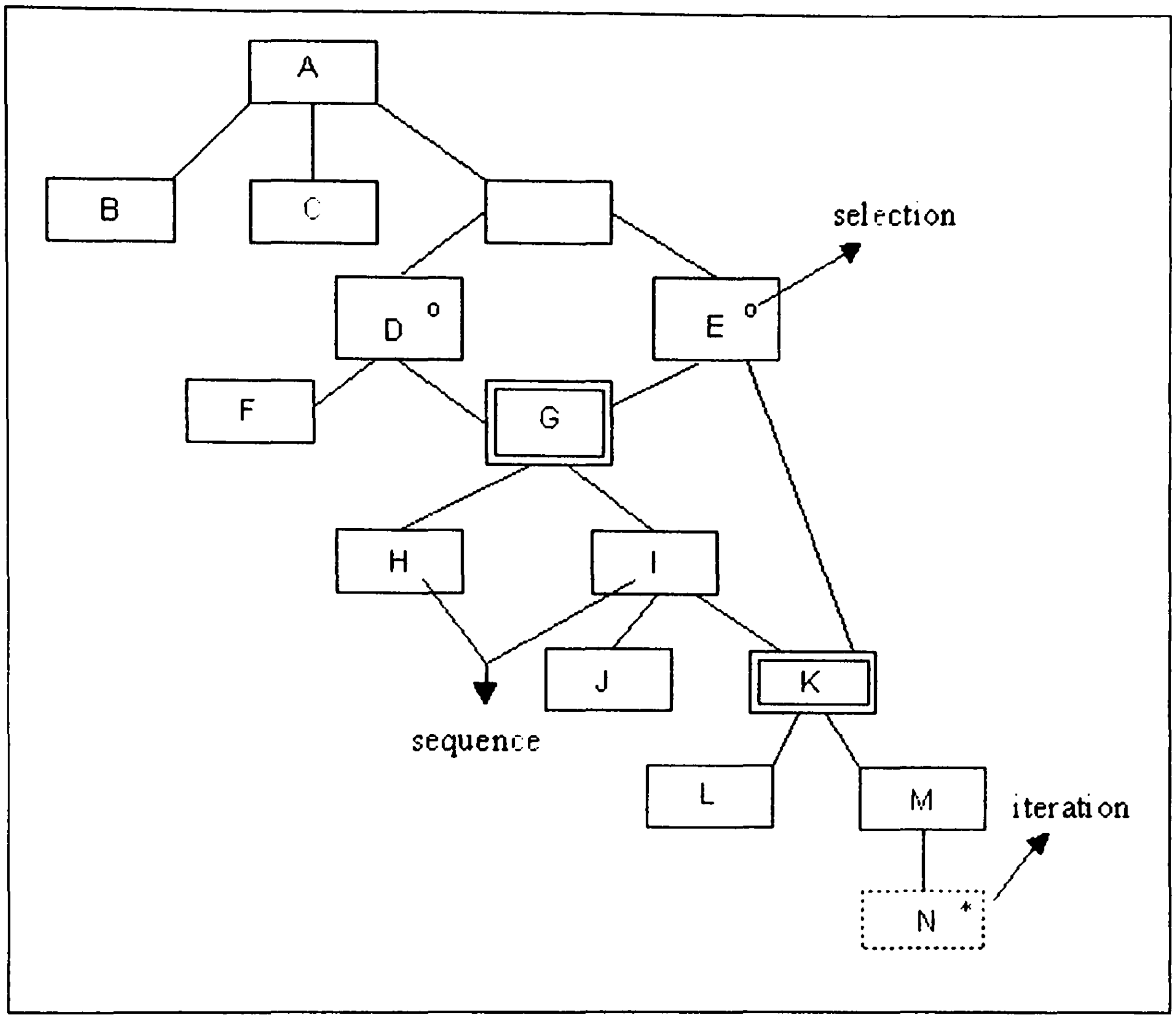


Figure 7.11: The Conceptual Design in Graph-form

A double-line box ▣ (as opposed to the single-line box) represents a formula or data (numeric constant) with multiple dependants. A dashed box ⬚ represents a range of related inputs (constants) treated and manipulated as a set. In order to effectively model the conceptual and logical designs of a spreadsheet model, these notations have been added to the conventional Jackson notations (Jackson-75) borrowed from software engineering.

STAGE 3: ***Logical Design of the Model Schema***

The logical perspective consists of a formal and implementation-free description of the model's logic and data structures (Isakowitz-95). The purpose of *Stage 3* is to resolve sub-structures with formulae or data with multiple dependants. A formula or data with multiple dependants normally form a graph. Structurally, the aim at this stage is to transform all *graph sub-structures* in the conceptual model to *trees* so that the entire model is in the form of a Jackson-like tree structure. From a more logical perspective, the objective of performing this task is to enable the direct mapping of the Jackson structure to the spreadsheet based on Jackson's method of mapping the data structure diagram to a computer program.

Figure 7.11 shows an example of a generic conceptual design containing graph sub-structures. For instance, there is a loop in the relationships connecting **E**, **G**, **I** and **K**, so that we no longer have a tree form. In this chart, K is a precedent of both **E** and **I**. We can turn the graph into a tree-structure. In order to accomplish this, two important steps prescribing the rules have to be observed:

Step 1

Each node or sub-structure with multiple dependants is duplicated and each copy is assigned as a direct precedent of every dependant of that node. Nodes with multiple dependants can be easily identified from the conceptual design as they are represented by double-line boxes. This is illustrated in Figure 7.12.

By performing this task, the graph structure is resolved into a tree-structure. However, in order to prevent multiple occurrence of the entire sub-structure, only the root node of each duplicated sub-structure appears in the logical design of the model at this point. Their precedents are therefore not included in the model.

Based on *Figure 7.12*, **G** and **K** are duplicated in order to resolve the graph structure, into a tree structure. The precedents of **G** and **K** are not included in the model. **K** is not even shown as a precedent of **G** in order to comply with the rule that precedents of duplicated nodes are not included in the main structure of the logical design.

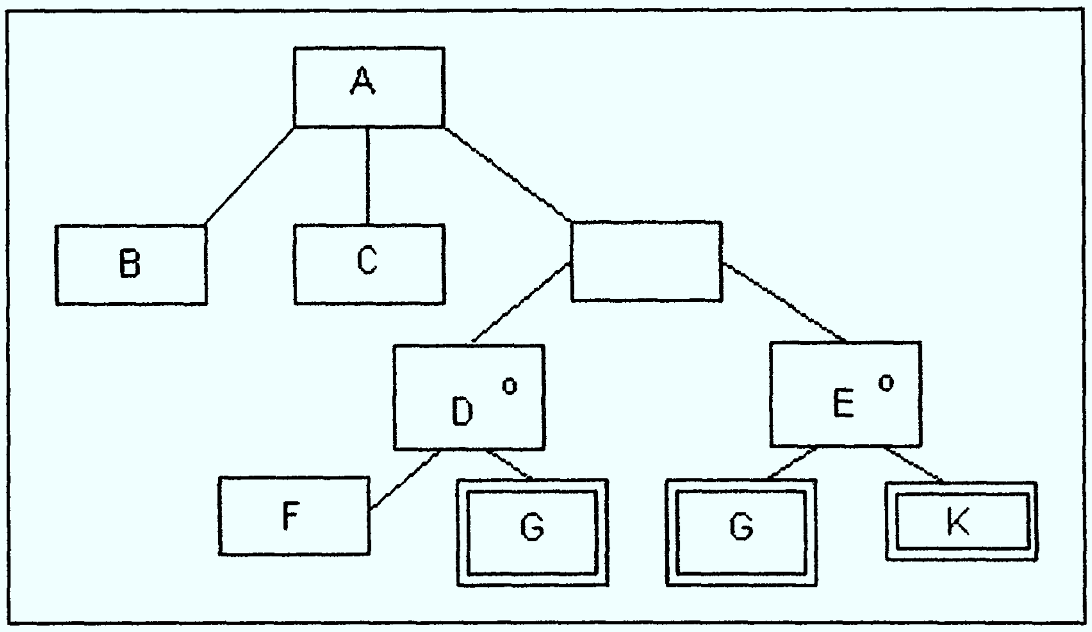


Figure 7.12: The Logical Design of the Main Structure Based on *Step 1*

Step 2

If a duplicated node has precedents (and therefore forming a sub-structure or branch), a distinct structured module is created, the logical design of which is represented by a separate Jackson tree structure. The structured module consists of the duplicated node as its root node/formula and the precedents of the particular formula. The structures resulting from the application of this step/rule are illustrated in Figures 7.13 (a) and 7.13 (b).

If the duplicated node is a *leaf* and therefore has no precedents, there is no need to define it as a separate module. As a rule, only a node or formula with precedents can be defined as a common module.

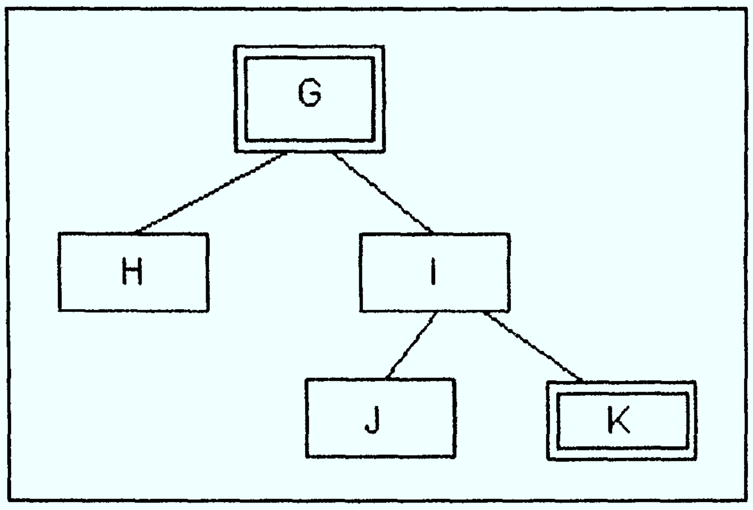


Figure 7.13 (a): The Logical Design of Module **G** (Based on *Step 2*)

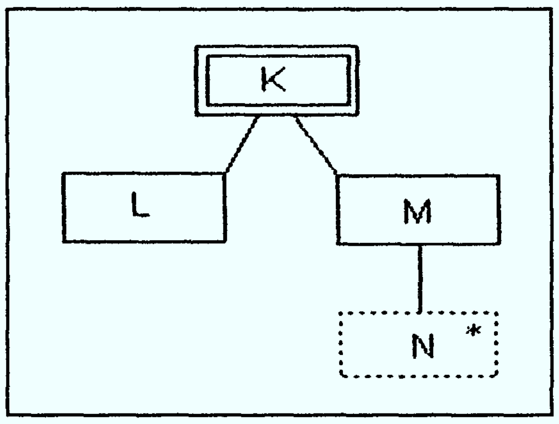


Figure 7.13 (b): The Logical Design of Module **K** (Based on *Step 2*)

Based on *Figures 7.13 (a)* and *7.13 (b)*, the sub-structures **G** and **K** are defined as separate modules, each of which will occur once in the implemented spreadsheet model. This is discussed more elaborately in *Stage 4*.

The conceptual design shown in *Figure 7.11* has now been transformed into a logical design consisting of three modules, represented by three separate Jackson structures. The modules consist of a main or primary module and two secondary modules. *Figure 7.14* shows the relationship between the modules.

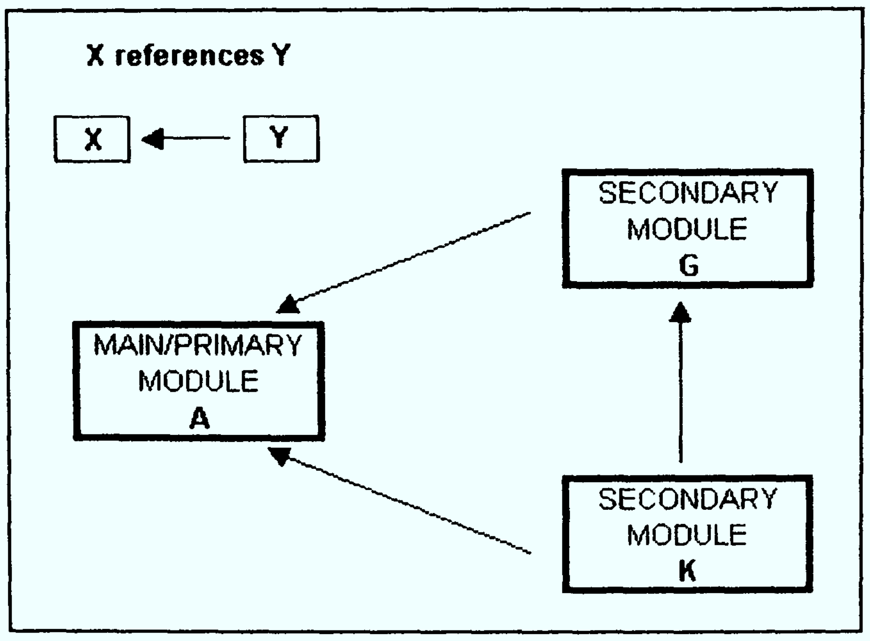


Figure 7.14: Relationship Between Modules

In general, we can always reduce a graph structure to a tree by this method, which conveniently produces a unique modularisation of the spreadsheet model.

STAGE 4: ***Physical Construction of the Model Schema Layout on the Spreadsheet***

The logical design of the model (represented as Jackson tree-like structures) is systematically mapped onto the physical spreadsheet based on rigorous rules prescribed by the methodology.

To maintain the structure modelled in the logical design in the spreadsheet view, the indentation principle is used, both on the row labels and on the corresponding values themselves. The values are indented by assigning a spreadsheet column to each level of indentation. These columns can be referred to as *virtual columns*. Based on the generic logical design shown in *Figures 7.12*, *7.13 (a)* and *7.13 (b)*, the corresponding structure of the spreadsheet view at this stage is shown in *Figure 7.15*.

input component contains all *data* and *assumptions* used in the spreadsheet model. It is not always necessary to explicitly separate the two. Benham (Benham-93) recommends that this section be partitioned into *decision variables*, *environmental variables*, and *parameters*.

The design of this part of the user interface should be as free from constraints as possible; so as not to hinder the main objective: ease of use and absence of data errors. We are therefore, quite at liberty to put all data input cells into unstructured modules, since there are never any dependencies between them. Any dependency relationship in spreadsheet involves a calculated cell, and either other calculated cells or data input cells. However, they do not exist between data input cells and other data input cells.

The *model schema* only holds absolute copies of the corresponding data in the input section. It is also protected as a precaution against any overwriting of data, and can only be manipulated by the programmer or model developer.

Based on the *leaves* identified in the Jackson structures, the *input* section can be created. The input section is constructed on a separate worksheet and should be labelled as such. The data input end-users must only be allowed to manipulate the input section for the entry and update of data. They are responsible for entering all the inputs to the spreadsheet model in this section. Based on *Figures 7.12*, *7.13 (a)*, *7.13 (b)* and *7.14*, the inputs to the model are B, C, F, H, J and L.

A problem that can be anticipated at this stage is the difficulty in adding or deleting data from the *input* section while having the changes reflected in the *model schema*. In view of this problem, the methodology requires that a group of related inputs be defined as a range and only the range is referred to in the model schema. A reference to a group of related inputs or an input set (range) is shown in the Jackson structure by a *leaf* shown as a dashed-line box and represented as an iterated component.

Based on *Figure 7.13 (b)*, N represents a group of related inputs. Therefore, the elements of N are defined as a range in the input component. It can also be observed in *Figure 7.13 (b)* that M is a function of N. In the model schema, M references the range N. The elements of N are not physically present in the model schema. This way, any changes that take place within N will not affect the integrity of the formulae or calculations in the model schema. *Figure 7.16* shows the input component derived from the logical design of the spreadsheet model.

STAGE 7: ***Implementation of References in the Output Component***

References to corresponding *formulae* in the *model schema* and *data* in the *input component*, can at this stage be entered into the relevant cells of the *output component*.

STAGE 8: ***Testing, Documentation and Administration of the Spreadsheet Model***

There should be organisational standards in place for the testing, documentation, and maintenance or administration of spreadsheet models (McMickle-89, Simkin-87: cited in Isakowitz-95). This stage brings the spreadsheet model development process to a conclusion. It consists of three principal steps:

- **Step 1:** **Testing**
- **Step 2:** **Documentation**
- **Step 3:** **Administration**

As this stage is not considered a core aspect of the methodology, each of its constituent steps will be addressed only briefly and in passing. It is recommended that conventional software engineering approaches and principles be used for the testing, documentation and administration of the spreadsheet model.

Step 1 of this final stage requires that the entire spreadsheet model be rigorously tested before it goes into operation. The spreadsheet model is tested with a comprehensive set of test data. Ray Butler (Butler-97) proposes that the spreadsheet model should also be reviewed by someone other than the developer for errors before being brought into use.

In *Step 2*, documentation of the spreadsheet model is incorporated into the model itself, typically on a separate worksheet. Kee (Kee-88) states that documentation materials provide the instructions needed to apply a template properly, as well as the technical details needed to understand its underlying structure. Without adequate documentation, it is often easier to develop a new template than to review somebody else's program (Kee-88).

Step 3 addresses the administration of the spreadsheet model. After the spreadsheet model goes into operational use, proper administration of the spreadsheet model is essential. Mason and Keane (Mason-89) have proposed that a *model administrator* regulates and monitors spreadsheet modelling activities across the organisation.

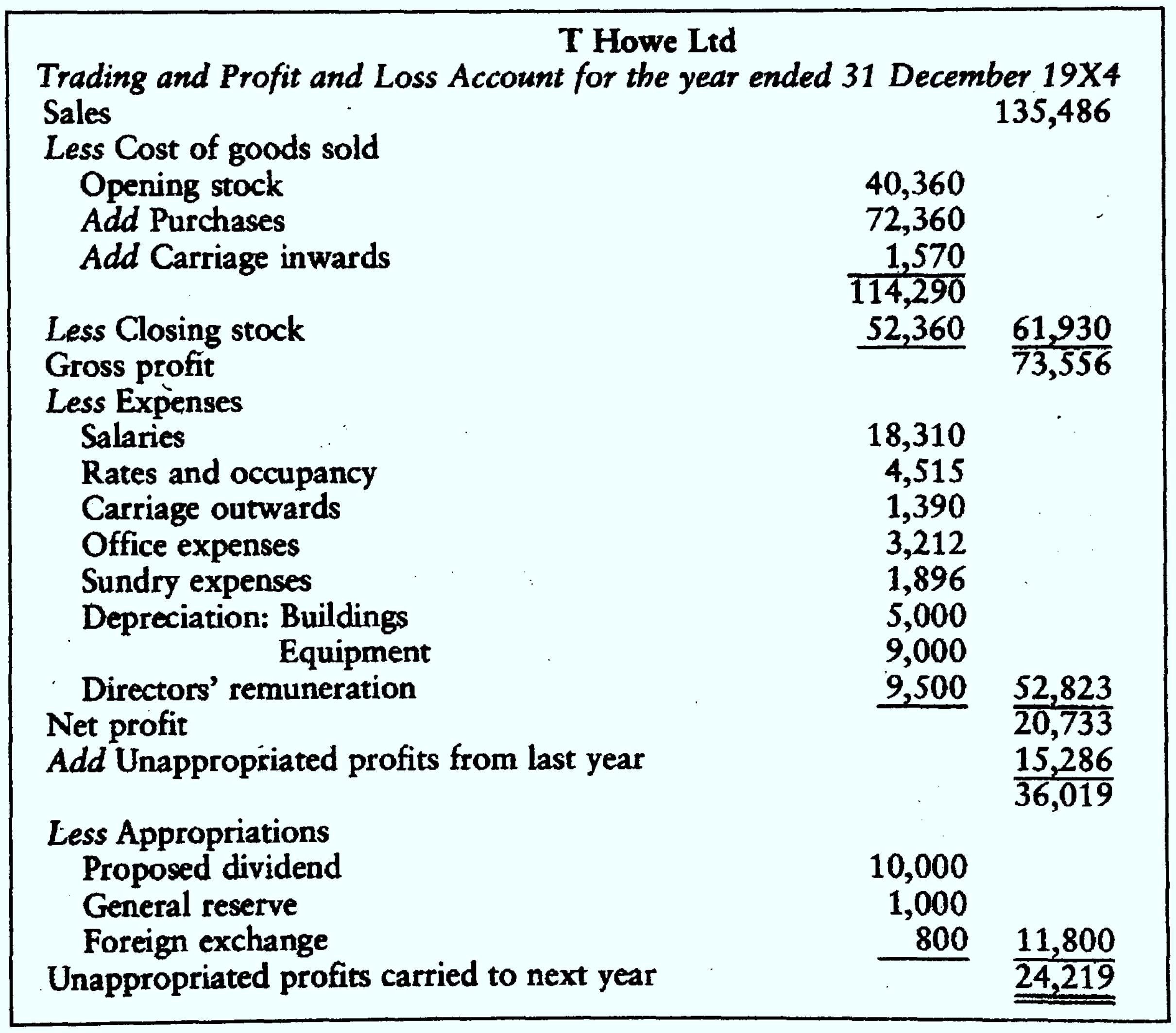
7.4 Application of the Proposed Methodology

In order to illustrate the application of the methodology in practice, three different spreadsheet models are used as examples.

Example 1: ***Trading and Profit and Loss Account for a Particular Year***

In this example, the methodology is applied in the construction of a spreadsheet model comprising a single module (as defined by the methodology). It is based on a *Trading and Profit and Loss Account for a particular year* (Ward-96). The original model is shown in *Figure 7.18.*

This is a simple model which does not require resolution of graph structures, which potentially result in the creation of separate modules, and recursive relationships. Most of the essential concepts and principles of the methodology are demonstrated, except the technique of *modularisation.* Module formation is shown in the second example, based on a *Post-tax Income Distribution Model.*



T Howe Ltd

Trading and Profit and Loss Account for the year ended 31 December 19X4

Sales		135,486
Less Cost of goods sold		
Opening stock	40,360	
Add Purchases	72,360	
Add Carriage inwards	1,570	
	114,290	
Less Closing stock	52,360	61,930
Gross profit		73,556
Less Expenses		
Salaries	18,310	
Rates and occupancy	4,515	
Carriage outwards	1,390	
Office expenses	3,212	
Sundry expenses	1,896	
Depreciation: Buildings	5,000	
Equipment	9,000	
Directors' remuneration	9,500	52,823
Net profit		20,733
Add Unappropriated profits from last year		15,286
		36,019
Less Appropriations		
Proposed dividend	10,000	
General reserve	1,000	
Foreign exchange	800	11,800
Unappropriated profits carried to next year		24,219

Figure 7.18: The Conventional Layout

The application of the proposed methodology in the analysis, design and implementation of this model is presented in detail in *Appendix C: Example 1.*

*Example 2: **Post-tax Income Distribution Model***

In this example, the methodology is applied in the construction of a spreadsheet model composed of multiple modules. In this respect, it is deemed to be a more complicated model than the spreadsheet model used in the first example. It is based on a *Post-tax Income Distribution Model* (Slater-90). The original model is shown in *Figure 7.19 (a)* and an abridged version of the same model in *Figure 7.19 (b)*.

The technique of modularisation, a critical and integral part of the proposed methodology, is demonstrated through this example, in addition to the other features and characteristics of the methodology.

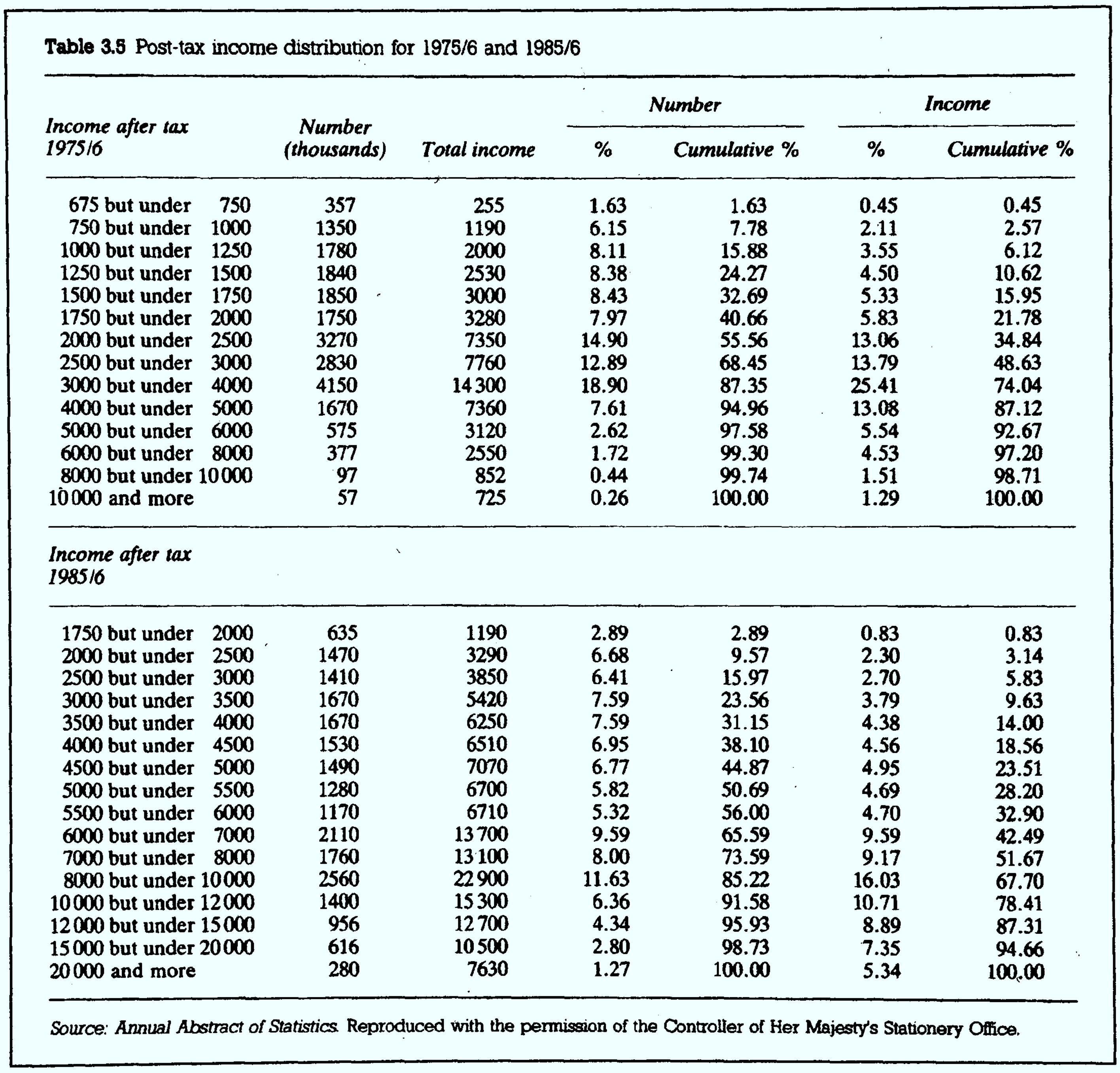


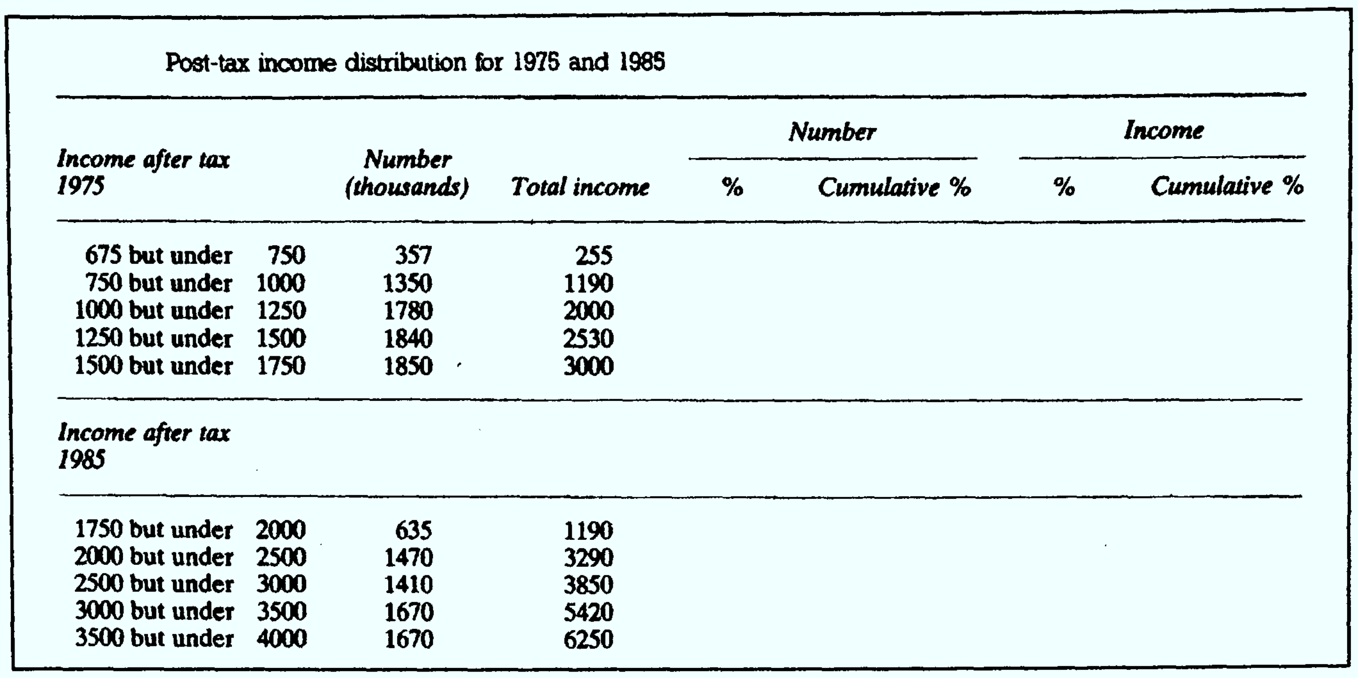
Table 3.5 Post-tax income distribution for 1975/6 and 1985/6

Income after tax 1975/6	*Number (thousands)*	*Total income*	*Number*		*Income*	
			%	*Cumulative %*	*%*	*Cumulative %*
675 but under 750	357	255	1.63	1.63	0.45	0.45
750 but under 1000	1350	1190	6.15	7.78	2.11	2.57
1000 but under 1250	1780	2000	8.11	15.88	3.55	6.12
1250 but under 1500	1840	2530	8.38	24.27	4.50	10.62
1500 but under 1750	1850	3000	8.43	32.69	5.33	15.95
1750 but under 2000	1750	3280	7.97	40.66	5.83	21.78
2000 but under 2500	3270	7350	14.90	55.56	13.06	34.84
2500 but under 3000	2830	7760	12.89	68.45	13.79	48.63
3000 but under 4000	4150	14 300	18.90	87.35	25.41	74.04
4000 but under 5000	1670	7360	7.61	94.96	13.08	87.12
5000 but under 6000	575	3120	2.62	97.58	5.54	92.67
6000 but under 8000	377	2550	1.72	99.30	4.53	97.20
8000 but under 10 000	97	852	0.44	99.74	1.51	98.71
10 000 and more	57	725	0.26	100.00	1.29	100.00
Income after tax 1985/6						
1750 but under 2000	635	1190	2.89	2.89	0.83	0.83
2000 but under 2500	1470	3290	6.68	9.57	2.30	3.14
2500 but under 3000	1410	3850	6.41	15.97	2.70	5.83
3000 but under 3500	1670	5420	7.59	23.56	3.79	9.63
3500 but under 4000	1670	6250	7.59	31.15	4.38	14.00
4000 but under 4500	1530	6510	6.95	38.10	4.56	18.56
4500 but under 5000	1490	7070	6.77	44.87	4.95	23.51
5000 but under 5500	1280	6700	5.82	50.69	4.69	28.20
5500 but under 6000	1170	6710	5.32	56.00	4.70	32.90
6000 but under 7000	2110	13 700	9.59	65.59	9.59	42.49
7000 but under 8000	1760	13 100	8.00	73.59	9.17	51.67
8000 but under 10 000	2560	22 900	11.63	85.22	16.03	67.70
10 000 but under 12 000	1400	15 300	6.36	91.58	10.71	78.41
12 000 but under 15 000	956	12 700	4.34	95.93	8.89	87.31
15 000 but under 20 000	616	10 500	2.80	98.73	7.35	94.66
20 000 and more	280	7630	1.27	100.00	5.34	100.00

Source: Annual Abstract of Statistics. Reproduced with the permission of the Controller of Her Majesty's Stationery Office.

Figure 7.19 (a): The Original Model

As the aim here is to illustrate how the proposed methodology would be applied in the construction of the above model, its data content is reduced for simplicity. We are more concerned about the structure of the model rather than its data. The abridged version of the model is shown in *Figure 7.19 (b)*.



Post-tax income distribution for 1975 and 1985

Income after tax 1975	*Number (thousands)*	*Total income*	*Number*		*Income*	
			%	*Cumulative %*	*%*	*Cumulative %*
675 but under 750	357	255				
750 but under 1000	1350	1190				
1000 but under 1250	1780	2000				
1250 but under 1500	1840	2530				
1500 but under 1750	1850	3000				
Income after tax 1985						
1750 but under 2000	635	1190				
2000 but under 2500	1470	3290				
2500 but under 3000	1410	3850				
3000 but under 3500	1670	5420				
3500 but under 4000	1670	6250				

Figure 7.19 (b): Abridged Version of the Original Model

In *Appendix C: Example 2*, the application of the proposed methodology in the analysis, design and implementation of this model is clearly demonstrated.

7.5 Potential for Quality Improvement

This section discusses the proposed methodology's potential for enhancing the quality of spreadsheet models. There are various features and characteristics within the methodology that contribute to the quality improvement of the models.

The proposed methodology specifies a systematic and disciplined method for analysing, designing and building spreadsheet models, and a standard structure for the models. According to Kee (Kee-88), such an approach forces developers to build their applications within a logical framework. This simplifies spreadsheet construction and enhances reliability.

Without standards and a structured methodology in place, model developers would develop spreadsheets in a wide variety of styles and layouts. Depending on the nature of the models and the competence of the model developer, the models would vary in terms of their comprehensibility, reliability and maintainability. By strictly conforming to the proposed structured methodology, a group of model developers asked to independently construct a spreadsheet model, should, generate models with virtually identical structures. These models would also possess the various desirable attributes of spreadsheet models. This gives scope for peer review at the logical design stage. The fact that there is a standard for logical design (using *Jackson* structures) means that design errors can be spotted much earlier in the process. This is the essence of quality software production. Moreover, the structure diagrams (logical model) also provide certain achievable sub-goals for the development. This also facilitates peer group walkthroughs and review at an early stage in the design, and has a benefit for quality control of the spreadsheet models.

The methodology essentially involves structured analysis of data, based on *Jackson structures*. It is shown that this analysis allows a straightforward modularisation, and that individual modules may be represented with indentation in the *block-structured* form of structured programs. The benefits of this structured format are increased comprehensibility, ease of maintenance, and reduction in errors. The model can be interpreted in an unambiguous way. The methodology also has the capacity to provide a global sense of the structure of a spreadsheet model using Jackson structures.

According to Brown and Gould (Brown-87), formulae are represented in a location that is physically separate from the spreadsheet itself and that the user typically has a "window" onto only one formula at a time. They have stated that an improved interface might make formulae more visible and salient in the interface, and might represent formulae integrated with, rather than separate from, the spreadsheet itself. The proposed methodology caters for these requirements by organising the formula and its operands in a structured manner, and in close proximity. This makes the formulae highly visible in the interface. The inter-relationships between the various formulae could also be easily inferred.

Figure 7.21 (a) shows the spreadsheet model resulting from the application of the proposed methodology based on *Appendix C: Example 1*.

spreadsheet model development. Various methods, tools and techniques are incorporated within the methodology, along with models, notations, rules and design advice.

In the proposed methodology, a diagrammatic representation of the logical design of the spreadsheet model is produced using *Jackson structures*. Other important software engineering principles and techniques have also been applied in the various stages of the methodology. They include *indentation and translation of data structure into structured form, virtual columns, separation of inputs, model schema and outputs*, and *modularisation.*

The proposed structured methodology consists of eight principal stages:

- Requirements Analysis and Development of *Output Structures*
- Conceptual Design of the *Model Schema*
- Logical Design of the *Model Schema*
- Physical Construction of the *Model Schema Layout* on the Spreadsheet
- Development of the *Input Component* and Entry of *Model Inputs*
- Implementation of *Formulae* and *Binding Relationships* in the *Model Schema*
- Implementation of *References* in the *Output Component*
- *Testing*, *Documentation* and *Administration* of the Spreadsheet Model

The application of the methodology is demonstrated using three different examples of spreadsheet models. They are a *Trading and Profit and Loss Account for a Particular Year*, a *Post-tax Income Distribution Model* and a *Trading and Profit and Loss Account for Several Years*.

The proposed methodology has various benefits in terms of quality improvement. It is based on a disciplined and standard approach to spreadsheet model development within a logical framework. The creation of standard model structures facilitates peer review, enabling the early detection of errors. The logic of the model can be easily understood from a clear representation of the dependencies between model elements. The structured format for spreadsheet models produced in the methodology can increase the comprehensibility, maintainability and accuracy of the models.

CHAPTER 8
EVALUATION STRATEGY AND EXPERIMENTS

8.1 Introduction

In order to evaluate the effectiveness of the proposed methodology presented in *Chapter 7*, a series of experiments had to be conducted. An analysis of the results of these experiments is used to assess the methodology's potential for integrity control of spreadsheet models.

This chapter begins by putting forth a plan for the evaluation of the proposed methodology based on experimental trials. The underlying evaluation strategy of the experiments is also discussed. The actual experiments undertaken are subsequently described in detail. At the end of the chapter, a tabulated summary of the experiments, their subjects, and their different aims is presented.

The experiments are aimed at testing the various features of the proposed structured methodology. The series of experiments involve a range of spreadsheet models used in educational institutions and industry. The elements of the methodology are tested on diverse groups of students. Two different strategies are formulated to evaluate the quality of the proposed methodology for spreadsheet model development. Various aspects of the experiments are meticulously studied in planning the experiments.

8.1.1 User Groups or Participants

Ideally, the methodology should be tested on spreadsheet users, of varying levels of spreadsheet literacy, in both business and academia. It has been virtually impossible to obtain consent to conduct trials in business organisations due to various reasons. In some cases, there were rules and policies in place against such experiments, conducted by external individuals or organisations. In others, staff were unwilling to participate in the trials due to the assumption that these experiments would consume considerable time and effort.

Referring to past experiments undertaken, as shown in *Figure 8.1* (Panko-96,98), it has been found that most of the participants of such tests were students at an institution associated with the author(s). In most cases where the subjects were industry or commercial users, the experiment was either conducted by the particular organisation or the information derived from the normal operations of the organisation and published by the company itself.

Study	Sample
Field Audits	
Davies & Ikin (Davies-87)	19 operational spreadsheets
Butler (Butler-92)	273 operational spreadsheets audited by 143 United Kingdom tax inspectors in 1992.
Cragg & King (Cragg-93)	20 operational spreadsheets from 10 firms.
Hicks (Hicks-95)	1 module with 19 submodules about to enter operation.
Coopers & Lybrand (Coopers-97)	23 spreadsheets from industry
KPMG (KPMG-97)	22 spreadsheets from industry
Butler (Butler-00)	7 spreadsheets for tax submissions
Cell Entry Experiments	
Olson & Nilsen (Olsen-87-88)	14 experienced Lotus 1-2-3 users.
Lerch (Lerch-88)	21 professionals with at least one year of Lotus 1-2-3 experience.
Development Experiments	
Brown & Gould (Brown-87)	9 highly experienced spreadsheet developers
Hassinen (Hassinen-88)	92 novice spreadsheet students developed 355 spreadsheets
Hassinen (Hassinen-88)	10 novice students developing 48 spreadsheets
Janvrin & Morrison (Janvrin-96,00)	61 upper division business and graduate accounting students
Janvrin & Morrison (Janvrin-96,00)	88 senior-level accounting students
Panko & Halverson (Panko-97)	35 undergraduate business students working alone
Panko & Halverson (Panko-97)	40 undergraduate business students working in groups of 4
Panko & Sprague (Panko-99)	102 undergraduate business students and 50 MBA students. 17 MBAs had more than 250 hours of experience
Teo & Tan (Teo-97)	168 undergraduate business students taking second-year IS course
(Unpublished)	80 undergraduate business students
Code Inspection Experiments	
Galletta et al (Galletta-93)	30 MBA students and 30 CPA accountants
Galletta et al (Galletta-97)	113 MBA students
Panko & Sprague (Panko-99)	23 undergraduate subjects with errors in initial model.
Panko (Panko-99a)	33 undergraduate MIS majors

Figure 8.1: Studies on Spreadsheet Errors

Based on these findings, it is clear that carrying out tests within academic institutions is the most feasible option. Tests are therefore, planned to be carried out at a London-based University, involving different groups of students. As learnt from previous experiments, an advantage of using students is that we are normally aware of their level of computer/spreadsheet literacy and the experiments can be better controlled.

Three different groups of students have been selected as participants for the proposed experiments. They are as follows:

- Undergraduates
- Post-graduate students
- Students on a short course designed primarily for professionals in industry

8.1.2 Types of Errors

Ideally, the tests should demonstrate the capacity of the proposed structured methodology to address all types of spreadsheet errors. The taxonomy or classification of spreadsheet errors presented in *Chapter 3* is used as a basis for organising tests for as many different types of errors as possible.

8.1.3 Spreadsheet Models

The spreadsheet models selected and used for experimental purposes should be common business and financial models. The models should address the different features of the proposed methodology. Moreover, the models should have the capacity to be used to test for as many different types of errors as possible.

The spreadsheet models selected for the experiments are as follows:

- A *Trading and Profit and Loss Account* for a particular year (Wood-96)
- A *Trading and Profit and Loss Account* for several years
- A *Post-tax Income Distribution Model* (Slater-90)
- A *Balance Sheet* (Read-99)

8.2 The Evaluation Strategies

Two different strategies have been developed to evaluate the quality of the proposed methodology for spreadsheet model development.

8.2.1 Error Prevention

The first strategy for testing the quality of the proposed methodology is based on error prevention. It involves comparing the occurrence of errors in spreadsheet models developed based on the proposed methodology to the occurrence of errors in models built using conventional unstructured methods. The aim of this strategy is to establish whether or not there is a material difference in error rates between spreadsheet models produced using the two different approaches. The hypothesis is that users commit significantly fewer errors by adopting the proposed structured methodology. The first experiment is based on this strategy while the subsequent three experiments are based on a different strategy (error detection).

8.2.2 Error Detection

The second strategy for evaluating the effectiveness of the proposed methodology is based on error detection. It involves comparing the probability of detecting errors in spreadsheet models developed based on the proposed methodology to the probability of detecting errors in models constructed based on conventional unstructured methods.

They were required to systematically organise and perform the appropriate calculations in a worksheet called *SCHEMA*, which was blank. This was their principal task. The calculations were based on the elements in the desired *output*. The *schema* sheet should contain all required data labels (e.g. *Net profit*, *Purchases*, *Salaries*, *Appropriations*, etc.) as well as their associated numeric values, either as an *input* or a *formula*. They were asked to try and present all the calculations within the same structure, so that the relationships between them would be clearer.

In order to carry out some of the calculations, they would require certain inputs. All the inputs required were provided in a worksheet labelled *Input*. This is shown in *Appendix D: Figure D1 (b)*. Participants were allowed to reorganise or restructure the inputs.

Finally, participants of the experiment had to use the results of the calculations to replace the unknown values in the output, denoted by a question mark (?). They were told not to alter the structure of the output as this was assumed to be the output style required by the end-user. The relevant cells were therefore protected against accidental overwriting or alteration.

A total of **42 post-graduate students** and **26 short course students** (most of whom were working in industry) took part in this experiment. Two tests were carried out in *Stage 1*.

Test 1

The *first test* was carried out on a group of **22 post-graduate students**. The students were pursuing a taught masters programmme. Most of them had graduated in other disciplines and had limited prior knowledge of information systems.

This test was split into two sessions. Both sessions involved the same set of participants carrying out the same task(s). Therefore, each participant had to build the same spreadsheet model twice, once in each session. The purpose of having the participants rebuild the same model was so that it can be used as a *control* in the experiment.

Test 2

The *second test* was performed on a group of **12 short course students**. Most of the students were employed on a full-time basis in industry. Each participant had to build the spreadsheet model without having had a lesson on the proposed methodology. Due to time constraint, participants were not asked to rebuild the same model for control purposes. However, in *Stage 2*, the results of this set of participants are compared against the results of another group of short course participants with a similar background.

Stage 2

The *second stage* of the experiment involved the development of the same spreadsheet model based on the *Trading and Profit and Loss Account*. However, before participants engaged in the experiment, they were given a tutorial/lesson on employing the proposed structured methodology for building and structuring a single-module spreadsheet model. During the tutorial, no references were made to elements of the spreadsheet model used in the experiment. Instead, participants were taught the generic algorithm and steps involved. Where deemed necessary, other examples were used. This stage too was composed of two tests.

Test 1

The *first test* was carried out on a different group of **20 post-graduate students**. The students were pursuing the same taught masters programmme. As carried out in *Stage 1*, this test was also divided into two sessions. Both sessions involved the same group of participants but they had to carry out a different set of tasks.

In the *first session*, each participant had to first build the spreadsheet model using a method they were familiar with. This was not based on any structured methodologies and was exactly the same as the experiment in *Stage 1*. None of these participants had however taken part in the previous tests. The purpose of this exercise was to ensure that the errors committed by this group of students were in fact consistent with those produced by the previous group (in *Stage 1*).

In the *second session*, the same group was first given a lesson/tutorial on using the proposed structured methodology to construct a single-module spreadsheet model. They subsequently had to re-construct the spreadsheet model based on the proposed methodology. Ideally, complying with the algorithm, steps and rules of the methodology, they were expected to produce a schema as shown in *Appendix D: Figure D1 (c)*.

Test 2

Test 2 was conducted on a group of **14 short course students**. This was a different group of students but who were pursuing a different offering of the same short course. Moreover, they had a similar background, in that they were also mainly holding professional positions in industry. The participants were asked to create the spreadsheet model, having had a lesson on building spreadsheet models using the proposed methodology. This was similar to *Session 2* of the previous test (*Test 1*).

8.3.2 Experiment 2

This experiment was based on the second evaluation strategy (error detection) and carried out in two stages. A total of **104 undergraduates** took part in this experiment. The students were in two different groups. The first group of 55 students took part in the *first stage* of the experiment while the second group of 49 students participated in the *second stage* of the experiment.

Both groups had to detect and correct a total of 12 errors that had been seeded into a spreadsheet model. They were given the same amount of time to complete the exercise. The model was based on a *Trading and Profit and Loss Account for several years*. However, there was a fundamental difference between the layout or structure of

Stage 2

In the second stage of the experiment, the spreadsheet model was re-designed and re-structured according to the proposed methodology. They same 10 errors were then deliberately seeded into the model. The participants of the experiment at this stage were given a brief and general tutorial/lesson on how to interpret a spreadsheet model based on the proposed methodology without any specific references to the particular model used.

The first test was performed on a different group of **22 post-graduate students** while the second test involved a group of **12 short course students** (on a different offering of the same short course pursued by subjects of *Test 2* in *Stage 1*).

The model given to the students (with the seeded errors) is shown in *Figure 8.6*. The model has been created based on the proposed methodology. However, cell addresses are used in formulae/references instead of meaningful labels, as recommended by the methodology. The input component of the model is displayed in *Appendix D: Figure D5 (a)*. *Appendix D: Figure D5 (b)* shows the spreadsheet model with the errors highlighted while *Appendix D: Figure D5 (c)* contains the formula view of the model. In *Appendix D: Figure D5 (d)*, the correct version of the model is presented.

8.3.4 Experiment 4

This experiment was very similar to the previous experiment (*Experiment 3*). The only difference was that a different spreadsheet model was used. However, this was also a common business model, a *balance sheet* (Read-99). The model was abridged before creating it on a spreadsheet, to make it less time-consuming to work on. The original model is displayed in *Appendix D: Figure D6 (a)* while the abridged version of the model (spreadsheet view) is shown in *Appendix D: Figure D6 (b)*. This is, therefore, the correct, error-free version of the model.

The experiment was carried out in two stages and involved a total of **44 post-graduate students** (pursuing the same course) and **23 short course students** (also on the same short course). Two identical tests were performed in each stage. Each test involved a different subset of students. The task of the 4 different groups of participants was to detect a total of 10 errors that had been seeded into the spreadsheet model. All participants were given the same amount of time to complete the exercise.

Stage 1

In the first stage of the experiment, the spreadsheet model was presented to participants based on the conventional layout. 10 errors had been deliberately seeded into the model. This erroneous model is shown in *Figure 8.7*. For the benefit of students not familiar with the interpretation of balance sheets, a set of relevant formulae was provided. This is shown in *Appendix D: Figure D6 (c)*. In *Appendix D: Figure D6 (d)*, the errors are highlighted and in *Appendix D: Figure D6 (e)*, the formula view of the erroneous model is displayed, with the flaws highlighted.

Two identical tests were carried out on different sets of participants. The first test involved a group of **24 post-graduate students** while the second test was conducted on a group of **12 short course students**.

8.4 Summary

Figure 8.9 provides a tabulated summary of the experiments, their subjects, and their different aims. These are also cross-referred to the research questions specified in *Chapter 1*. *Experiment 1* is different from the other three experiments. Therefore, it has a different aim and tries to address the research questions differently. On the other hand, as *Experiments 2*, *3* and *4* are very similar in nature, they have the same aim and attempt to address the research questions in the same way.

Experiment	**Subjects**	**Aim**	**Research Questions Addressed**
Experiment 1		To determine whether adoption of the proposed structured methodology could result in a significant reduction in the number of errors committed when producing a spreadsheet model, compared to the development of the model using an unstructured or conventional approach.	Primary question: The experiment is used to show whether the proposed structured methodology can reduce the occurrence of user-generated errors when building a spreadsheet model. Secondary question(s): The experiment can be used to assess the feasibility of a software engineering based methodology for building spreadsheet models in a practical situation. The results of the experiment can demonstrate the degree of effectiveness of the framework in spreadsheet model building. The experiment can show if software engineering principles are useful in building a spreadsheet model of a higher quality.
Stage 1			
Test 1			
Session 1	22 post-graduate students		
Session 2	22 post-graduate students		
Test 2	12 short course students		
Stage 2			
Test 1			
Session 1	20 post-graduate students		
Session 2	20 post-graduate students		
Test 2	14 short course students		

continued ...

Experiment	Subjects	Aim	Research Questions Addressed
Experiment 2 Stage 1 Stage 2	 55 under-graduate students 49 under-graduate students	To determine whether significantly more seeded errors can be detected in a spreadsheet model built based on the proposed methodology, compared to a model constructed based on an unstructured or conventional approach.	Primary question: The experiment can be used to assess whether the proposed structured methodology can reduce the occurrence of user-generated errors by enhancing the comprehensibility of spreadsheet models. Secondary question(s): The experiment can show whether a software engineering based methodology can enhance the comprehensibility of spreadsheet models in a practical situation. A comparison of error detection rates can be used to assess the effectiveness of the framework. The experiment can reveal the usefulness of software engineering principles in increasing quality by making spreadsheet models more understandable.
Experiment 3 Stage 1 Test 1 Test 2 Stage 2 Test 1 Test 2	 19 post-graduate students 11 short course students 22 post-graduate students 12 short course students	To determine whether significantly more seeded errors can be detected in a spreadsheet model built based on the proposed methodology, compared to a model constructed based on an unstructured or conventional approach.	Primary question: The experiment can be used to assess whether the proposed structured methodology can reduce the occurrence of user-generated errors by enhancing the comprehensibility of spreadsheet models. Secondary question(s): The experiment can show whether a software engineering based methodology can enhance the comprehensibility of spreadsheet models in a practical situation. A comparison of error detection rates can be used to assess the effectiveness of the framework. The experiment can reveal the usefulness of software engineering principles in increasing quality by making spreadsheet models more understandable.

continued ...

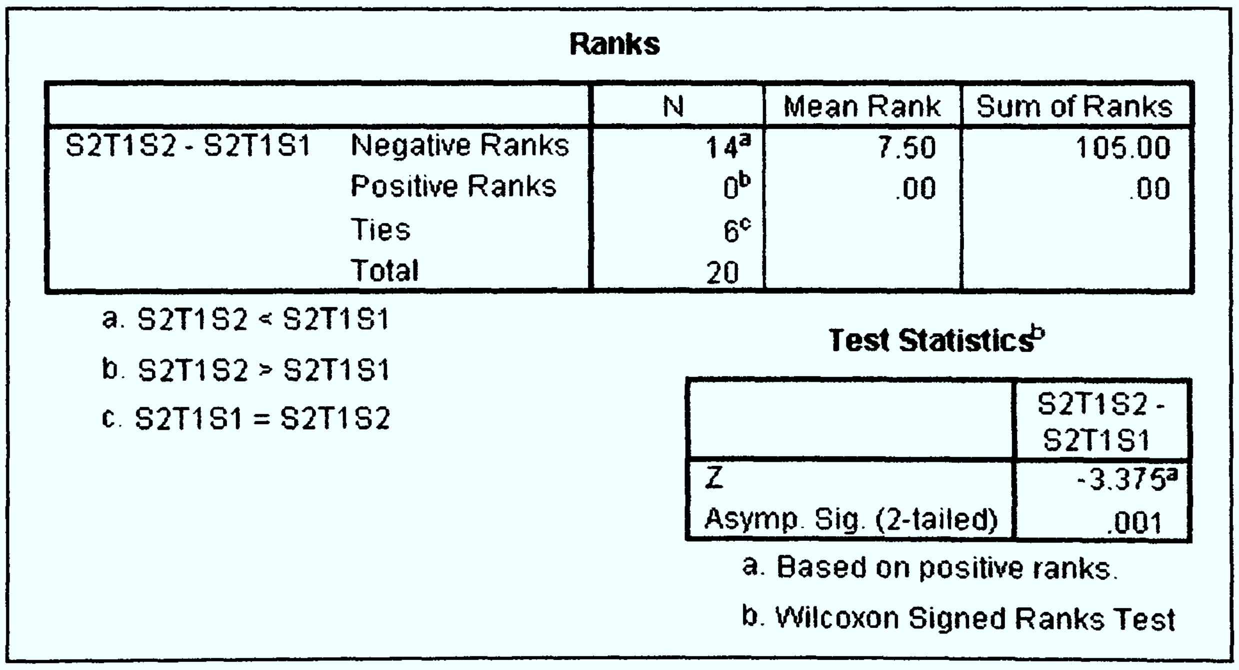
Experiment	Subjects	Aim	Research Questions Addressed
Experiment 4		To determine whether significantly more seeded errors can be detected in a spreadsheet model built based on the proposed methodology, compared to a model constructed based on an unstructured or conventional approach.	Primary question: The experiment can be used to assess whether the proposed structured methodology can reduce the occurrence of user-generated errors by enhancing the comprehensibility of spreadsheet models. Secondary question(s): The experiment can show whether a software engineering based methodology can enhance the comprehensibility of spreadsheet models in a practical situation. A comparison of error detection rates can be used to assess the effectiveness of the framework. The experiment can reveal the usefulness of software engineering principles in increasing quality by making spreadsheet models more understandable.
Stage 1			
Test 1	24 post-graduate students		
Test 2	12 short course students		
Stage 2			
Test 1	20 post-graduate students		
Test 2	11 short course students		

Figure 8.9: Tabulated Summary of Experiments

The purpose of this experiment was to establish whether adoption of the proposed structured methodology could result in a significant reduction in the number of errors committed when producing a spreadsheet model. This is compared against development of the model using an unstructured or conventional approach.

The results of *Test 1* were analysed to test this hypothesis. Firstly, the two sets of correlated dependent samples [**S1 T1 S1** and **S1 T1 S2**] and [**S2 T1 S1** and **S2 T1 S2**] were assessed. In order to find out if subjects performed significantly better in *Session 2* of *Stage 2* using the proposed structured methodology, compared to their performance in *Session 1* of *Stage 2* (using an unstructured approach), a *Wilcoxon Signed Rank Test* was carried out. This is the non-parametric equivalent of a *Paired T-Test*. A *Paired T-Test* could not be done as normality tests showed that the data from **S2 T1 S2** were not normally distributed. The results of the normality tests are shown in *Appendix E*: *Figures E1 (a)* and *E1 (b)*.

The *Wilcoxon Signed Rank Test* revealed that subjects did in fact commit significantly fewer errors in *Session 2* of *Stage 2* where the proposed structured methodology was adopted in creating the spreadsheet model. *Figure 9.2 (a)* shows the results of the test. *Figure 9.2 (b)* shows a plot of the data obtained from **S2 T1 S1** and **S2 T1 S2**. It can be clearly seen that on the whole, subjects in **S2 T1 S2** committed fewer errors compared to subjects in **S2 T1 S1**. The raw data from **S2 T1 S1** and **S2 T1 S2** are presented in *Appendix F*.



Ranks

		N	Mean Rank	Sum of Ranks
S2T1S2 - S2T1S1	Negative Ranks	14[a]	7.50	105.00
	Positive Ranks	0[b]	.00	.00
	Ties	6[c]		
	Total	20		

a. S2T1S2 < S2T1S1

b. S2T1S2 > S2T1S1

c. S2T1S1 = S2T1S2

Test Statistics[b]

	S2T1S2 - S2T1S1
Z	-3.375[a]
Asymp. Sig. (2-tailed)	.001

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

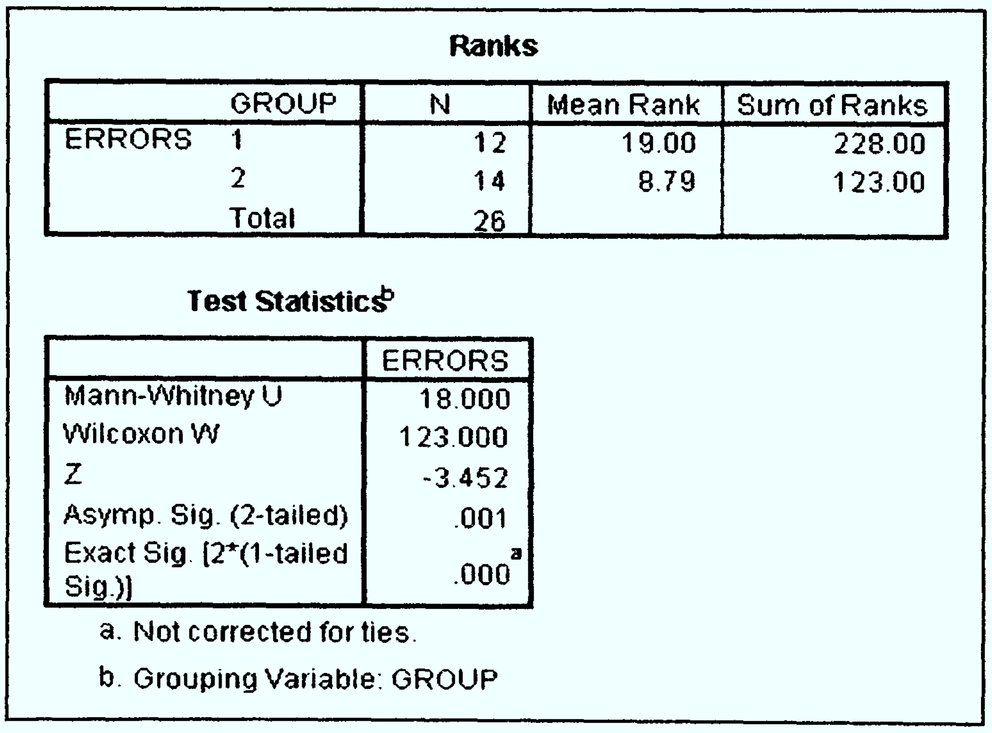
The 1-tailed P-Value (0.0005) is less than 0.01. Therefore, there is a very significant decrease in the number of errors committed in S2 T1 S2.

Figure 9.2 (a): Wilcoxon Signed Rank Test (in *SPSS*)

Finally, the results of *Test 2* were analysed. Test 2 was conducted in two stages. In *Stage 1*, a group of short course students had to build a spreadsheet model without any help or guidance. In *Stage 2*, a different group of short course students were given a tutorial on the proposed methodology prior to the creation of the spreadsheet model.

A non-parametric test for the independent samples had to be performed instead of a *T-Test* as the data from **S2 T2** (Stage 2 - Test 2) was found not to be normally distributed. A normality test, however, showed that the data from **S1 T2** (Stage 1 - Test 2) was in fact normally distributed, although this did not make a difference. The results of the normality tests can be seen in *Appendix E: Figures E1 (e)* and *E1 (f)*.

The *Mann-Whitney U Test* performed provided extremely strong evidence that subjects using the proposed methodology (**S2 T2**) committed significantly fewer errors compared to participants using their own methods and techniques (**S1 T2**). The results of the *Mann-Whitney U Test* are shown in *Figure 9.5 (a)*. *Figure 9.5 (b)* shows a plot of the data obtained from **S1 T2** and **S2 T2**. It can be clearly seen that on the whole, subjects in **S2 T2** committed fewer errors compared to subjects in **S1 T2**. The raw data from **S1 T2** and **S2 T2** are presented in *Appendix F*.



Ranks

	GROUP	N	Mean Rank	Sum of Ranks
ERRORS	1	12	19.00	228.00
	2	14	8.79	123.00
	Total	26		

Test Statistics[b]

	ERRORS
Mann-Whitney U	18.000
Wilcoxon W	123.000
Z	-3.452
Asymp. Sig. (2-tailed)	.001
Exact Sig. [2*(1-tailed Sig.)]	.000[a]

a. Not corrected for ties.

b. Grouping Variable: GROUP

Group 1: S1 T2 **Group 2: S2 T2**

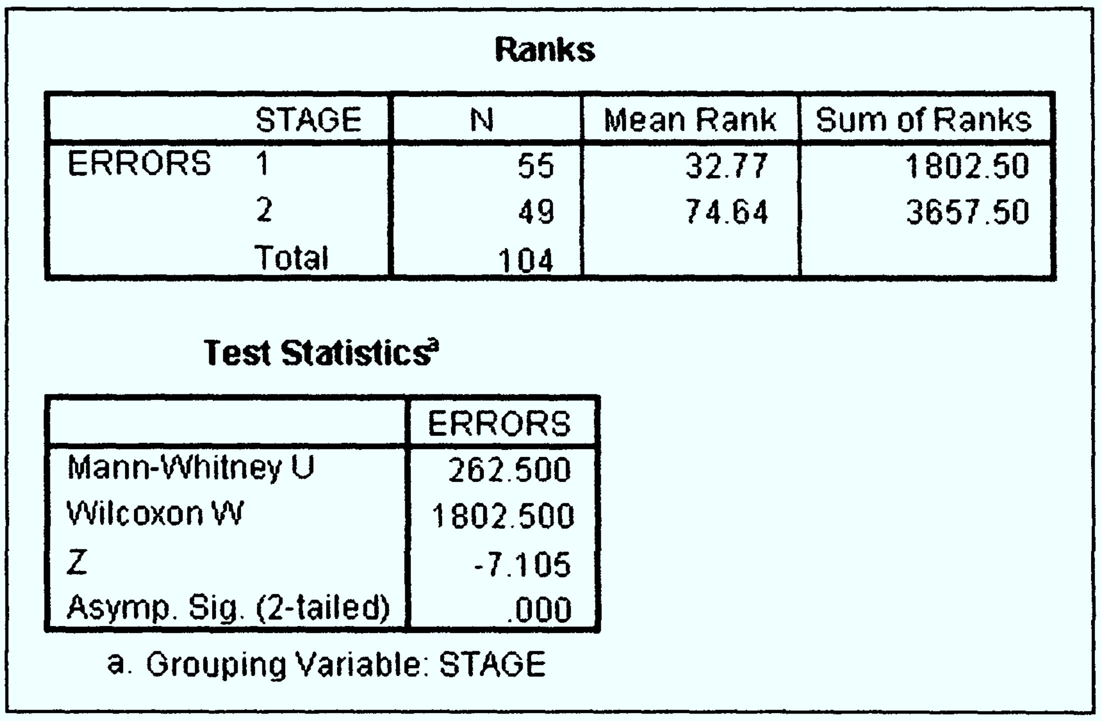
As the 1-tailed P-Value is far less than 0.01, there is evidence of a highly significant reduction in the number of errors made by subjects in S2 T2.

Figure 9.5 (a): Mann-Whitney U test result (in *SPSS*)

Therefore, a *Mann-Whitney U test* for independent samples had to be carried out instead of a *two-sample t-test*. The results of the normality tests are shown in *Appendix E: Figures E2 (a)* and *E2 (b)*.

The non-parametric *Mann-Whitney U* test was carried out on the two independent samples, from *Stage 1* and *Stage 2*, to establish whether subjects participating in the experiment at *Stage 2* were able to detect significantly more errors that had been seeded into the spreadsheet model. The hypothesis was that subjects of the experiment at *Stage 2* would be able to accomplish this due to the fact that the spreadsheet model had been built based on the proposed structured methodology. On the contrary, the model used in *Stage 1* had been constructed based on a conventional, unstructured approach.

The results of the *Mann-Whitney U* test proved the hypothesis by providing very strong evidence that subjects in *Stage 2* had detected significantly more seeded errors compared to subjects in *Stage 1*. This can be regarded as testimony to the increased comprehensibility of the model built based on the proposed methodology. The results of the *Mann-Whitney U* test are displayed in *Figure 9.7 (a)*. *Figure 9.7 (b)* shows a plot of the data obtained from *Stage 1* and *Stage 2*. It can be distinctly seen that on the whole, subjects in *Stage 2* detected more errors compared to subjects in *Stage 1*. The raw data from *Stage 1* and *Stage 2* are given in *Appendix F*.



Ranks

	STAGE	N	Mean Rank	Sum of Ranks
ERRORS	1	55	32.77	1802.50
	2	49	74.64	3657.50
	Total	104		

Test Statistics[a]

	ERRORS
Mann-Whitney U	262.500
Wilcoxon W	1802.500
Z	-7.105
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: STAGE

As the 1-tailed P-Value is far less than 0.01, there is evidence of a highly significant increase in the number of errors detected by subjects in Stage 2.

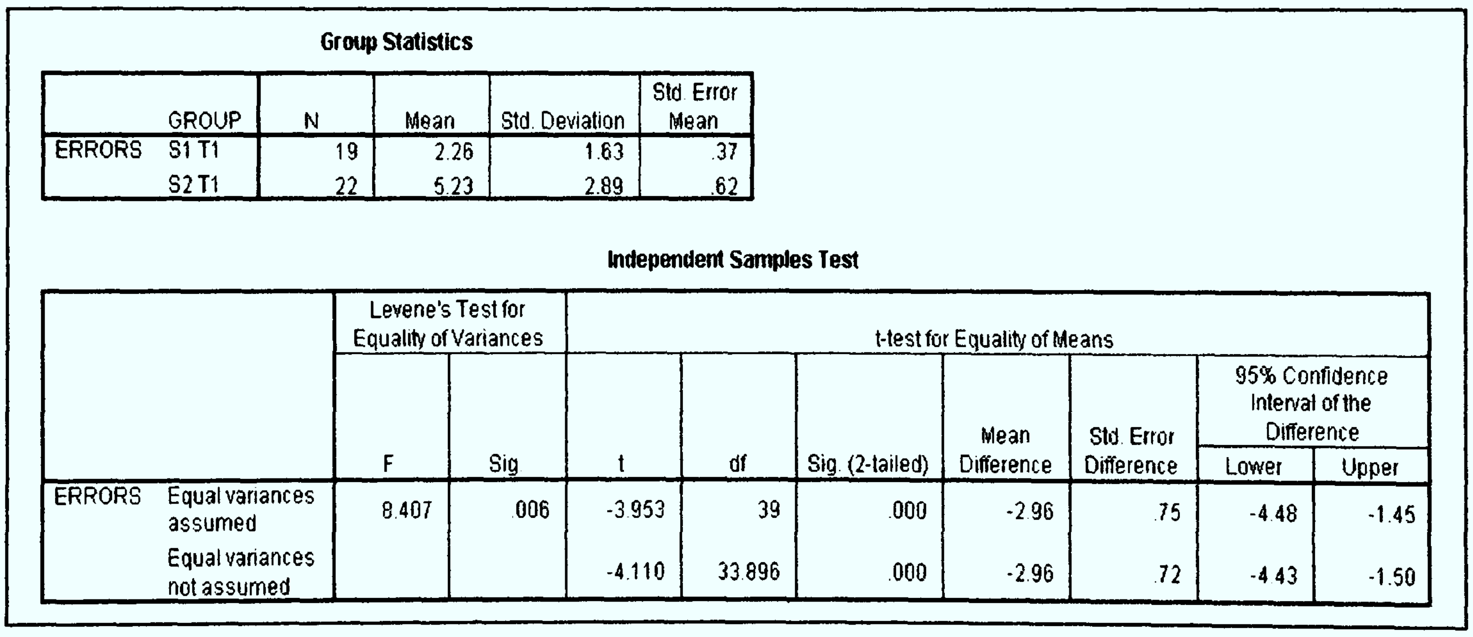
Figure 9.7 (a): Mann-Whitney U Test Result (in *SPSS*)

The following abbreviations are used to refer to the various parts of this experiment:

S1 T1	Stage 1 - Test 1
S1 T2	Stage 1 - Test 2
S2 T1	Stage 2 - Test 1
S2 T2	Stage 2 - Test 2

Normality tests were initially carried out to ascertain whether each sample was from a normal distribution. The normality tests showed that the data from all four samples were indeed normally distributed. Therefore, *Two-Sample T-Tests* could be conducted on the independent samples [**S1 T1** and **S2 T1**] and [**S1 T2** and **S2 T2**]. The results of the normality tests are shown in *Appendix E: Figures E3 (a)*, *E3 (b)*, *E3 (c)* and *E3 (d)*.

Firstly, a *Two-Sample T-Test* was used to analyse the results of *Test 1*. It was carried out on the independent samples **S1 T1** and **S2 T1**. The subjects of the test were post-graduate students. The results of the *T-test*, with equal variances not assumed, distinctly revealed that participants of the experiment in **S2 T1** detected significantly more seeded errors compared to subjects in **S1 T1**. The spreadsheet model used in **S2 T1** had been created based on the proposed methodology. The results can be seen in *Figure 9.9 (a)*. *Figure 9.9 (b)* shows a plot of the data obtained from **S1 T1** and **S2 T1**. It can be clearly seen that on the whole, subjects in **S2 T1** were able to detect more errors compared to subjects in **S1 T1**. The raw data from **S1 T1** and **S2 T1** are presented in *Appendix F*.



Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
ERRORS	S1 T1	19	2.26	1.63	.37
	S2 T1	22	5.23	2.89	.62

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
ERRORS	Equal variances assumed	8.407	.006	-3.953	39	.000	-2.96	.75	-4.48	-1.45
	Equal variances not assumed			-4.110	33.896	.000	-2.96	.72	-4.43	-1.50

The P-Value of the F-test is 0.006. As this is less than 0.05, equal variances are not assumed. The 1-tailed P-Value of the T-test is evidently far less than 0.01. Therefore, there is an extremely significant increase in the number of errors detected by subjects in S2 T1.

Figure 9.9 (a): Two-Sample T-Test (in *SPSS*)

9.3 Summary

The purpose of *Experiment 1* was to determine whether employing the proposed structured methodology could result in a significant reduction in the number of errors committed when producing a spreadsheet model. This inevitably involves a comparison with the development of the model using an unstructured or conventional approach. The principal objective of *Experiments 2*, *3* and *4* was to establish whether spreadsheet models built based on the proposed structured methodology were more comprehensible by evaluating users' capacity to detect seeded errors.

The results obtained from *Experiment 1* have distinctly and consistently demonstrated that there is a drastic decrease in the number of user-generated errors committed by subjects adopting the proposed structured methodology to develop a spreadsheet model. On the contrary, subjects produced significantly more errors when their own methods and techniques were employed. A combination of several appropriate statistical tests and techniques, namely *Normality* tests, the *Wilcoxon Signed Rank* test, a *Paired T-Test* and *Mann-Whitney U* tests, were used to analyse the results of *Experiment 1*. The conclusion that can be drawn from this experiment is that the proposed methodology has the potential to reduce the occurrence of user-generated errors in spreadsheet models.

The results of *Experiments 2*, *3* and *4* proved beyond any doubt that subjects were able to detect considerably more seeded errors in spreadsheet models built based on the proposed structured methodology, in comparison to models created using conventional unstructured or less structured methods. An analysis of the data using techniques such as *Normality* tests, *F-tests*, *Two-Sample T-tests* and *Mann-Whitney U* tests, revealed that all the results were statistically significant. They strongly supported the hypothesis that the error detection rate in models built based on the proposed methodology was considerably higher compared to those constructed using conventional methods. This is clearly due to the fact that models conforming to the proposed methodology facilitate better comprehension.

The results of the series of four experiments conducted provide adequate testimony to the methodology's potential for enhancing the quality, controlling the integrity and improving the comprehensibility of spreadsheet models.

CHAPTER 10
CONCLUSIONS AND FUTURE WORK

10.1 Conclusions

Important contributions have been made in this research programme. The primary question posed in the research is whether a structured methodology can be developed for the integrity control of spreadsheet models and if such a framework can reduce the occurrence of user-generated errors. The most significant contribution of this research programme is a structured methodology for the development and integrity control of spreadsheet models. Through the various experiments conducted and a meticulous analysis of their results, the proposed methodology's potential for integrity control has been demonstrated. The proposed methodology can reduce the occurrence of user-generated errors by ensuring consistency in the spreadsheet model development process and producing more comprehensible, reliable and maintainable models.

It is of utmost importance to gain a thorough insight into the nature and properties of spreadsheet errors in order to development an effective methodology for controlling the integrity of spreadsheet models. A secondary research question concerns the possibility of developing a classification of user-generated spreadsheet errors based on a rational taxonomic scheme. The construction of the proposed methodology was preceded and inspired by a more comprehensive classification of user-generated errors, than presented before, based on systematic taxonomic methods. This is an immensely important by-product of the research and clearly establishes the possibility of developing a comprehensive classification or taxonomy of the different types of user-generated spreadsheet errors based on a rational taxonomic scheme. The provision of this taxonomy offers an extremely important means of comprehending, analysing and comparing the different types of spreadsheet errors.

The next secondary research question asks what framework for spreadsheet model development is most likely to be optimum in a practical situation. A thorough investigation of past work on the phenomenon of spreadsheet errors has revealed an urgent need to adopt a structured and software engineering based methodology as an optimum framework for spreadsheet development in a practical situation. The proposed methodology represents a new approach or paradigm to the provision of such a discipline for the development of spreadsheet models. As explained in Chapter 6 (Section 6.3), at the present time, the structured techniques based on *Jackson structural forms* appear to be the most approachable due to its simplicity in concept, maturity and likely acceptance by spreadsheet users. More sophisticated approaches such as *object-oriented methods* and *entity relationship modelling* might become feasible as the practice develops industrially.

Based on one of the secondary research questions, an investigation is conducted into the possibility of applying software engineering principles to the process of spreadsheet model building to help improve the quality of the models. Structured techniques and software engineering principles form the foundation and backbone to the proposed methodology. The rigorous application of structured methods and established software engineering principles makes this a novel structured methodology for the development and quality control of spreadsheet models. The methodology consists of numerous software engineering based methods and techniques that are effectively applied to the process of spreadsheet model building. The experiments conducted clearly demonstrated that the principles and techniques advocated within the methodology have the potential to improve the quality of spreadsheet models.

In order to answer the secondary research question on how effective the proposed framework is, the various features of the proposed structured methodology are tested on a range of spreadsheet models through a series of experiments. The results of the various experiments performed have distinctly and consistently demonstrated that the proposed methodology has tremendous potential to drastically reduce the incidence of errors and enhance the comprehensibility of spreadsheet models. This provides a very strong testimony to the effectiveness of the proposed structured methodology.

In conclusion, the research programme has established that a structured methodology for the integrity control of spreadsheet models can indeed be produced. The framework, primarily based on software engineering principles, can be applied to the development of spreadsheet models and decrease the occurrence of user-generated errors. This represents a significant contribution of additional knowledge and novel methods to the area of integrity control of spreadsheet models and structured spreadsheet development.

10.2 Future Work

The aim of the research was to create a methodology for improving the quality of spreadsheet models. However, this should not impose considerable extra burden on model developers. To this end, it will be immensely beneficial to build an automatic support tool to assist in the design, structuring and implementation of the spreadsheet model. This will take the form of a CASE (Computer-Aided Software Engineering) tool.

Future work on this project is envisaged on two important issues. The first is to produce an automatic spreadsheet-engineering tool to assist in the production of new spreadsheet models based on the proposed methodology. This tool should encompass both the front-end and back-end phases of the spreadsheet building process. In the front-end, it should offer facilities to produce the conceptual and logical designs in the form of *Jackson structures*. In the back-end stages, the tool should be able to automatically map the logical design onto an implemented model schema. Apart from that, it should also have mechanisms to perform the various update operations without affecting the integrity of the model.

The second issue concerns the re-engineering of existing spreadsheet models built based on conventional or unstructured methods. The tool should have a reverse-engineering function to extract information on structure from existing spreadsheets, and translate these models into structured form, based on the proposed methodology.

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APPENDIX A
FREQUENCY OF SPREADSHEET ERRORS

The information in this table is presented by Panko and Halverson (Panko-96,98,00).

Study	Sample	Study	Cell Error Rate (CER)	% of Models with Errors
Field Audits				
Davies & Ikin (Davies-87)	19 operational spreadsheets	14 had qualitative errors. Methodology unspecified.		21%
Butler (Butler-92)	273 operational spreadsheets audited by 143 United Kingdom tax inspectors in 1992.	Only counted "material" errors. Inspectors used a spreadsheet analysis program designed to identify suspicious parts of a model. Such programs identify only some errors.		10.7%
Cragg & King (Cragg-93)	20 operational spreadsheets from 10 firms.	150 to 10,000 cells. Had been in use for median of 6 months		25%
Hicks (Hicks-95)	1 module with 19 submodules about to enter operation.	Part of a capital budgeting system for NYNEX. Checked heavily ahead of time. Code inspection by three analysts. Found 45 errors in 3,856 cells.	1.2%	100% (1)
Coopers & Lybrand (Coopers-97)	23 spreadsheets from industry	Spreadsheets off by at least 5%		91%
KPMG (KPMG-97)	22 spreadsheets from industry	Spreadsheets containing major errors.		91%
Butler (Butler-00)	7 spreadsheets for tax submissions	Spreadsheets audited with enhanced methodology and software. Single auditor.		86%
Total	367 spreadsheets	Weighted average		24%
Since 1997	54 spreadsheets	Weighted average		91%
Cell Entry Experiments		***Errors counted when made, even if corrected later***		
Olson & Nilsen (Olsen-87-88)	14 experienced Lotus 1-2-3 users.	Filled in formulas in skeleton model. 4 formula cells per person. 56 total.	21% (2)	
Floyd & Pyun (Floyd-87)		Reanalysed Olson & Nilsen (Olsen, 85,87-88) for errors in text cells.	12.5%	
Lerch (Lerch-88)	21 professionals with at least one year of Lotus 1-2-3 experience.	Filled in formulas in template. CER based on formulas only. CER especially high for formulas referring to cells in both different rows and different columns.	11.3% (2)	

continued ...

Study	Sample	Study	Cell Error Rate (CER)	% of Models with Errors
Development Experiments		***Errors counted at end of development process***		
Brown & Gould (Brown-87)	9 highly experienced spreadsheet developers	Developed 3 models apiece. All made an error in at least one model. Minimum definition of errors, excluding the omission of requirements.		44%
Brown & Gould (Brown-87)		Broader definition of errors including the omission of requirements.		63%
Hassinen (Hassinen-88)	92 novice spreadsheet students developed 355 spreadsheets	Paper and pencil exercise. Subjects filled in formulas in a skeleton model containing organization and numbers.	4.3% (2)	55%
Hassinen (Hassinen-88)	10 novice students developing 48 spreadsheets	Computer exercise for same task.		48%
Janvrin & Morrison (Janvrin-96,00)	61 upper division business and graduate accounting students	Study 1: Developed model with multiple worksheets. Had template with filled-in values. Measured incorrect links between worksheets. Model had 51 links. Students had 16 days to do task. Worked an average of 8.8 hours	7%-14% (3)	84%-95%
Janvrin & Morrison (Janvrin-96,00)	88 senior-level accounting students	Study 2: Developed model with multiple worksheets. 66 links between worksheets. No templates to work from; only 1 check figure. CER is percent of incorrect links between spreadsheets.	8%-17% (3)	
Panko & Halverson (Panko-97)	35 undergraduate business students working alone	Developed pro forma income statement based on the Galumpke task.	5.4%	80%
Panko & Halverson (Panko-97)	40 undergraduate business students working in groups of 4	Developed pro forma income statement based on the Galumpke task	2.0%	60%
Panko & Sprague (Panko-99)	102 undergraduate business students and 50 MBA students. 17 MBAs had more than 250 hours of experience	Developed a model based on the Wall task designed to be relatively simple and free of domain knowledge. No difference in errors across groups.	2.0%	35%
Teo & Tan (Teo-97)	168 undergraduate business students taking second-year IS course	Developed a model based on the Wall task, then did a what-if analysis	2.0%	42%
(Unpublished)	80 undergraduate business students	Developed spreadsheet working alone or in triad (group of 3). Error rates for individual, triad.	4.6%, 1.0%	86%, 27%

continued ...

Study	Sample	Study	Cell Error Rate (CER)	% of Models with Errors
Code Inspection Experiments		***Subjects looked for errors in a model***		
Galletta et al (Galletta-93)	30 MBA students and 30 CPA accountants	Examined 6 small model with 1 seeded error in each. Subjects with 250 hours or more of spreadsheet experience did not find more errors than those without experience.	34%-54% (4)	
Galletta et al (Galletta-97)	113 MBA students	Finding eight seeded errors in a student budgeting model.	45%-55% (4)	
Panko & Sprague (Panko-99)	23 undergraduate subjects with errors in initial model.	Study described above. Code inspected own models. Fixed 18% of errors. Only 13% of spreadsheets were fixed completely. One was made worse.	81% (4)	
Panko (Panko-99a)	33 undergraduate MIS majors	Code inspected 11 spreadsheet models, individually and then in groups. Missed errors for individuals, groups.	40%, 17% (4)	

APPENDIX B
SURVEYS ABOUT CORPORATE CONTROL POLICIES

The information in this table is presented by Panko and Halverson (Panko-96).

Study	Method/Sample	Selected Findings
Cale (Cale-94)	52 IS & non-IS managers in 25 firms	Less than 1/10 of companies had written policies on testing spreadsheets; about ¼ had unwritten polices; about 6/10 had no policies. Documentation standards similar. About 70% strongly agreed that lack of testing standards produced serious problems. None disagreed. Reluctant to impose standards if developed by person for own use. More likely as used by others, if updates database, or as size grows. 90% would require testing for development lasting one week; 100% if one month.
Cragg & King (Cragg-93)	FTF interviews with 17, questionnaire survey of 14, N=31.	1/10 said firm had formal policies. 9/10 said no one in firm responsible for SS development.
Floyd, Walls & Marr (Floyd-95)	72 end users in 4 corporations	1/7 had development policies, 2/5 implementation policies; 2/3 development policies. 1/3 required approvals only for important models. Almost all: any policy existing initiated by workgroup. All functions had some policies; modification policies most common. None reported comprehensive standards for all models. None knew of disasters in their firms. Clan-based control policy: socialization.
Galletta & Hufnagel (Galletta-92)	107 MIS executives in mail survey	End user computing, not just spreadsheeting. Restrictions on application development? 23% rule, 58% guideline, 28% don't address; compliance level if address: 27% full compliance, 58% partial compliance; 15% ignore. Post-development audit requirement? 15% rule, 34% guideline, 52% don't address; compliance level if address: 10% full compliance, 49% partial compliance; 41% ignore.
Hall (Hall-96)		Only 11% new of a comprehensive corporate policy; only 1/3 of these could be located it in written form.

continued ...

Study	Method/Sample	Selected Findings
Hendry & Green (Hendry-94)	Ethnographic interviews with 11 SS developers	Modeled after Nardi & Miller (Nardi-91) but added a part in which the interviewer went over a specific SS with the developer. Generally repeated Nardi & Miller, but noted pattern of difficulty in comprehending parts of spreadsheets. Describing efforts to build error-free models by taking specific actions.
Nardi & Miller (Nardi-91)	Ethnographic interviews with 11 SS developers	Extensive joint development mixed programming & domain expertise; sometimes other built difficult parts; other times other checked for reasonableness, gave guidance. Considerable evidence of taking care in development; conscious of errors; spend considerable time debugging. Reasonableness, cross-footings, spot-checking of values, examining formulas. Gave one example of comprehensive code inspection—the subject was taking over a SS developed by another.
Speier & Brown (Speier-96)	Study of 3 departments	Study of overall EUC, not just SS. Interviewed managers of 3 departments in a firm: financial operations, marketing and sales. Questionnaire interviews of 22 end users. Company has few corporate rules beyond backup, which is not enforced. Managers differed in concerns. End users differed by department in awareness of norms and perceptions of benefits. Mostly unwritten norms. Underscores importance of department perspective.

STAGE 2:
Conceptual Design of the Model Schema

Based on the desired outputs of the *Trading and Profit and Loss Model*, shown in *Figure C1*, the model developer would firstly determine the operands of each output formula. This step was performed in the previous stage and therefore does not have to be repeated. The precedent-dependant relationships between the output formulae are then established. As described in *Chapter 5* (*Section 5.2*), if **B** is a precedent of **A**, this is represented by an arrow pointing from **B** to **A**, i.e. **B** → **A**, or **A** ← **B**. The dependencies between the formulae are shown in *Figure C2*.

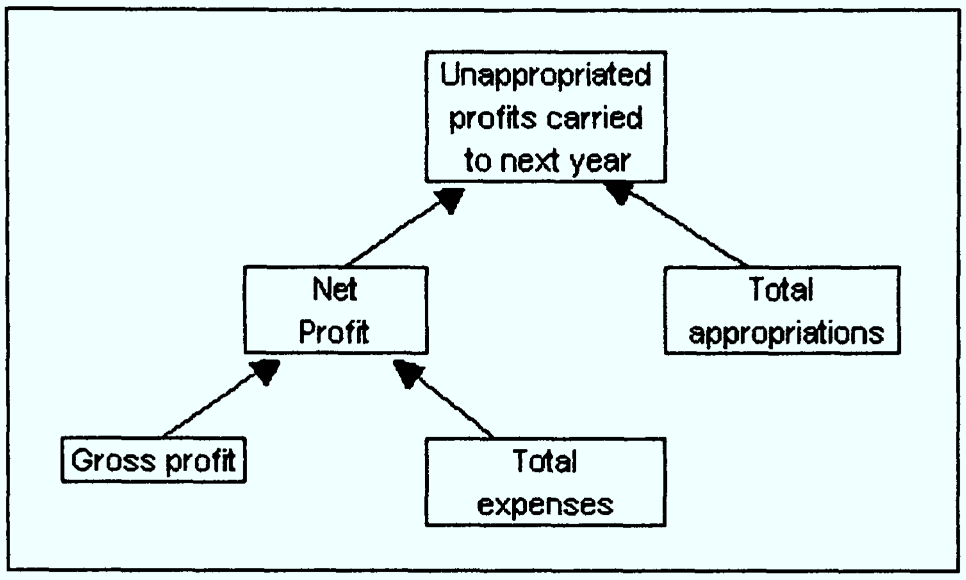

Figure C2: Dependencies Between Formulae

From *Figure C2*, the only root formula is easily identifiable, i.e. *Unappropriated profits carried to next year*. This is because it has no dependants.

The Jackson structure representation of the direct and indirect precedents of the root formula is shown in *Figure C3*. This diagram also represents the conceptual design of the spreadsheet model.

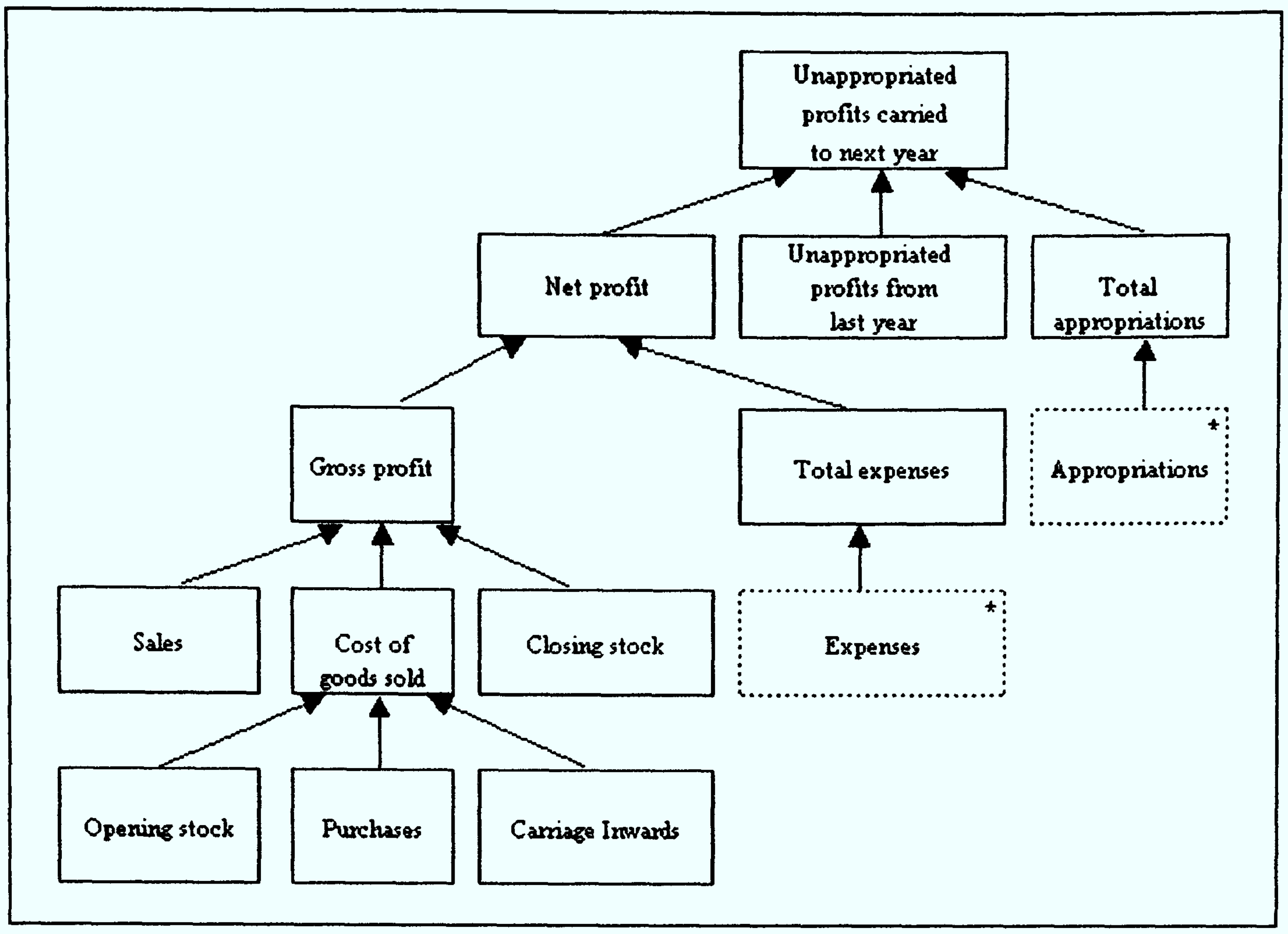

Figure C3: Conceptual Design of the *Model Schema*

This model distinctly shows the precedents of the various functions. The leaves *expenses* and *appropriations* are represented as iterations in *Figure C3*. This is because each of them refers to a group of related inputs, defined as a range. The elements of a range are always operated on or manipulated as a set rather than individually. These iterations also indicate that the contents of the defined set (or input range) can change frequently as a result of data entry operations. It is also assumed that *unappropriated profits from last year* is an input.

STAGE 3:
Logical Design of the Model Schema

Observing the conceptual design of the model, shown in *Figure C3*, it is found that there are no nodes or formulae with multiple dependants. As a result, there are no graph sub-structures within the model that need to be resolved. Therefore, in this particular example, the logical design of the model schema is said to be identical to the conceptual design.

STAGE 4:
Physical Construction of the Model Schema Layout on the Spreadsheet

Applying the steps and techniques associated with this stage, the logical design of the *Trading and Profit and Loss* model shown in *Figure C3* can be mapped onto a physical spreadsheet structure as shown in *Figure C4*. *Indentation* is used to show the different levels within the model. An asterisk (*) is placed next to a row label (in column A) to denote that the formula operates on an *input range*.

Based on *Figures C9 (a)* and *C9 (b)*, the required formulae that can be identified are *number %*, *number cumulative %*, *income %* and *income cumulative %* for each range of each year.

The logical mathematical equations for the formulae are as follows:

- {Number %} = Range number as a percentage of Total number for the year
- {Number cumulative %} = Number cumulative % of previous range + number %
- {Income %} = Total range income as a percentage of Total year income
- {Income cumulative %} = Income cumulative % of previous range + Income %

A formula within curly brackets represents multiple iterations/instances.

STAGE 2: ***Conceptual Design of the Model Schema***

The desired output of the model is shown in *Figure C9 (a)*. Its representation in spreadsheet form is shown in *Figure C9 (b)*.

Based on the desired outputs of the *Post-tax Income Distribution Model*, the operands of each output formula have already been determined. The precedent-dependant relationships between the output formulae are now established. This is shown in *Figure C10*.

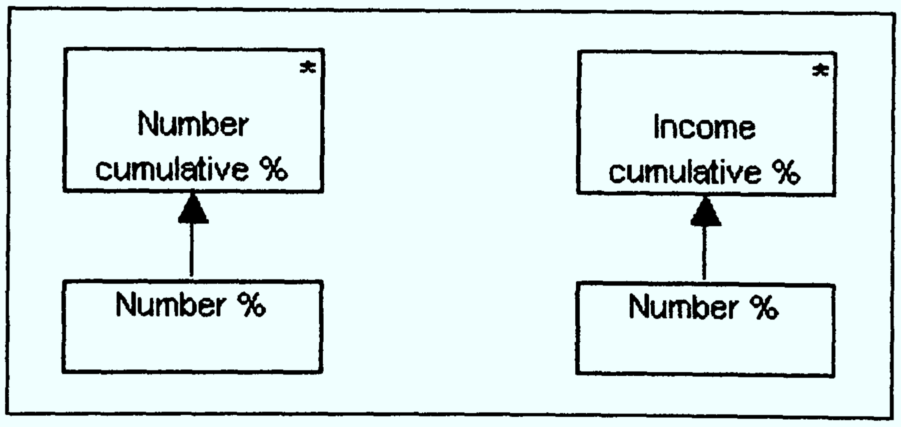

Figure C10: Precedent-Dependant Relationships Between the Output Formulae

From *Figure C10*, it can be observed that there are two sets of root formulae, namely, an *iteration of number cumulative %'s* and an *iteration of income cumulative %'s*. The next step is to use a Jackson structure to represent the direct and indirect precedents of each set of root formulae.

As each root formula is an iterated component, the iteration group(s) of each root formula has to be identified. According to the logic of the model, the *number cumulative %* and *income cumulative %* are to be calculated for each range of each year. This is shown in *Figure C11*.

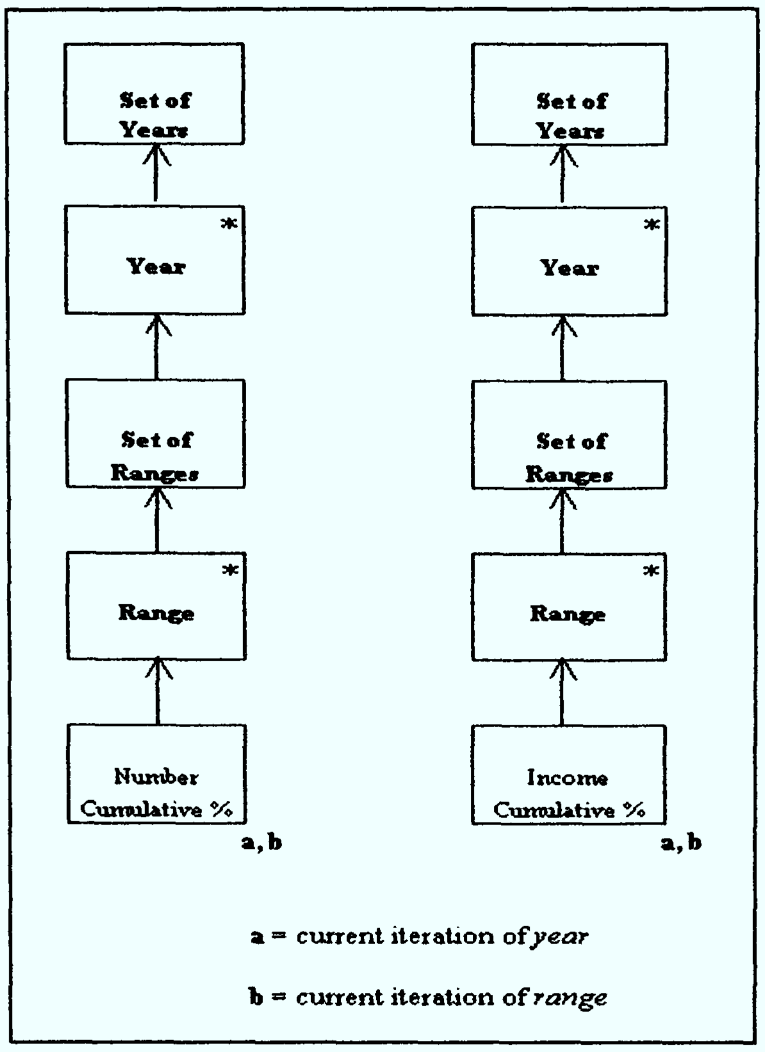

Figure C11: Relationship Between *Iterations*

Each iterated component is associated with an index that is used to indicate which iteration each of its precedents belongs to. The diagram in *Figure C11*, constructed using Jackson notation, represents the conceptual design of the spreadsheet model. The Jackson structures of both sets of root formulae have been merged into a single structure representing the entire spreadsheet model.

Based on *Figure C12*, by adopting a top-down approach without duplicating model elements, a graph-like structure, as opposed to a tree structure, is produced. The model distinctly shows the direct and indirect precedents of each formula (represented by a *node* that is not an *end-leaf*).

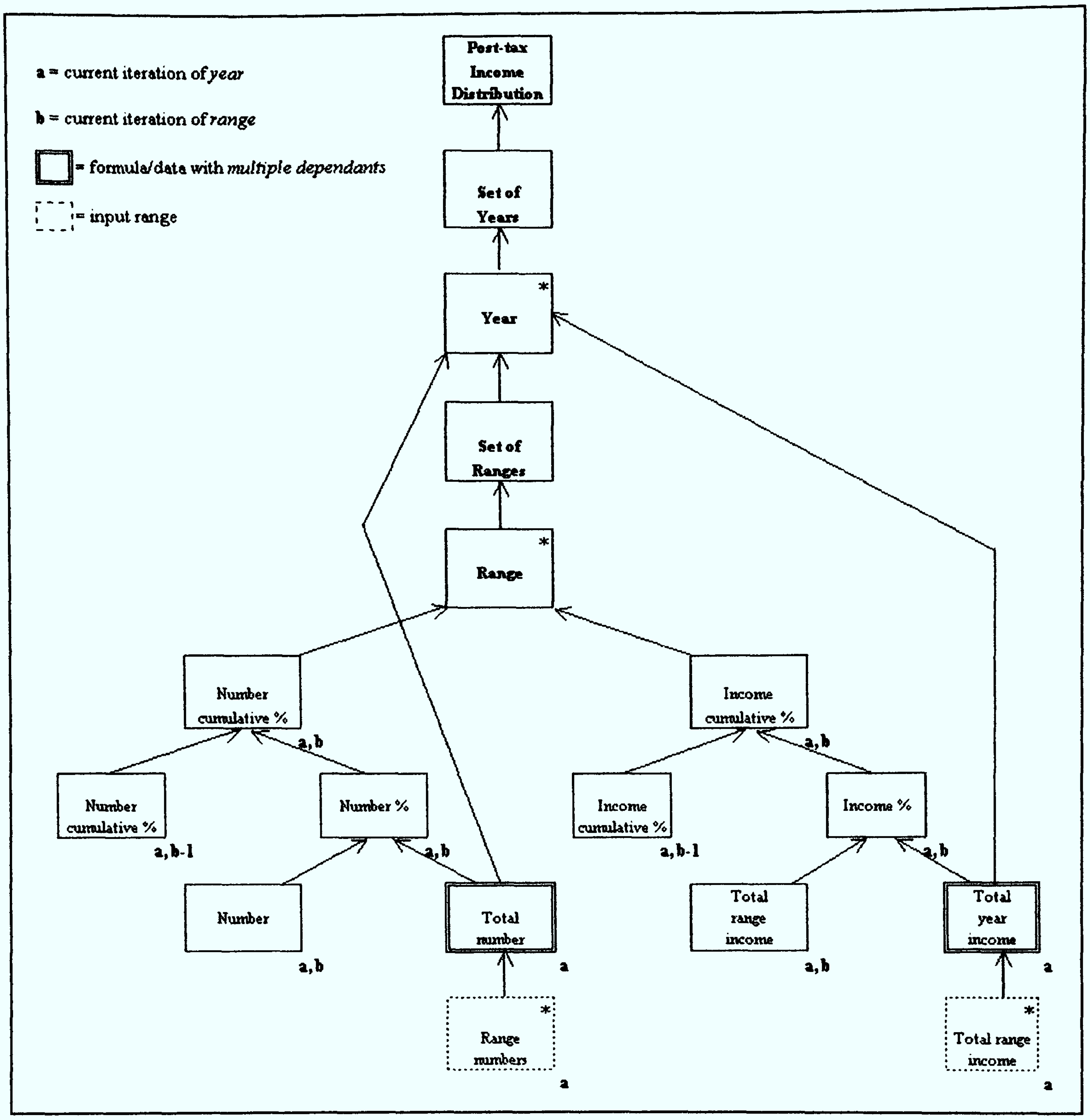

Figure C12: Conceptual Design of the *Post-tax Income Distribution Model*

STAGE 3:
Logical Design of the Model Schema

In *Example 1*, the conceptual design took the form of a tree. Not all spreadsheet conceptual models are of this simple form, but have underlying structures in the form of a more general graph.

Figure C12 shows the conceptual design of the *Post-tax Income Distribution Model*. There are two nodes with multiple dependants, namely, *total number* and *total year income*. Applying *Steps 1* and *2*, the conceptual design is transformed into a logical design of a pure tree structure by resolving the irregularities. The logical design of the model schema is presented in *Figure C13*.

Looking at *Figure C13*, the duplicated nodes *total number* and *total year income* are defined as separate modules.

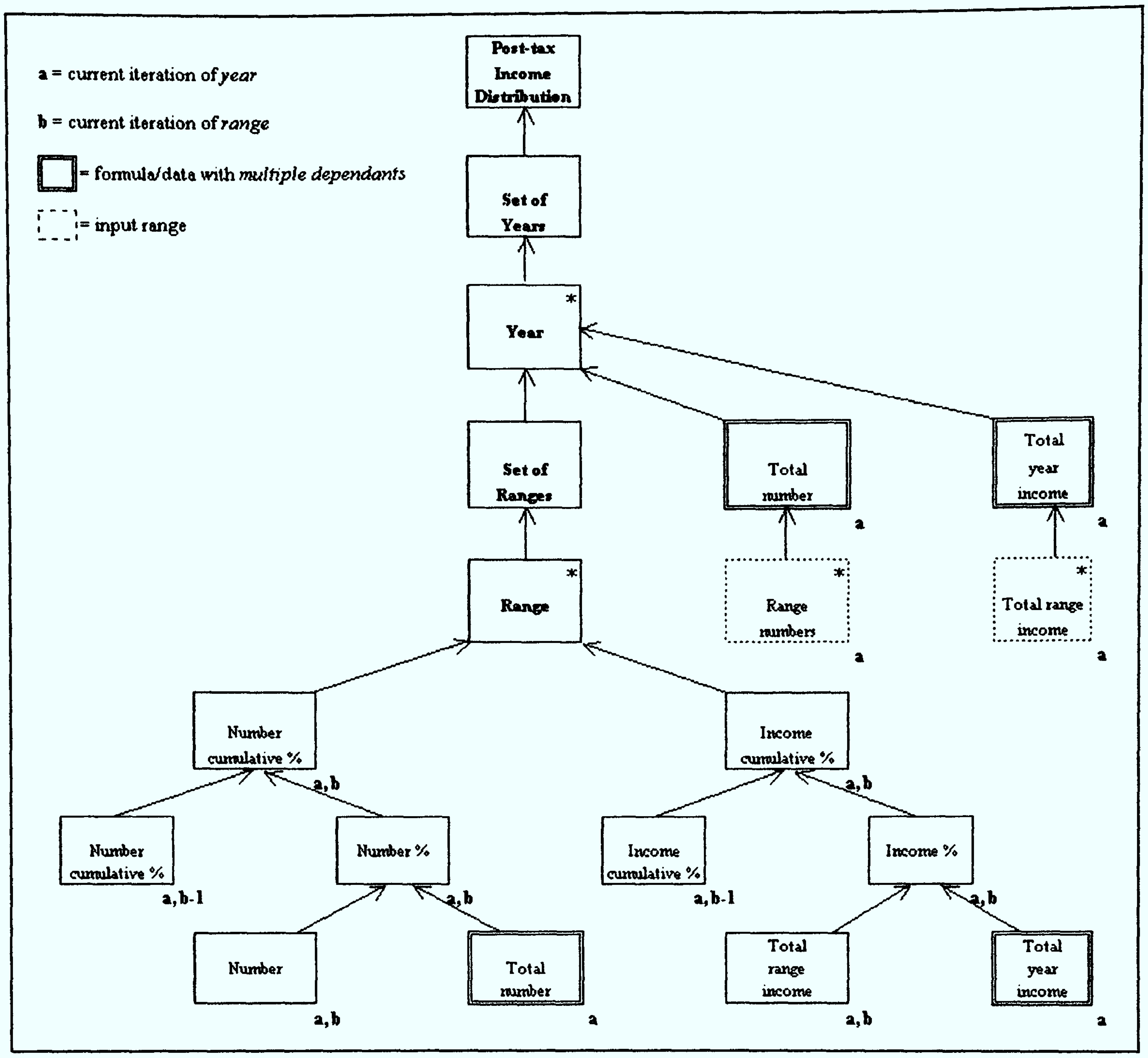

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Figure C13: Logical Design of the Model Schema

STAGE 4: ***Physical Construction of the Model Schema Layout on the Spreadsheet***

The structure or layout of the *model schema* can now be created by mapping the logical model onto the physical spreadsheet according to the rules and steps of this stage. The first column contains module headings and names of iterated components. These are appropriately indented based on the logical design. The second column contains the names of formulae and data used in the spreadsheet model schema, also systematically indented. The resulting structure of the model schema is illustrated in *Figures C14 (a)*, *C14 (b)* and *C14 (c)*.

STAGE 2:
Conceptual Design of the Model Schema

The Jackson structure representation of the conceptual design of the spreadsheet model is displayed in *Figure C19*.

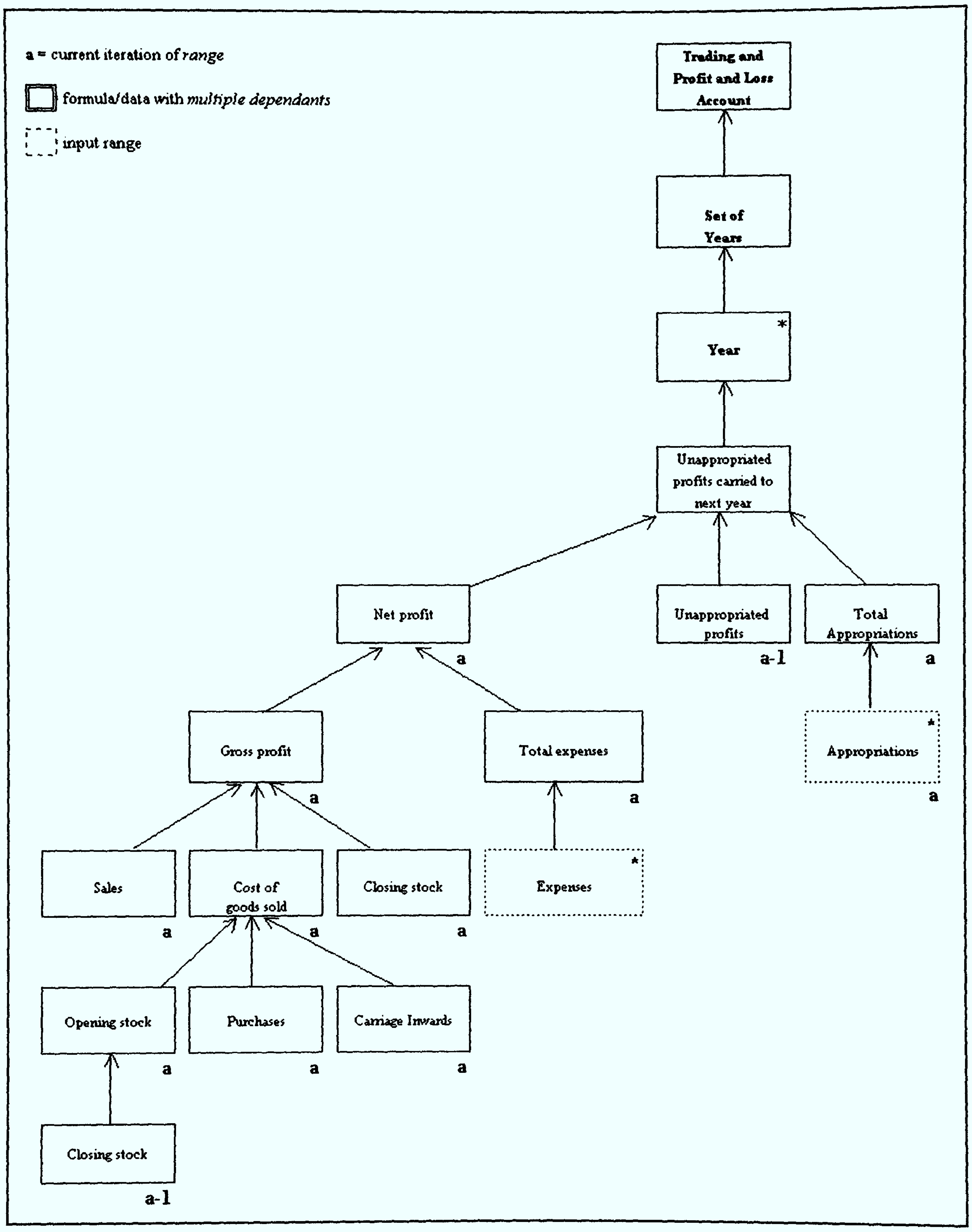
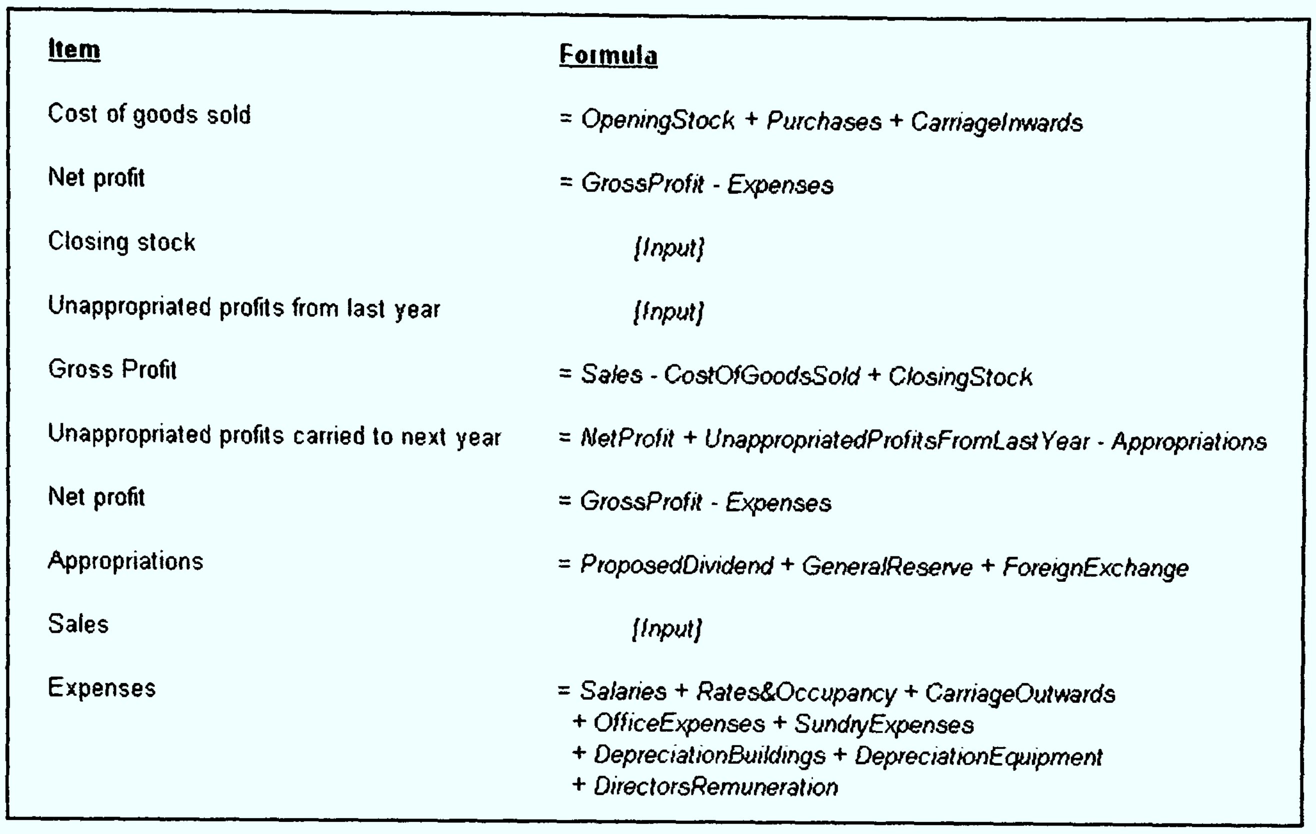


Figure C19: Conceptual Design

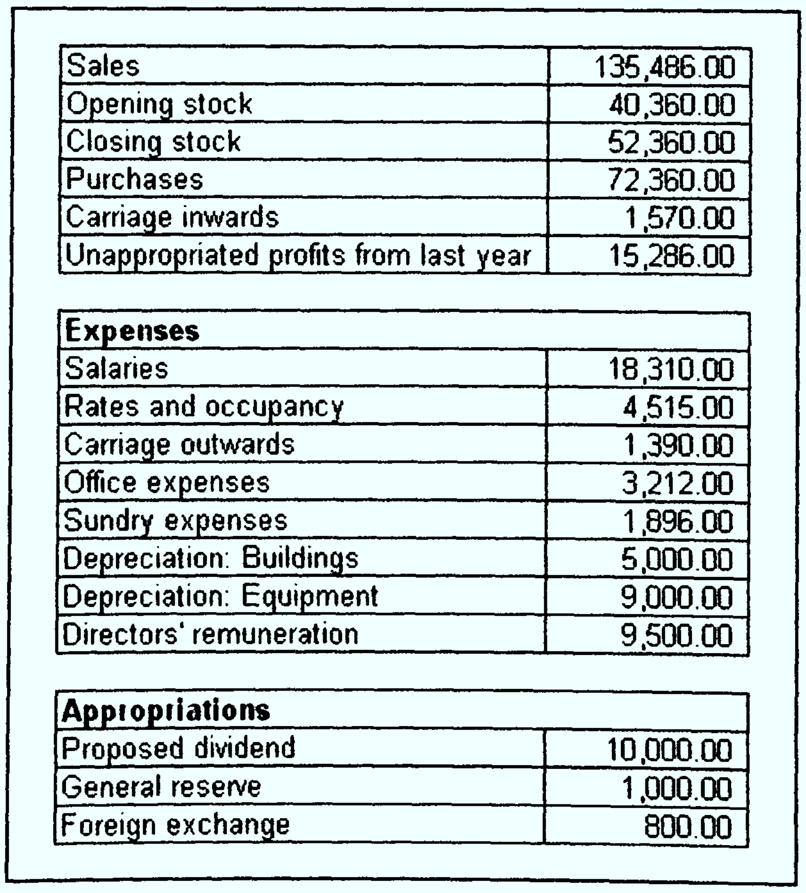
APPENDIX D
SPREADSHEET MODELS USED IN THE EXPERIMENTS

Experiment 1



Item	Formula
Cost of goods sold	*= OpeningStock + Purchases + CarriageInwards*
Net profit	*= GrossProfit - Expenses*
Closing stock	*{Input}*
Unappropriated profits from last year	*{Input}*
Gross Profit	*= Sales - CostOfGoodsSold + ClosingStock*
Unappropriated profits carried to next year	*= NetProfit + UnappropriatedProfitsFromLastYear - Appropriations*
Net profit	*= GrossProfit - Expenses*
Appropriations	*= ProposedDividend + GeneralReserve + ForeignExchange*
Sales	*{Input}*
Expenses	*= Salaries + Rates&Occupancy + CarriageOutwards + OfficeExpenses + SundryExpenses + DepreciationBuildings + DepreciationEquipment + DirectorsRemuneration*

Figure D1 (a): Formulae



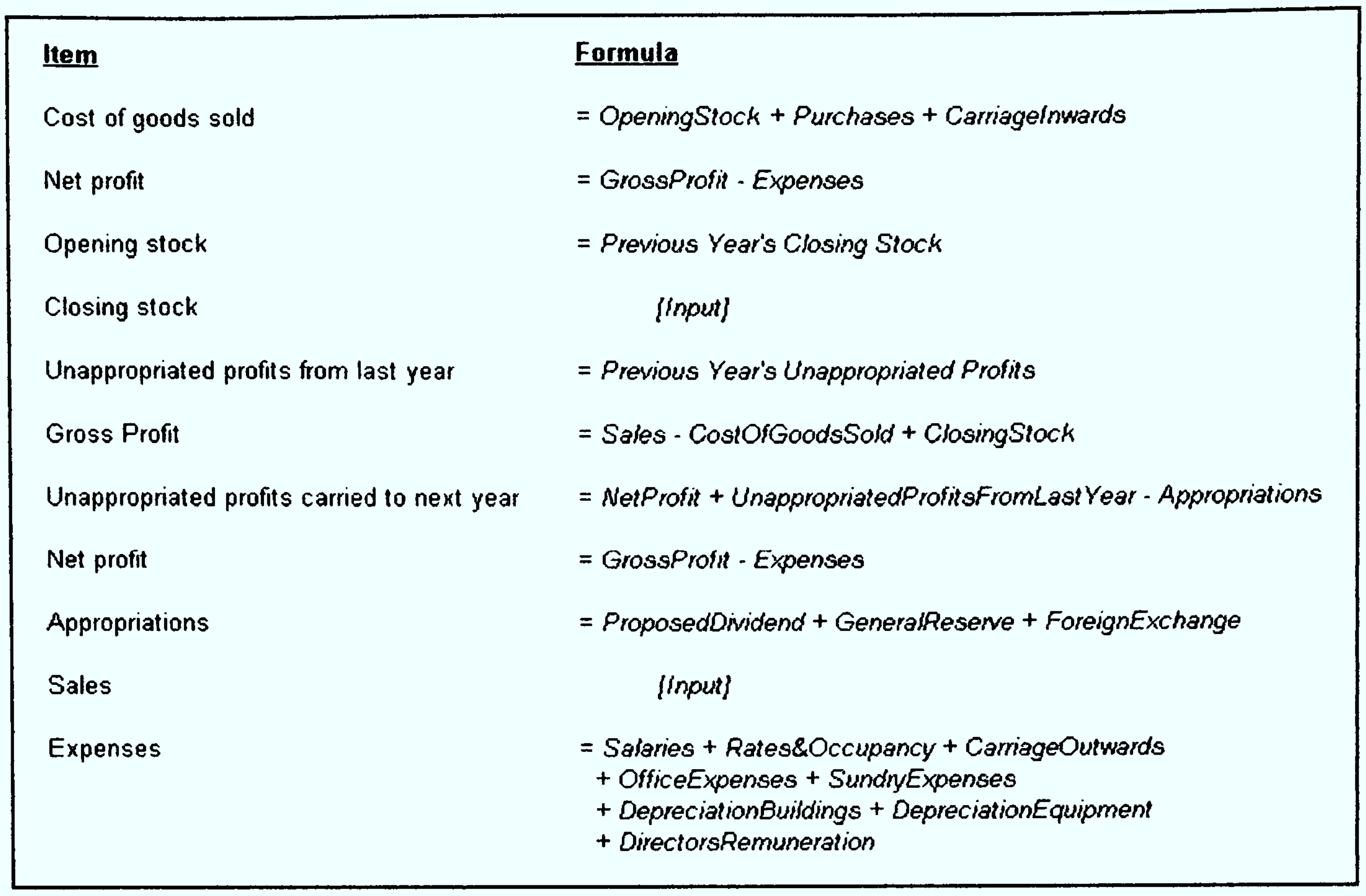
Sales	135,486.00
Opening stock	40,360.00
Closing stock	52,360.00
Purchases	72,360.00
Carriage inwards	1,570.00
Unappropriated profits from last year	15,286.00

Expenses	
Salaries	18,310.00
Rates and occupancy	4,515.00
Carriage outwards	1,390.00
Office expenses	3,212.00
Sundry expenses	1,896.00
Depreciation: Buildings	5,000.00
Depreciation: Equipment	9,000.00
Directors' remuneration	9,500.00

Appropriations	
Proposed dividend	10,000.00
General reserve	1,000.00
Foreign exchange	800.00

Figure D1 (b): Inputs

Experiment 2



Item	Formula
Cost of goods sold	= *OpeningStock + Purchases + CarriageInwards*
Net profit	= *GrossProfit - Expenses*
Opening stock	= *Previous Year's Closing Stock*
Closing stock	*{Input}*
Unappropriated profits from last year	= *Previous Year's Unappropriated Profits*
Gross Profit	= *Sales - CostOfGoodsSold + ClosingStock*
Unappropriated profits carried to next year	= *NetProfit + UnappropriatedProfitsFromLastYear - Appropriations*
Net profit	= *GrossProfit - Expenses*
Appropriations	= *ProposedDividend + GeneralReserve + ForeignExchange*
Sales	*{Input}*
Expenses	= *Salaries + Rates&Occupancy + CarriageOutwards + OfficeExpenses + SundryExpenses + DepreciationBuildings + DepreciationEquipment + DirectorsRemuneration*

Figure D2 (a): Formulae

Experiment 3

Item	**Formula**
Number %	*= (Number ('000) / Total Number ('000)) * 100*
Number Cumulative %	*= Number % + Number Cumulative % of previous range*
Total Number ('000)	*= SUM of Total Number ('000) for each range (within a year)* *= Total Number ('000)* $_{RANGE\ 1}$ *+ Total Number ('000)* $_{RANGE\ 2}$ *+ Total Number ('000)* $_{RANGE\ n}$ *= SUM (Total Number ('000)* $_{RANGE\ 1}$*: Total Number ('000)* $_{RANGE\ n}$*)*
Number ('000) *for each range*	*[Input]*
Income %	*= (Total Range Income / Total Year Income) * 100*
Income Cumulative %	*= Income % + Income Cumulative % of previous range*
Total Year Income	*= SUM of Total Range Income for each range (within a year)* *= Total Range Income* $_{RANGE\ 1}$ *+ Total Range Income* $_{RANGE\ 2}$ *+ Total Range Income* $_{RANGE\ n}$ *= SUM (Total Range Income* $_{RANGE\ 1}$*: Total Range Income* $_{RANGE\ n}$*)*
Total Range Income *for each range*	*[Input]*

Figure D4 (a): Formulae

APPENDIX F
RAW DATA FROM THE EXPERIMENTS

Experiment 1

STAGE 1	**Test 1**	
	Session 1	***Session 2***
	Without lesson	***without lesson***
Subject Type	**post-graduate students**	**post-graduate students**
	Number of Errors Committed	
Subject 1	1	1
Subject 2	4	3
Subject 3	5	4
Subject 4	2	1
Subject 5	0	0
Subject 6	5	5
Subject 7	6	6
Subject 8	4	5
Subject 9	5	5
Subject 10	3	3
Subject 11	4	4
Subject 12	4	4
Subject 13	3	3
Subject 14	2	3
Subject 15	7	7
Subject 16	5	5
Subject 17	2	2
Subject 18	6	4
Subject 19	4	4
Subject 20	6	6
Subject 21	1	2
Subject 22	7	6
Mean	**3.91**	**3.77**
Standard Deviation	**1.97**	**1.82**

STAGE 1	**Test 2**
	without lesson
Subject Type	**short course students**
	Number of Errors Committed
Subject 1	3
Subject 2	2
Subject 3	3
Subject 4	4
Subject 5	5
Subject 6	2
Subject 7	3
Subject 8	4
Subject 9	4
Subject 10	3
Subject 11	5
Subject 12	2
Mean	**3.33**
Standard Deviation	**1.07**

STAGE 2	**Test 1**	
	Session 1	***Session 2***
	without lesson	***with lesson***
Subject Type	**post-graduate students**	**post-graduate students**
	Number of Errors Committed	
Subject 1	3	2
Subject 2	4	1
Subject 3	4	1
Subject 4	3	1
Subject 5	5	2
Subject 6	4	1
Subject 7	4	0
Subject 8	5	1
Subject 9	3	0
Subject 10	2	2
Subject 11	3	3
Subject 12	2	2
Subject 13	3	0
Subject 14	2	2
Subject 15	3	0
Subject 16	4	4
Subject 17	6	3
Subject 18	5	1
Subject 19	4	0
Subject 20	2	2
Mean	**3.55**	**1.40**
Standard Deviation	**1.15**	**1.14**

STAGE 2	**Test 2**
	with lesson
Subject Type	**short course students**
	Number of Errors Committed
Subject 1	0
Subject 2	1
Subject 3	1
Subject 4	2
Subject 5	0
Subject 6	3
Subject 7	2
Subject 8	1
Subject 9	4
Subject 10	0
Subject 11	2
Subject 12	0
Subject 13	0
Subject 14	1
Mean	**1.21**
Standard Deviation	**1.25**

Experiment 2

STAGE 1	*without lesson*
Subject Type	**under-graduate students**
	Number of Errors Detected
Subject 1	4
Subject 2	3
Subject 3	5
Subject 4	2
Subject 5	4
Subject 6	3
Subject 7	4
Subject 8	1
Subject 9	3
Subject 10	2
Subject 11	3
Subject 12	4
Subject 13	5
Subject 14	4
Subject 15	6
Subject 16	10
Subject 17	2
Subject 18	4
Subject 19	3
Subject 20	3
Subject 21	5
Subject 22	1
Subject 23	4
Subject 24	8
Subject 25	4
Subject 26	3
Subject 27	3
Subject 28	5
Subject 29	4
Subject 30	1
Subject 31	4
Subject 32	3
Subject 33	2
Subject 34	5
Subject 35	5
Subject 36	2
Subject 37	4
Subject 38	3
Subject 39	4
Subject 40	5
Subject 41	6
Subject 42	5
Subject 43	3
Subject 44	6

Subject 45	5
Subject 46	3
Subject 47	6
Subject 48	4
Subject 49	0
Subject 50	5
Subject 51	6
Subject 52	3
Subject 53	4
Subject 54	7
Subject 55	2
Mean	**3.91**
Standard Deviation	**1.78**

STAGE 2	***Without lesson***
Subject Type	**under-graduate students**
	Number of Errors Detected
Subject 1	10
Subject 2	9
Subject 3	6
Subject 4	12
Subject 5	11
Subject 6	8
Subject 7	1
Subject 8	8
Subject 9	10
Subject 10	0
Subject 11	4
Subject 12	10
Subject 13	9
Subject 14	12
Subject 15	7
Subject 16	11
Subject 17	9
Subject 18	10
Subject 19	9
Subject 20	7
Subject 21	10
Subject 22	9
Subject 23	8
Subject 24	12
Subject 25	3
Subject 26	11
Subject 27	11
Subject 28	9
Subject 29	7
Subject 30	9
Subject 31	10

Subject 32	8
Subject 33	9
Subject 34	11
Subject 35	9
Subject 36	10
Subject 37	3
Subject 38	10
Subject 39	9
Subject 40	12
Subject 41	9
Subject 42	7
Subject 43	10
Subject 44	5
Subject 45	11
Subject 46	9
Subject 47	9
Subject 48	8
Subject 49	11
Mean	**8.61**
Standard Deviation	**2.71**

Experiment 3

STAGE 1	Test 1
	without lesson
Subject Type	post-graduate students
	Number of Errors Detected
Subject 1	2
Subject 2	4
Subject 3	2
Subject 4	1
Subject 5	3
Subject 6	0
Subject 7	3
Subject 8	4
Subject 9	2
Subject 10	6
Subject 11	1
Subject 12	3
Subject 13	5
Subject 14	0
Subject 15	1
Subject 16	1
Subject 17	2
Subject 18	1
Subject 19	2
Mean	**2.26**
Standard Deviation	**1.63**

STAGE 1	Test 2
	without lesson
Subject Type	short course students
	Number of Errors Detected
Subject 1	3
Subject 2	3
Subject 3	0
Subject 4	1
Subject 5	2
Subject 6	5
Subject 7	1
Subject 8	0
Subject 9	4
Subject 10	3
Subject 11	4
Mean	**2.36**
Standard Deviation	**1.69**

STAGE 2	Test 1
	with lesson
Subject Type	post-graduate students
	Number of Errors Detected
Subject 1	8
Subject 2	2
Subject 3	2
Subject 4	9
Subject 5	3
Subject 6	1
Subject 7	8
Subject 8	10
Subject 9	6
Subject 10	5
Subject 11	1
Subject 12	6
Subject 13	4
Subject 14	5
Subject 15	6
Subject 16	9
Subject 17	4
Subject 18	7
Subject 19	2
Subject 20	4
Subject 21	3
Subject 22	10
Mean	**5.23**
Standard Deviation	**2.89**

STAGE 2	Test 2
	with lesson
Subject Type	short course students
	Number of Errors Detected
Subject 1	7
Subject 2	9
Subject 3	4
Subject 4	4
Subject 5	8
Subject 6	9
Subject 7	6
Subject 8	1
Subject 9	6
Subject 10	7
Subject 11	3
Subject 12	6
Mean	**5.83**
Standard Deviation	**2.44**

Experiment 4

STAGE 1	**Test 1**
	without lesson
Subject Type	**post-graduate students**
	Number of Errors Detected
Subject 1	7
Subject 2	4
Subject 3	1
Subject 4	3
Subject 5	4
Subject 6	8
Subject 7	5
Subject 8	4
Subject 9	7
Subject 10	4
Subject 11	3
Subject 12	6
Subject 13	5
Subject 14	7
Subject 15	5
Subject 16	3
Subject 17	5
Subject 18	4
Subject 19	4
Subject 20	7
Subject 21	0
Subject 22	2
Subject 23	5
Subject 24	3
Mean	**4.42**
Standard Deviation	**1.98**

STAGE 1	Test 2
	without lesson
Subject Type	**short course students**
	Number of Errors Detected
Subject 1	2
Subject 2	4
Subject 3	0
Subject 4	5
Subject 5	5
Subject 6	1
Subject 7	8
Subject 8	3
Subject 9	2
Subject 10	4
Subject 11	3
Subject 12	7
Mean	**3.67**
Standard Deviation	**2.35**

STAGE 2	Test 1
	with lesson
Subject Type	**post-graduate students**
	Number of Errors Detected
Subject 1	8
Subject 2	5
Subject 3	9
Subject 4	4
Subject 5	2
Subject 6	6
Subject 7	7
Subject 8	5
Subject 9	10
Subject 10	6
Subject 11	9
Subject 12	7
Subject 13	4
Subject 14	8
Subject 15	5
Subject 16	10
Subject 17	7
Subject 18	9
Subject 19	10
Subject 20	4
Mean	**6.75**
Standard Deviation	**2.36**

STAGE 2	**Test 2**
	with lesson
Subject Type	**short course students**
	Number of Errors Detected
Subject 1	8
Subject 2	7
Subject 3	9
Subject 4	10
Subject 5	3
Subject 6	6
Subject 7	8
Subject 8	10
Subject 9	7
Subject 10	9
Subject 11	9
Mean	**7.82**
Standard Deviation	**2.04**