APPLYING QUALITATIVE REASONING TO FINANCE

WOON Mei Yen, Irene

Doctor of Philosophy

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Qualitative reasoning has traditionally been applied in the domain of physical systems, where there are well established and understood laws governing the behaviour of each 'component' in the system. Such application has shown that it is possible to produce models which can be used for explaining and predicting the behaviour of physical phenomena and also trouble-shooting. The principles underlying the theory ensure that the models are robust and exhibit consistent behaviour under all conditions.

This research examines the validity of applying the theory in the financial domain where such laws may not exist or if they do, may not be universally applicable. In particular, it investigates how far these principles and techniques may be applied in the construction of financial analysis models. Because of the inherent differences in the nature of these two domains, it is argued that a different qualitative value system ought to be employed. The dissertation enlarges on the constraints this places on model descriptions and the effect it may have on the power and usefulness of the resulting models. It also describes the implementation of a system that investigates the implications of applying this theory by way of testing it on situations drawn from both text-books and published financial information.

Keywords: Qualitative Reasoning, Qualitative Models in Finance, Ambiguity.

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1 Introduction

In the beginning, there were rule-based expert systems; knowledge was represented in the form of production rules and the inference engine operated as a simple mechanism. This approach worked fine for simple problems, typically for diagnostic systems that have their knowledge in the form: observations → hypothesis. However, when these problem specifications became more complex and did not quite fit into the standard mould, all manner of inadequacies were revealed. Prominent among these are the inability to cope with anything less than complete information, the inability to represent and exploit causal relations and the inability to solve simpler problems than those they were designed for. This sparked off the search for *the* alternative answer.

1.1 What is Qualitative Reasoning?

At present, the most hopeful line of research seems to be that broadly known as qualitative reasoning (also variously referred to as deep reasoning, causal modelling, naive physics and qualitative physics). The pioneers of this particular approach are researchers like McCarthy (in Hobbs & Moore 1985) and Hayes (1985) who believe that the answer to building truly intelligent programs lies in capturing and modelling the kind of knowledge that an ordinary person would use in everyday living; what they refer to as 'commonsense theories'. Since this knowledge is viewed from a perspective different to a scientist's, it would be more informal and intuitive. A new theory to accomplish this is necessary since current theories and models have been developed solely through the efforts of academicians and scientists. This is the theory of qualitative reasoning.

Qualitative reasoning systems model a particular domain by incorporating fundamental knowledge about the structure of the domain and its functions. The resulting model, termed a qualitative model, is derived by taking a step back from the details provided by the quantitative model; the real-number values used by the quantitative model to describe its parameters are reduced to qualitative values by mapping the real-number continuum into disjoint, abutting intervals. This mapping produces a new representation that is more convenient to use, especially in situations where the information is inherently qualitative, imprecise or incomplete. More significantly, a qualitative model is able to describe the underlying mechanisms relating cause and effect, which endows it not only with the ability to generate causal explanations so useful to interpretation, trouble-shooting and prediction tasks, but also with the ability to perform these tasks in novel situations. Qualitative models have been built in several application areas including engineering, electronics, medicine and more recently, economics.

1.2 Research Motivation and Objectives

There are always rich financial rewards for anyone capable of developing systems that can capture the minds and imagination of the business and financial community. The latest computer technology that has been offered to this very conservative fraternity is artificial intelligence and in particular, expert systems. According to a report to the Department of Trade and Industry in the UK (Ovum Ltd 1988), the response has been encouraging, albeit not at levels of activity sustained by firms in the U.S.A. Since commercial firms have demonstrated that they are aware of the advantages to be gained from using 'intelligent' systems, it would be logical to conclude that they will respond favourably to systems that promise to overcome the inadequacies of these existing systems. By far the most popular paradigm has been rule-based expert systems. These systems however have known limitations, some of which have just been mentioned. One of the research motivations then is to build systems that represent an advancement on existing systems.

The kind of human reasoning used in financial analysis is similar to that which is used in reasoning about physical models. Since it appears that it is possible to construct qualitative physical models, it should also be possible to construct qualitative models for the financial domain. The feasibility of qualitative financial models is also strongly supported by the fact that a substantial portion of basic textbook descriptions of company operations are qualitative in nature (Solomon & Pringle 1977, Van Horne 1983).

The main objectives for constructing physical models using the qualitative reasoning approach are:

1. to build models that are robust which means that such models are able to predict behaviour in a novel situation correctly.

2. to build models that can generate adequate causal explanations.

These objectives are powerful motives for attempting to construct qualitative models for finance. Consider that fundamental to decision-making within the financial environment is the ability to cope and manage changing contexts, for example, changes in legal regulations, in competition and in the behaviour of consumers etc. A qualitative financial model which is robust enough to support the changing and ever-evolving structure of the domain, will therefore be an invaluable aid to decision-making. The less esoteric objective of constructing models that can generate causal explanation pin-points one of the major drawbacks of current financial models, namely, the question of interpretation. If qualitative models can identify basic cause-effect relationships, it should also be possible for it to analyse alternative courses of action and select those which are appropriate to meet a given set of company goals. Thus, it may be said that the main objectives that qualitative physical models seek to fulfil are also precisely those which financial modellers hope to achieve but have failed so far to do so.

This research study therefore set out to fulfil the following objectives:

1. To evaluate the flexibility and power of qualitative models. This is necessary to establish and confirm the basis for constructing qualitative financial models.

2. To investigate the feasibility of constructing qualitative models in the financial domain. This phase will proceed only if there are grounds to believe that qualitative models can fulfil their promise.

3. To define the principles and methodology for the construction of such qualitative models. This phase will also only proceed if it is possible to construct qualitative financial models since the scope of this investigation attempts to define how systematic such an activity can be.

The research does not debate the philosophical issues underlying the development of particular qualitative reasoning approaches. The style of approach taken is purely pragmatic; the questions asked are: is a particular concept useful?, and if so, how can it be used?, and if not, can it be modified so that it may be useful? Thus, the investigation intends to build on an existing body of work, by investigating its possible application to a more complex domain.

1.3 Preamble to Dissertation

The substance of the dissertation begins with Chapter 2 which gives a quick tutorial in finance, covering various aspects most relevant to the research study: financial theory which allows the reader to assess its complexity and maturity in relation to theories in physics and engineering, and the role of the analyst which serves to illustrate the kind of reasoning and the types of data used in the financial domain thus permitting the reader to make fair comparisons against those used in the physical domain. Finally, an overview of the variety of models used in the domain area is presented, which provides a background against which the strengths and weaknesses of qualitative models may be evaluated.

Much of the work in qualitative reasoning is inspired by researchers like Forbus (QP theory), de Kleer & Brown (theory of Envisioning) and Kuipers (Qualitative Simulation). Section 3.1 reviews these different approaches, concentrating on practical aspects of each one of them, namely, the use of concepts and algorithms. This is followed by an analysis of the various approaches in terms of the activities associated with building a qualitative model; this re-classification serves to sharpen the similarities and differences between the different approaches. Attempts have been made to apply these theories to domains other than that of physics and engineering; the last section of this chapter reviews the application of qualitative reasoning approaches in the domains of economics and business. Since the nature of these two domains is more closely allied to that of finance (than that of physics and engineering), success in these two fields of study would strongly support the success of applying the theory in finance.

Chapter 4 consolidates the main strands of thought from the two review chapters to show why the proposed research project is a viable proposition, and presents a plan for organising and managing the research project.

2 A Tutorial in Finance

The aim of this chapter is to give the reader an appreciation of the domain area with a view to understanding the particular problems that arise in attempting to apply qualitative reasoning principles and techniques to it. As it is aimed towards an audience with very little background in finance, this chapter proceeds in a tutorial mode; the material presented has largely been drawn from two texts: 'An Introduction to Financial Management' written by Solomon & Pringle (1977) and 'Financial Policy and Management' by Van Horne (1983). Readers well versed in the language of finance may choose to skip this chapter.

The first section concentrates on defining the objectives and scope of the financial domain, spanning theory to practice. This provides the reader with an idea of the nature of the domain area, in particular about how well developed (or not so well developed as the case may be), the laws and theories in the field are. The second section presents an overview of the various types of models that are used by theorists and practitioners in the area. This is particularly relevant since the central theme of this thesis revolves around one particular type of model, the qualitative model.

2.1 Scope of the Tutorial

The study of finance can be approached from many distinct angles and points of view. At one extreme is the microeconomic approach which addresses itself to the efficient use of scarce resources. This approach however by-passes most of the operating realities and difficulties that faces a financial manager in the real world. At the other extreme is the approach that examines the various diverse actions and decisions that occupy financial managers. Such a treatment is rather dull and results in a sketchy understanding of the field.

This tutorial extends the discussion on the basic microeconomic theory as far as it is relevant to the specific issues relating to efficient capital usage in the real world. It does not define however the role of the financial manager, as only aspects of financial management considered pertinent to the development of the research idea are covered. Instead, the role of another player in the game of finance is considered: the financial analyst, a general term for an outsider (e.g. a creditor, a current or potential shareholder etc) who practices the art of evaluating the performance and standing of business corporations.

2.1.1 Financial Theory and Policy

Finance is concerned with the issues that confront a firm making choices amongst a myriad of sources and uses of funds available to it. Various sources of funds are available to a firm, both internally and externally. The main source of internal financing is through the use of past (retained) profits generated from operations, while there are two main sources of external financing, namely, debt (e.g. overdraft facility) and equity (capital from shareholders e.g. through floating new shares). Since each source of financing possesses characteristics peculiar to itself (e.g. effect on firm's risk profile, payment schedule, terms and conditions attached etc), a firm will have to weigh these various options in the light of what it hopes to achieve. Funds that are procured by the firm are put to investments, both to finance the everyday operations (e.g. maintain stock levels) and to finance long term projects (e.g. purchase of land or equipment). Since each form of investment and project will have a associated set of risks and returns attached to it, the firm will again have to analyse these options in relation to its goals.

The general criterion for all corporate finance decisions is taken as that of value maximisation i.e. maximising the shareholders' wealth. This maxim may be viewed as a development of the profit maximisation rule in microeconomic theory, not surprisingly since corporate finance only emerged as a separate body of study from microeconomics at the turn of the century. These two domains share the same objective: that of the efficient allocation of resources. In microeconomics, the theory of prices rules that this goal will be achieved if a firm exhibits profit maximisation behaviour. However, this simple model assumes that the outcomes of decisions can be known with certainty and that cash flows take place in a single period of time i.e. it does not consider the risks and uncertainties a business unit has to operates within. Value maximisation as a decision criterion takes such factors into account and will therefore ensure that funds acquired will be allocated efficiently. Consider the fact that if a firm chooses to maximise profits, it will invest in 'risky' projects which might yield low or no returns resulting in an inefficient allocation of resources.

There is however some disagreement as to the measure of shareholders' wealth; some theorists feel it should be earnings per share (EPS) while others feel it should be market price per share etc. The measure chosen is entirely at the firm's discretion and has important implications on its decision-making behaviour. For instance, a firm which chooses EPS as its measure may never pay a dividend. Besides the choice of a measure, there are other difficulties in applying this criteria.

Firstly, there are conflicting views as to which type of decisions affect the value of the shareholders' wealth. Financial researchers have mainly focused on investigating the impact of capital structure (proportion of debt *vs* equity), investment policies, and dividend policies on the market value of the firm. For instance, Neo-Classical theorists (Copeland & Weston 1988) hold the view that a firm's share price is independent of its capital structure and is dependent solely on the firm's earnings potential. This implies that the firm should always resort to debt for raising funds as this is generally a cheaper source of finance compared to equity (the rate of return required from creditors being lower as they have a prior claim on the assets). Behavioral economists (Copeland & Weston 1988) on the other hand, believe that the firm's share price may be manipulated and distorted by its financing policy. They hold that there is an optimal capital structure at which the cost of capital is at its minimum and the value of the firm is maximised.

Empirical evidence to support or refute any of these theories is inconclusive largely because empirical testing is such a difficult and complex task.

Secondly, there has been very little effort expanded in understanding the impact, if any, of working capital management policies on the value of the firm. Working capital management policies determine the operational level of the firm (e.g. volume of transactions) and the level of funds that are readily available to the firm enabling it to cope with any emergencies or unexpected crisis (e.g. cash). As a result of the relative inactivity of research interest in this aspect of financial management, models developed for the management of working capital are 'optimizing'; they seek to maximise profit as opposed to shareholders' wealth.

Thirdly, the decision criterion is difficult to use for performance appraisal especially for a division of the firm and for the short run. As a result, alternative yardsticks are used e.g. sales trend, profit contribution per cost centre, return on investment. This means that if the yardsticks chosen are inappropriate surrogates for the decision criteria, decisions may be made based on misleading information. This will result in the firm making inefficient use of its resources.

It may therefore be said that the domain area is characterised by the lack of a widely accepted set of principles that defines how a firm should be operated and controlled to achieve a given set of objectives. While there have been contributions to the theory of investment policy, portfolio selection, dividend policy, debt policy, there have been few attempts to integrate the theory into a consistent whole and the theory is more developed for some aspects of finance than others. Therefore, the current theory of corporate finance at best provides models and general guide-lines that may be applied to give a solution under a variety of assumptions.

2.1.2 The Role of the Financial Analyst

A financial analyst relies on several sources of information in evaluating a firm's condition and performance. One of these sources is the periodically published financial statements which a firm is obliged under statutory law to produce. There are two main types of financial statements: the Balance Sheet and the Income (or Profit and Loss) Statement. The information recorded in these statements is made in terms of financial variables e.g. cash, loans, dividends.

The Balance Sheet is a financial snapshot of the firm's position at a particular point in time; it shows what the firm owes and what it owns at that time point. What it owes is known as liabilities and these are the funds that the firm has raised to set up and operate the business - through bank loans, shareholders' contributions (or funds) and lines of credit for everyday operations. The firm uses these funds to purchase and own tangible, physical facilities (e.g. plant and equipment) and items (e.g. stock or inventory) which will allow it to carry out its avowed function and these are referred to as assets.

All financial variables in the Balance Sheet are categorised into one of a number of mutually exclusive and exhaustive categories, which are hierarchically structured. The three main categories have just been mentioned: assets, liabilities and equity (or shareholders' funds). Liabilities may be divided into various categories. The major categories are current liabilities and long term liabilities; the sole distinction between them being the time element. Current liabilities are those debts which have to be settled within a year (e.g. supplier's credit) whilst the repayment period of long term liabilities extends over a year. Shareholders' funds represent what the business owes its owners. Similarly, assets may be categorised; the major ones being current assets, fixed assets, intangible and miscellaneous assets. Current assets circulate and vary frequently; they are to be converted to cash in the course of the business e.g. stock. Fixed assets, on the other hand, are the tangible, physical facilities utilized by the firm in carrying out its function and will be in use over a long period of time e.g. plant and machinery. Whether an asset is classified as a current asset or a fixed asset depends on the nature of the business. A firm selling lorries will list it (a lorry) as a current asset whereas a firm using lorries to deliver goods will list it as a fixed asset. Intangible assets are distinguished by the fact that it is difficult to assign monetary values to them e.g. goodwill and exclusive franchises. For this reason, they are quite often left out of the Balance Sheet. Miscellaneous assets (e.g. loans to employees) are identified through the process of elimination - they are neither current, fixed or intangible. Table 2.1 shows the typical Balance Sheet of a retail store.

Variables	as at 28.06.1981 (£000s)	as at 27.03.1983 (£000s)
Inventory (or stock)	7275	9884
Receivables (or debtors)	2054	820
All other current assets	4097	5092
Total Current Assets	**13426**	**15796**
Fixed Assets	3411	9963
All others	-	-
Total Assets	**16837**	**25759**
Payables	3945	5774
Short Term Loans	1570	7085
Other Current Liabilities	1857	3180
Total Current Liabilities	**7372**	**16039**
Long term loans	113	-
Other Long Term Liabilities	996	-
Shareholders' Funds	8356	9720
Total Liabilities	**16837**	**25759**

Table 2.1 Balance Sheet of Habitat Design

Rather than a being a snapshot of the firm at a point in time, the Income Statement (see Table 2.2) describes the performance of the firm over a particular period of time. It shows the income earned, the expenses incurred and the resulting profit and loss from its operations. Details on income and expenses shown in the statement differ according to the firm, industry and country.

Variables	1981/1982 (£000s)	1982/1983 (£000s)
Sales	38909	41589
Cost of Sales	34909*	36989*
Trading Profit	**4000***	**4600***
Admin and Selling Expenses	342*	242*
Net Profit before Taxes	**3658**	**4842**

* Records are incomplete, figures given for illustration

Table 2.2 Income Statement of Habitat Design

A variety of standard techniques are used to interpret these financial statements. Typically, the trend of absolute historical figures, the trend of certain ratios (the proportion of one financial variable to another) and the sources and uses of funds are analysed.

An analysis of the periodical series of absolute financial figures is undertaken in order to draw attention to changes that have taken place, identifying trends and regular changes due to trade cycles, and irregular fluctuations which denote instability and greater risks. This initial analysis provides a rough indicator to the condition of the firm. The analysis of a firm's ratios involves a more detailed scrutiny of the financial statements. There are several reasons why ratio analysis is used. Isolated figures mean very little on their own. For example, does an increase in sales indicate that the firm is better off? Surely not, if its costs are increasing on a larger scale. Thus, significant pieces of data need to be logically related, if their meaning is to be interpreted correctly. Ratio analysis also allows for meaningful comparisons within a firm over time, against other firms and against the industry as a whole.

As pointed out previously, in order to have any meaning, the variables (i.e. the numerator and denominator) of a ratio must be related in a logical pattern. How these ratios and their meaning are defined are beyond the scope of this thesis. It is evident however that ratio analysis represents an attempt at identifying and quantifying the strengths and weaknesses of the firm (Brigham & Gapenski 1988; Miller 1972; Van Horne 1983). Individual ratios are grouped into different categories, each representing a financial concept such as liquidity, profit, risk, growth which is deemed relevant in characterising a firm's financial condition and performance. Judgement of whether the firm is adequate in these areas is made by comparing the firm's ratios against those for the industry as a whole (industry average). There are various categorisation schemes and some variation in the definition of the ratios. For instance, some authors e.g. Van Horne (1983) advocate the inventory turnover ratio be computed from the cost of goods sold and average inventory while others e.g. Miller (1972) advocate the use of sales and end of year inventory values.

The categories identified by Van Horne (1983) are: liquidity, debt, coverage and profitability ratios. Liquidity ratios (or short-term insolvency ratios) indicate the adequacy of the firm's working capital (amount of current assets and current liabilities) and its ability to meet its daily obligations. It is possible for a firm to be profitable and yet fail if it is unable to settle its short-term debts. Examples of liquidity ratios are: ratio of current assets to current liabilities (or the current ratio), ratio of all current assets except inventory to current liabilities (or the quick ratio) and ratio of cost of goods sold to average inventory. Debt ratios (sometimes called long-term insolvency ratios) show the relative claim of creditors and shareholders on the firm and thus indicate the ability of the firm to deal with financial problems and opportunities as they arise. A firm highly dependent on creditors might suffer from creditor pressure, be less of a risk-taker and have difficulty raising funds i.e. it will have less operating freedom. An example of debt ratios is the ratio of total debt to total shareholders' fund. Coverage ratios are designed to relate the financial charges of a firm to its ability to service them e.g. the ratio of interest to pre-tax profit. Lastly, the profitability ratios indicate the firm's efficiency of operation. Examples of ratios measuring profitability are: the ratio of profit to sales, the ratio of profit to total assets and the ratio of profit to shareholders' funds.

Besides ratio analysis, financial analysts may carry out a funds flow analysis i.e. the sources and uses of funds analysis. This quantitative analysis proceeds following several rules:

1. Identify the firm's sources of funds. These are represented by decreases in assets, increases in liability, increases in shareholders' funds and profits from current operations.

2. Identify the firm's uses of funds. These are represented by increases in assets, decreases in liability, decreases in shareholders' funds (e.g. repurchase of shares) and losses from current operations.

3. Compare the sources of funds against the uses of funds to detect any imbalances between them. There are no hard and fast rules as to how this evaluation is to be carried out. Some examples of the types of analysis possible are given subsequently.

The funds flow analysis is able to depict how the firm's growth has been financed and whether the level of financing is appropriate. For example, management would be worried if it consistently needed to finance the firm's operations from debt as this would indicate the inability of the firm to survive in the market place in the long run. It is also useful to analyse the mix of short term and long term financing in relation to the fund needs of the firm. Management should be worried if the firm's acquisition of fixed assets were financed primarily from short-term sources as this indicates the inability of the firm to generate profits sufficient to make provisions for such commitments. An analysis over several years may also reveal imbalances in the growth of different assets e.g. inventories may have grown out of all proportion to growth in sales and fixed assets. This could possibly be traced to inefficiencies in inventory management which if not corrected, would affect the firm's profitability and cash position. Inventory not only ties up funds which could have been invested at profitable rates but, more importantly, represents losses if not sold since there is a limit on its life due to perishability, technological change or changes in fashion.

Sources (£000s)		Uses (£000s)	
Funds provided by operations: Net Profit and Depreciation	4842	Additions - fixed assets	6552
Decrease - accounts receivable	1234	Increase - inventories	2609
Increase - accounts payable	1829	Increase - other current assets	995
Increase - short term loans	5515	Decrease - long term loans	113
Increase - other current liabilities	1323	Decrease - long term liabilities	996
Increase - shareholders' funds	1364	Increase - miscellaneous items	4842 *
	16107		16107

* Due to incomplete records, this figure may represent several items, e.g. dividends.

Table 2.3 Funds Flow Analysis Statement of Habitat Design 1982/1983

Looking at the data provided by Table 2.3, the firm's major sources of funds are net profit and short term loans. These funds are used to reduce debts, to increase fixed assets and inventories. The major striking feature of this analysis is the increase in the illiquidity of the firm: short term claims have replaced long term claims and total £6.8 million while inventories have increased by £2.6 million, and the amount of total current assets (£2.4 million) is insufficient to support the firm's amount of total current liabilities (£6.8 million). This means that the firm will be under severe pressure in repaying its short-term contractual obligations. This analysis can further be confirmed by comparing the firm's ratio of current assets to current liabilities (1.0) against that of the industry's (mean is 1.9), and the firm's quick ratio of 0.4 against the industry's mean of 0.8.

There are many sources of information e.g. internal records, insider information etc, some of which may provide conflicting views of the firm. The only sources considered by this piece of research are the published financial statements and published financial ratios of the firm and its industry since these are easily available and relatively uncontroversial sources. However, financial statements only contain quantitative data. It is recognised that qualitative information about a firm will have to be captured and analysed if a comprehensive evaluation of the firm is to be accomplished, but this is currently not handled. There are also a wide variety of tools and techniques for interpreting the published financial statements. No single technique is able to provide all the answers; each technique is able to analyse only certain aspects of the firm, but collectively, these analytical approaches may add up to give the whole picture of a firm. As it is not possible to consider all the different techniques of analysis, only the more popular tools have been selected i.e. ratio analysis and funds flow analysis. The funds flow analysis presented here has been approached quantitatively. In Chapter 5, this analysis is discussed, but this time from a qualitative point of view.

2.2 Models in Finance

One of the objectives of this research was to build a qualitative model within the financial domain. It therefore seems pertinent to review the kinds of models currently in use since this will provide a platform for discussion of the relative merits and demerits of a qualitative model.

Models in any domain area may be broadly classified as mathematical models and non-mathematical models e.g. maps, heuristic models. All models found in financial management-type texts (e.g. Van Horne 1983) fall into the first category. The non-mathematical models to be described are specific research works that do not form part of the standard teaching text.

2.2.1 Mathematical models

Mathematical models describe a particular aspect of the finance function by abstracting the key variables involved and quantifying the relationships between these variables. Not surprisingly, many of the insights developed in the field of mathematics (e.g. functions, differential calculus) and statistics (e.g. probability distributions, sensitivity analysis) have been used to express and construct these relationships.

There are numerous mathematical models used for a wide variety of applications; to give a flavour of models that have been constructed, the formulation of the Capital Asset Pricing model (CAPM) and Discounted Cash Flow Valuation model (DCF) proceeds. CAPM (Copeland & Weston 1988) illustrates the use of statistical measures of mean, variance and covariance to derive the required rate of return for any asset under certain assumptions:

$$E(R_i) = R_f + [E(R_m) - R_f] \frac{\sigma_{im}}{\sigma_m^2}$$

where $E(R_i)$ is the expected return on asset I, R_f is return for risk-free asset, $E(R_m)$ is the expected return for the market portfolio, σ_{im} is the covariance between the asset I and the market portfolio, σ_m^2 is the variance of the market portfolio. In other words, the rate of return for any asset depends on the risk free rate of return and the risk premium of the asset. This basic model for quantifying risk is useful for many applications e.g. the valuation of assets which have a risky payoff at the end of the period, or for developing measures to evaluate projects that have different risk profile from that of the firm as a whole. The next model, the DCF model (Solomon & Pringle 1977) provides the basic analytic framework for investment decisions i.e. calculating the total returns expected from an investment project. This model makes use of the concept of functional relationships where the value of the total returns, DCF depends on the values of C_t (the amount received at time t), k (the interest rate) and n (the number of years):

$$DCF = \sum_{t=1}^{n} \frac{C_t}{(1+k)^t}$$

These two models represent the types of models which are used in the decision-making process. However, more dynamic and sophisticated simulation and optimisation models are also used e.g. Hertz's simulation model (in Van Horne 1983) for evaluating risky investments and Myers & Pogue's linear programming model (Brigham & Gapenski 1988) aimed at optimising shareholders' wealth. Of these two types of models, simulation models which seek to explore all alternatives by imitating the operations of a firm, are more popular (Grinyer & Wooller 1978). 98% of the companies in the UK using some sort of model, implemented a simulation model. Only 22% of these firms utilized a optimisation-type model and then, only the oil companies (who have had a long acquaintance with mathematical models) seemed to be particularly happy with them. This is despite the fact that optimisation models are able to identify the optimum solution given the operating constraints and set of objective functions. The main drawbacks cited were the high costs of developing these models, and the difficulty in understanding and interpreting the results of such models. The latter criticism is true to some extent of mathematical models in general. Even the relatively simple models which have been chosen as illustrations contain numerous implicit assumptions concerning their applicability and interpretation. As a result, these models are often intelligible to anyone except the designer and those trained to use them.

2.2.2 Non-mathematical models

Non-mathematical models represent yet another approach at abstracting and re-creating the environment. So far, these appear to be similar to simulation-type models, except that they are driven by procedures (describing task-related behaviour) and heuristics.

One of the main difficulties of defining a mathematically-based simulation model is to find mathematical expressions which produce the desired behaviour under a variety of conditions. As the behaviour to be simulated becomes more complex, this task becomes exceedingly difficult and even impossible. In such instances, a simulation model may not be mathematically driven. Clarkson (1963) produced a computer model to simulate the behaviour of a trust investment officer in selecting a portfolio of common stock. His model encodes procedures for choosing investment policies for particular clients, evaluating the alternatives presented by the market and selecting the required portfolios. The need for developing these procedures was identified by analysing the 'thinking aloud' protocols of a trust investment officer at a medium sized national bank. Bouwman (1978) also makes use of protocol analysis in developing a cognitive model for making financial diagnosis. What is especially novel about his approach is the use of qualitative data and operators; quantitative data about a manufacturing concern was translated into qualitative data via operators. Each operator has specific rules on how this conversion is to be performed e.g. the INCR operator applied to a set of the two most recent figures will give the qualitative result of 'increase', 'decrease' or 'same' and the qualification of this effect (i.e. 'small', 'large', 'unspecified'). The results of this conversion are evaluated against the 'thinking aloud' protocols of a group of subjects. Heuristic rules were then applied to the results and 'significant facts' selected e.g. sudden changes in value, deviation from similar item, sharp deviation from industry average etc. These qualitative results were then matched against the expectations generated by an internal model. This internal model describes the functioning of a firm and is described by qualitative expressions that define the relationships between the variables e.g. demand(p) = market demand * market share reads as the demand for product (p) is influenced by two factors, market demand and market share. If either of these two factors change, then demand will also change in the same direction. Thus, the internal model only generates kinds and directions of effects.

'Significant facts' located are chained together by referencing this model and used to generate diagnosis of the firm. Those facts which are contradictory or not recognised by the internal model are discarded.

The last two models to be described do not adopt the method of analysing task-related thoughts of a human subject i.e. the protocol analysis technique. Rather, they rely on rules of thumb which have been derived from examining the past experiences of decision-makers in terms of key decision parameters e.g. buy when prices move up rapidly. They may be termed pure heuristic models and have proven to be especially useful where the decision is ill-structured or where the range of feasible solutions is very large. FANFARE (Ganoe 1984) is a small prototype system which performs liquidity analysis. The knowledge of the system comprises a set of heuristic rules which is applied to the input data to derive results. An example of a rule (slightly reworded) is:

> If current ratio is 'below medium'
> and inventory/working capital ratio is 'high'
> and cost of sales/inventory is 'not high'
> then liquidity is 'low'

Iwasieckzo *et al.* (1986) adopted the same approach in building their system to perform financial analysis. Rule 11 in their system states:

> If free financing means on bank account
> and correct financing of assets
> and correct structure of assets
> then good financial situation

Two fundamental assumptions are made whenever this approach is used. The first is that the past will predict the future which will ensure the stability and acceptability of the system and the second is that cues from the environment represent reliable information.

In summary, it may be said that although these simulation-type models can capture and manipulate information that defy a mathematical description to produce behaviour, they cannot analyse their behaviour automatically. In order to arrive at a complete analysis of the behaviour of the models, numerous runs must be carried out and the results compared. Even so, this procedure cannot uncover behaviours that are not possible. This feature is useful in defining the scope of the model applicability. Qualitative analysis is able to identify such behaviours; since all possible behaviours are derived automatically, any behaviour not defined in this range is a behaviour that is not possible. These two inadequacies of simulation-type models are the strengths of qualitative models and their associated style of reasoning. How qualitative models achieve these functionalities are shown in the next chapter.

2.3 Summary

This chapter serves to focus the reader on aspects of the financial domain pertinent to the development of the research theme.

Firstly, the maturity of theories in the domain were considered since this has important implications on the effectiveness of the theory of qualitative reasoning in the domain. Domain areas may be seen as lying on a continuum, from the highly formalised fields (e.g. physics and algebra) to the less structured domains where the models are based on experientially derived knowledge (e.g. medicine) or where the models are based on evolutionary knowledge (e.g. managerial type problems). As shown in Section 2.1.1, theories in the financial domain are not fully established. In the absence of such formalisation, problem solving is likely to depend on more informal, intuitive and transient models. The description of how financial analysts carry out a diagnosis of a firm's financial performance given in Section 2.1.2 is an example of such a problem-solving approach.

Secondly, an overview of the various types of models were presented largely to illustrate their inadequacies, which may be overcome if a qualitative model were to be used. The advantages of qualitative models provides one of the motivations of this research. In Section 2.2, only the virtues of qualitative models have been mentioned; a full description of their characteristics and uses are given in the next chapter.

3 Review of Related Literature

The review of related literature is divided into two sections. In the first, a description of specific work in the field of qualitative reasoning is presented. This is concluded with a general discussion of the major issues involved. It would have been ideal if this section could have been followed up with some illustrations of how this approach has been successfully (or unsuccessfully) applied in the financial domain. To date, however, there is no known work of this nature; as a substitute, experimental work on building qualitative business and economic models is discussed.

3.1 Mainstream Approaches

The best known research in the field of qualitative reasoning may be classified as the component-centred approach (de Kleer & Brown 1983a, 1983b, 1984), the process-centred approach (Forbus 1981, 1984) and the constraint-centred approach (Kuipers 1984, 1985, 1986, 1987), according to their particular emphasis in the modelling process. In the following section, the focus will be on the mechanics of the particular qualitative reasoning styles.

3.1.1 The Component-centred Approach

Every physical situation is regarded by de Kleer & Brown (1984) as some sort of physical device which consists of individual components. The functioning of a device is determined by the behaviour of each component (which is in turn governed by a set of physical laws) and the coupling topology of all the components (i.e. the device's structure). This structure in turn imposes constraints on the functioning of the device.

The set of physical laws governing the behaviour of a component has conventionally been described by quantitative equations. For instance, Newton's law which states the effects of force on an object with a mass is given as force = mass * acceleration. To model this situation qualitatively requires that each quantitative equation be transformed to a qualitative equation; each quantitative variable needs to be converted to a qualitative variable; and each conventional operator needs to be converted to a qualitative operator.

Unlike quantitative variables, qualitative variables can only take on a small number of values. Each of these values corresponds to some interval on the real-number continuum. In principle, this interval is determined with reference to a special value usually referred to as a landmark value, of which zero is the most commonly used. + represents the case where the quantitative value is positive in relation to this landmark value, 0 represents the case when this value is the landmark value and - represents the case when this value is negative in relation to the landmark value. (For clarity, all qualitative variables will be notated by the use of '[]' e.g. [x] is the qualitative value of the variable x.) Qualitative variables may also be described by their derivative value. The candidates for the qualitative value set are quite clear: + to indicate that the change in the qualitative value of the variable is increasing, 0 to indicate that there is no change in this value and - to indicate that the change in the qualitative value of the variable is decreasing. (Changes in qualitative values of the variables are notated by the use of '∂' e.g. ∂x is the qualitative change in the qualitative value of the variable x.)

[x] [y]	-	0	+
-	-	-	?
0	-	0	+
+	?	+	+

Table 3.1 Addition Operation: [x] + [y]

[x] [y]	-	0	+
-	+	0	-
0	0	0	0
+	-	0	+

Table 3.2 Multiplication Operation: [x] * [y]

Conventional operators specify the relationship of the operands. Similarly, qualitative operators define the relationships between qualitative variables. The definitions for the qualitative addition and qualitative multiplication operator are shown in Tables 3.1

and 3.2. No special notation is devised to indicate the fact that an operator is qualitative; an operator is taken to be a qualitative operator if its operands are qualitative variables (denoted by []). The definition of the qualitative multiplication table is quite straightforward; it is defined as [xy] = [x][y]. Unfortunately, addition is more complicated since [x] + [y] ≠ [x+y]. This occurs when [x] = + and [y] = - or when [x] = - and [y] = +. Qualitatively adding [x] and [y] will give an ambiguous result (shown in the tables as '?') since the quantitative magnitudes of both variables are not considered. Ambiguous results, therefore, reflect the loss of information when only qualitative values are considered.

A result that is ambiguous could be any one of the three qualitative values (depending on the relative quantitative magnitudes which are not used). This means the qualitative equality operator has to be less strict than a conventional equality operator to allow the expression of this relationship. Thus, a qualitative equality test is satisfied under two conditions: firstly, if the two values are identical and secondly, if at least one of the two values is ambiguous. The qualitative subtraction operator is taken to be the inverse of the qualitative addition operator and the qualitative division operator is taken to be the inverse of the qualitative multiplication operator.

The component-centred approach places its emphasis on changes i.e. what causes a change and what happens as a result of a change. Consequently, the laws governing the device are transformed into qualitative differential equations named confluences. The confluence for Newton's law is therefore given as [force] = ∂velocity (acceleration is the change in velocity) since mass is always positive and unchanging.

Figure 3.1 shows the variables of a pressure regulator whose purpose is to maintain a constant output pressure (at C) even though the supply (connected to A) and loads (connected to C) vary. An explanation of how it achieves this function might be:

An increase in the source (A) pressure increases the pressure drop across the valve (B). Since the flow through the valve is proportional to the pressure across it, the flow through the valve also increases. This increased flow will increase the pressure at the load (C). However, this increased pressure is sensed (D) causing the diaphragm (E) to move downwards against the spring pressure. The diaphragm is mechanically connected to the valve, so the downward movement of the diaphragm will tend to close the valve thereby pinching off the flow. Because the flow is now restricted, the output pressure will rise much less than it otherwise would have. (de Kleer & Brown 1984, p10).

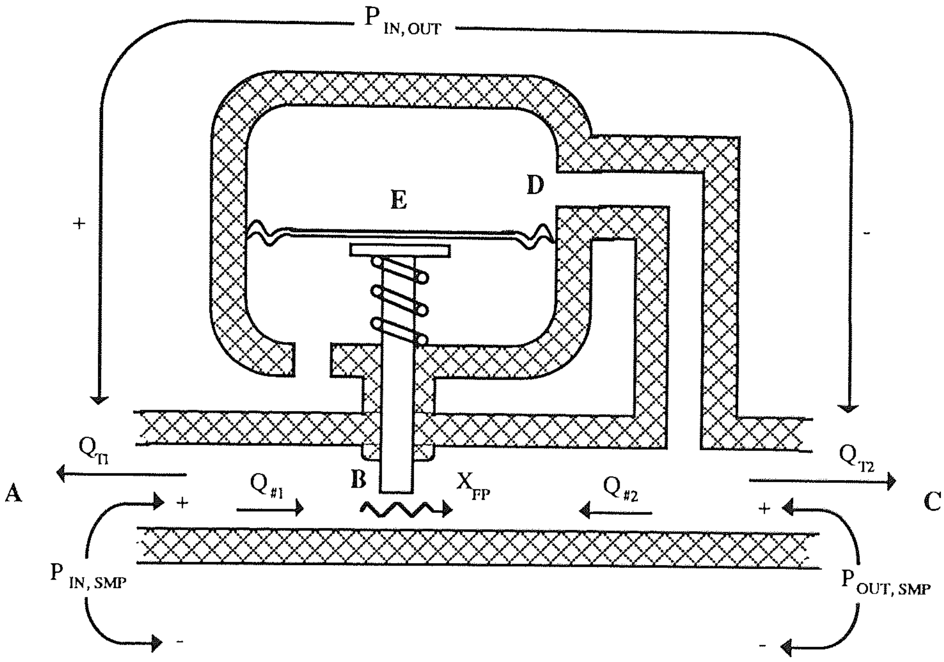


Figure 3.1 Model of a Pressure Regulator

From this, it may be deduced that the pressure regulator is made up of three components; the pressure sensor that senses the change in output pressure, the spring that allows the movement of the diaphragm and the valve that controls the flow.

Looking at one of these components, the valve, in detail; it can be observed that the position of the valve (marked as X_{FP}) varies inversely with the output pressure, which in turn affects the flow through the valve. The confluence, $\partial P_{in,out} - \partial Q_{\#1(vv)} + \partial X_{FP} = 0$

expresses the qualitative behaviour of a valve where $P_{in,out}$ is the pressure drop from input to output, $Q_{\#1(vv)}$ is the flow from terminal 1 (i.e. the location marked A) into the valve and ∂X_{FP} is the change in the position of the valve (which is proportional to the area available for flow). The detailed reading of this equation is: the change in the area positively influences the change in the flow rate and negatively influences the change in the pressure (i.e. if $\partial X_{FP} = +$, $\partial Q_{\#1(vv)} = 0$, then $\partial P_{in,out} = -$), the change in the pressure positively influences the change in the flow rate and negatively influences the change in the area, the change in the flow rate positively influences both the change in the pressure and in the area.

A single confluence cannot always characterise the behaviour of a component over its entire operating range. The notion of a qualitative state is needed to divide the behaviour of a component into different regions. Each region of operation will be specified solely in terms of inequalities between variables (called a state specification). For instance, the afore-mentioned confluence only describes the behaviour of the valve when it is operational. The behaviour of the valve when it is closed and when it is completely opened needs to be described using a different set of confluences. The state specifications for the valve are given in Table 3.3 where A is the cross sectional area available for flow:

State	Specifications	Confluences
open	$A = A_{max}$	$[P_{in,out}] = 0$, $\partial P_{in,out} = 0$
working	$0 < A < A_{max}$	$[P_{in,out}] = [Q_{\#1(vv)}]$, $\partial P_{in,out} - \partial Q_{\#1(vv)} + \partial X_{FP} = 0$
closed	$A = 0$	$[Q_{\#1(vv)}] = 0$, $\partial Q_{\#1(vv)} = 0$

Table 3.3 State Specifications of the Valve

When the valve is in the state, open (i.e. completely open), the valve functions as a simple conduit; there is no pressure drop across it and the flow is not controlled. When the valve is in the state, closed, there is no flow through the valve and the pressure across it is unconstrained. Only when the valve is in the state, working, does the control mechanism between the pressure, flow and area for flow come into play.

State	Specifications	Confluences
$F > 0$	$F > 0$	$\partial V_{FP} = +$
$F = 0$	$F = 0$	$\partial V_{FP} = 0$
$F < 0$	$F < 0$	$\partial V_{FP} = -$

Table 3.3a State Specifications of the Pressure Sensor

Similarly, states and state-specific confluences may be defined for the two other components of the pressure-regulator i.e. the pressure sensor and the spring. The model of the pressure sensor can be described adequately using the qualitative version of Newton's law, $[F] = \partial V_{FP}$ where F represents the force that is directly related to the output pressure and V_{FP} is the velocity of the valve movement (and is proportional to the change in the area available for flow). The states and state-specific confluences for the pressure sensor are given in Table 3.3a. The model for the spring is derived from the qualitative version of Hooke's law, $\partial F_{A(M)} = [V]$ where $F_{A(M)}$ is the force pushing the

State	Specifications	Confluences
$V > 0$	$V > 0$	$\partial F_{A(M)} = +$
$V = 0$	$V = 0$	$\partial F_{A(M)} = 0$
$V < 0$	$V < 0$	$\partial F_{A(M)} = -$

Table 3.3b State Specifications of the Spring

valve's mass. The states and state-specific confluences for the spring are given in Table 3.3b.

The cross-product of all the components' qualitative states represents all the possible states of behaviour a device might be in. The device model for the pressure regulator will specify twenty-seven states since each of its three components (i.e. a valve, pressure sensor and spring) could be in one of three different states. For each of these states, the values of the variables can be determined by solving the confluences that are applicable for that state. There may be several possible solutions to a set of confluences. Such an instance may arise due to the imprecision of qualitative values; consider solving the confluence, $\partial P_{in,out} - \partial Q_{\#1(vv)} + \partial X_{FP} = 0$. When $\partial P_{in,out} = +$ and $\partial X_{FP} = -$, the confluence is satisfied since the result of $\partial P_{in,out} + \partial X_{FP}$ is ambiguous (unknown). Thus, $\partial Q_{\#1(vv)}$ could be any value, resulting in three solution sets for $P_{in,out}$, X_{FP} and $Q_{\#1(vv)}$: {+,-,+}, {+,-,0} and {+,-,-}. Multiple solution sets may also arise when not enough information is known, requiring the introduction of premises to propagate the changes, with each premise deriving a different set of solutions. Suppose the set of confluences that needs to be solved is:

$$\partial P_{in,out} - \partial Q_{\#1(vv)} + \partial X_{FP} = 0$$

$$\partial P_{in,out} + \partial P_{out,smp} - \partial P_{in,smp} = 0$$

and that only $\partial P_{in,out}$ is known. In such a situation, premises about ∂X_{FP}, $\partial Q_{\#1(vv)}$, $\partial P_{out,smp}$ or $\partial P_{in,smp}$ may be introduced, each leading to a different solution set (interpretation).

All the twenty-seven possible qualitative states may be organised into a network which identifies legal transitions from one state to another (each state may have many interpretations). This network is called a state diagram. Behaviour within a state terminates when one or more of the variables defining that state exceeds or falls below some threshold value. The possibilities for the device's subsequent behaviour are given by the state diagram. Which behaviour the device will exhibit depends on the direction of the changes of the variables. According to the state diagram in Figure 3.2, a device in state 4 could move to either state 3 or state 5. If $\partial F_{A(M)}$ = -, then the device will move to state 3 and if $\partial F_{A(M)}$ = +, then the device will move to state 5.

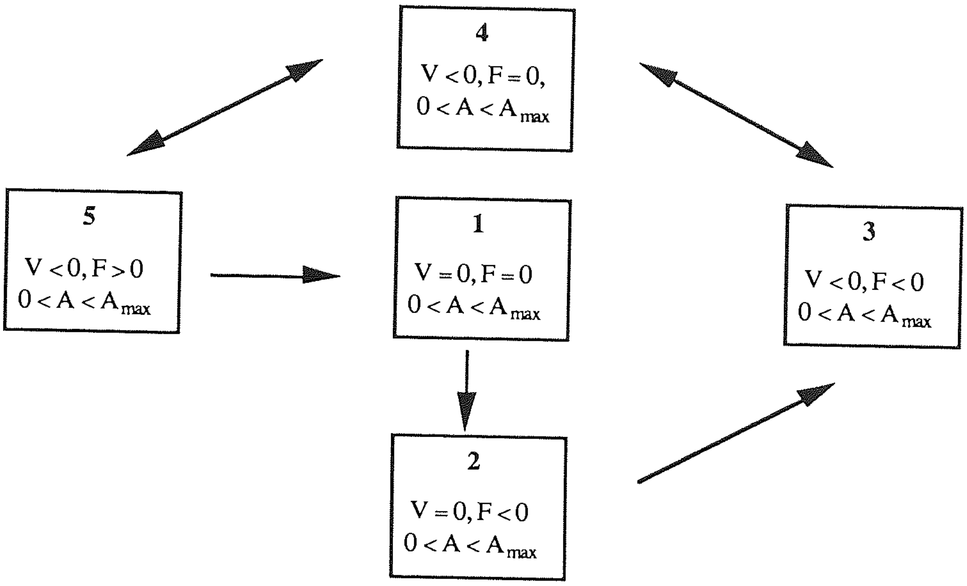


Figure 3.2 State Diagram of a Pressure Regulator

The result of this analysis (sometimes called the theory of Envisioning) can be viewed as the description of all the possible behaviours of the device, within a state and between states.

The concepts and techniques of the theory of Envisioning form the basis for the development of the system EQUAL (de Kleer 1984), whose purpose is to analyse digital circuits. EQUAL is able to accept a circuit schematic as its input. As output, it produces a qualitative prediction of the behaviour of the circuit and an explanation of its behaviour. In addition, the system performs teleological reasoning i.e. it is able to reason about the purpose of each component and the device. (How this is done is beyond the current scope of review; details of it are to be found in the paper referenced.) Thus, it also produces a teleological parse that relates every component to the overall purpose of the device.

3.1.2 The Process-centred Approach

Forbus (1984) operates on the assumption that all changes in a physical situation are caused directly or indirectly by processes. Thus, a physical situation is regarded as a collection of objects, together with the properties and relationships between them, on which processes are acting.

The two modelling primitives used in this approach are ‘views’ and ‘processes’. A view is a concept introduced to describe the properties of objects (individuals) and the relationships between these properties. It may be considered as an equivalent to the state-specific confluence in that it describes the different modes of behaviour of an object e.g. the behaviour of a substance when its temperature is below freezing point or its behaviour when its temperature is above boiling point. The properties of objects are described by an amount and a derivative referred to as a ‘quantity’. Both amounts and derivatives are numbers which have a sign (A_s refers to the sign of the amount and D_s the sign of the derivative) and a magnitude (A_m and D_m refers to the magnitude of the amount and the derivative respectively). Magnitudes are described with reference to a quantity space which is an ordered set of landmark values; a landmark value being a value that

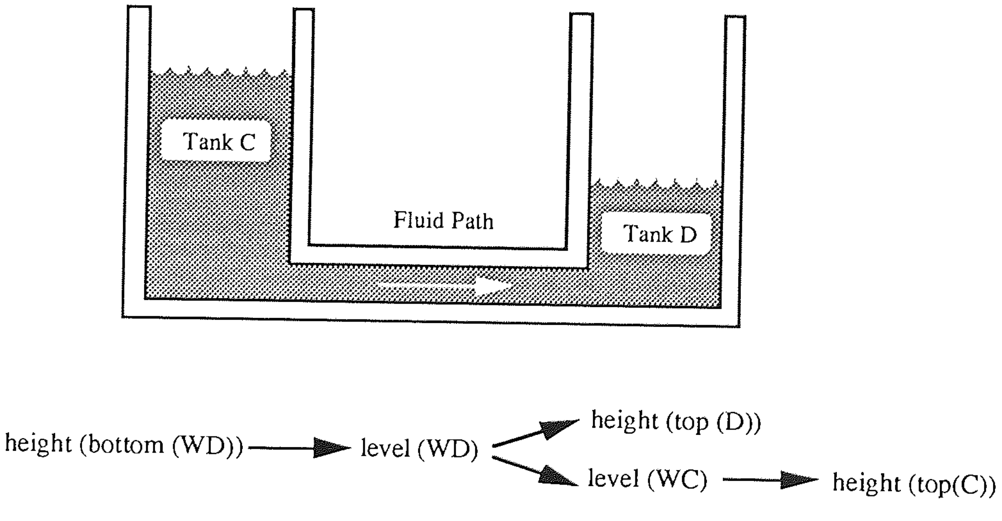


Figure 3.3 Graphical Representation of the Quantity Space of the Fluid Levels

delineates the quantitative scale. Take the case of fluid flowing between two tanks, C and D connected by a pipe (with WC denoting the fluid in tank C and WD denoting the fluid in D). The quantity space for the level of fluid is shown in Figure 3.3. The ordering of the elements is indicated by the arrows; quantities at the head of the arrow are greater than quantities at its tail. A special type of landmark value are limit points around which the object undergoes phase changes resulting in a different behaviour. A limit point in this case would be top(D) at which time, any additional fluid will either spill over tank D or the flow will cease depending on the initial total amount of fluid in both tanks. Signs take on the values of -1, 0 and 1. The relationships between the properties are represented by qualitative proportionalities: level(p) $\propto_{Q+}$ amount-of(p) expresses the fact that the level of fluid in the tank increases as the amount of fluid increases.

A process acts through time to transform and change the properties of objects. 'Influences' are used to represent these direct effects: I-(amount-of(source), A[flow-rate]) expresses the fact that during a fluid flow process, the flow rate will make the amount-of(source) decrease. These direct effects are propagated by available relationships between properties. Indirect influences occur when two properties are qualitatively proportional to each other and one of them is changing due to some other influence e.g. if the proportionality relation, level(source) $\propto_{Q+}$ amount-of(source) exists, then the flow rate will indirectly influence the level of fluid in the tank. This theory (sometimes called QP theory) assumes that a property can either be directly influenced, indirectly influenced or not influenced at all, but that it cannot be both directly and indirectly influenced at the same time.

Since several processes may be acting at any one time, in order to deduce how a quantity is changing, it will be necessary to resolve all its influences. Resolving a quantity that is directly influenced requires adding up the influences to determine its direction of change (the sign of its derivative). Table 3.4 shows shows how signs combine across

A \ B	- 1	0	1
- 1	- 1	- 1	N1
0	- 1	0	1
1	N1	1	1

N1:

if magnitude(A) > magnitude(B), then s(A)

if magnitude(A) < magnitude(B), then s(B)

if magnitude(A) = magnitude(B), then 0

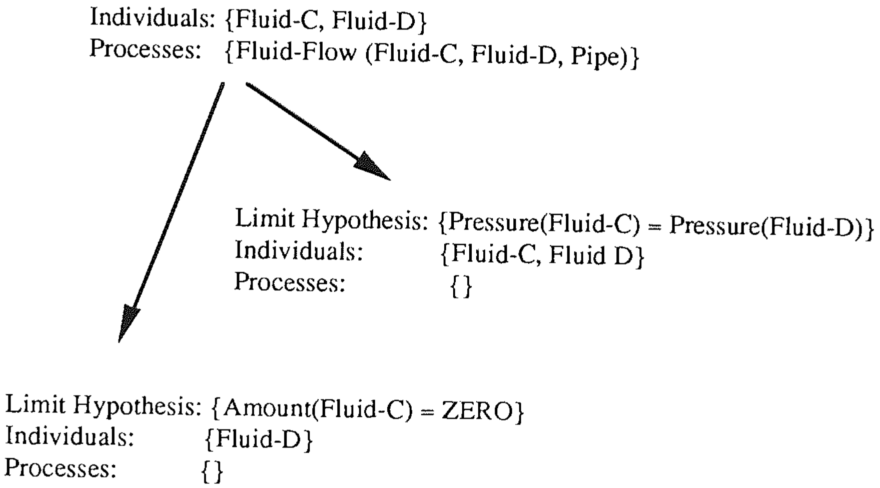
Table 3.4 s[A+B] and s[A*B]

addition and multiplication. Similarly, indirect influences for a quantity need to be resolved and this involves gathering the $\propto_Q$ statements that reference the quantity. Ambiguous results may occur because detailed information concerning the functional relationship is not known. For example, consider the following statement, $Q_0 \propto_{Q+} Q_1 \wedge Q_0 \propto_{Q-} Q_2$ which satisfies the both the equations: $Q_0 = Q_1 - (k * Q_2)$ and $Q_0 = Q_1/Q_2$.

A situation description at any point in time consists of active views and processes. Views are deemed to be active when conditions for their existence are enabled. These conditions are referred to as quantity conditions and can be expressed solely within the theory e.g. the view GAS is active if there is a substance whose temperature is greater than its boiling point. Similarly, processes have conditions (quantity conditions and preconditions) that specify when they are enabled. The fluid flow process is initiated when the pressure at the source is greater than the pressure at the destination. Preconditions are those factors outside QP theory which nevertheless are relevant in determining whether the process occurs e.g. someone opening or closing a valve to establish a fluid path so that the fluid flow process may occur.

When a process is active, it will influence the properties of the objects, causing them to change. To determine these changes, all influences on the objects are resolved. Changes in the quantities are mapped onto its quantity space to deduce if processes will terminate. This task requires the identification of neighbours: elements that are ordered with no elements in between them e.g. level(WD) has bottom(WD) and top(D) as neighbours but not top(C). Processes will not terminate if there are no neighbours in the quantity space in the direction of the changes of the quantities. If there are neighbours in the direction of change, then the ordering between the neighbours and the current amount of the quantity can be combined to see if a new ordering will result. Tables which specify the combination process can be found in Forbus (1984, pp 114). If this new ordering corresponds to a limit point, then the process may terminate.

For a given situation description, there may be several possible next situation descriptions. These arise because an element may have more than one neighbour, a process may affect more than one quantity or because more than one process may occur at any one time. Each possibility is referred to as a limit hypothesis and the task of identifying all these possibilities is known as limit analysis. An example of limit analysis is given in Figure 3.4. The basic QP theory is not able to predict which of the alternative events will occur. This is due to the fact that the theory does not include explicit integrals which are needed to identify which of the changing quantities will reach their limit points first.



Individuals: {Fluid-C, Fluid-D}
Processes: {Fluid-Flow (Fluid-C, Fluid-D, Pipe)}

Limit Hypothesis: {Pressure(Fluid-C) = Pressure(Fluid-D)}
Individuals: {Fluid-C, Fluid D}
Processes: {}

Limit Hypothesis: {Amount(Fluid-C) = ZERO}
Individuals: {Fluid-D}
Processes: {}

Figure 3.4 Limit Analysis of Fluids Flowing from Tank C to Tank D

The qualitative reasoning process is applied to each situation description until all situation descriptions have been generated (i.e. no new descriptions) and all transitions between the situation descriptions have been determined. Its result is therefore a description of all active views and processes and all possible process transitions.

QP theory was developed in part to be used in the STEAMER project, whose goal is to provide instruction about the operation of steam propulsion plants to U.S. Navy trainees. Functions of the various components of the steam propulsion plant e.g. boiler assembly, turbines, condenser assembly are modelled qualitatively. The domain model consists of 8 object types, 23 views and 14 processes and is believed to be the largest qualitative model built to date. A specialised query language was developed as an interface to this qualitative model; some questions that could be asked are: what affects the efficiency of the plant? What is causing the black smoke to rise from the furnace? How many mass flows are there? Apparently, this system has been well received when used for actual training (Wenger 1987).

3.1.3 The Constraint-centred Approach

Classical physicists describe physical situations using quantitative differential equations, which have a rich vocabulary of relationships: arithmetic operators, trigonometric functions, exponentiation and many others. Kuipers (1986) models a physical situation using a set of qualitative constraints that attempt to capture some of the semantics of this vocabulary.

In his constraint-centred approach, landmark values are either points pre-defined by the user, or are points, discovered by simulation, at which the derivative of the value is zero. The value of a parameter at any given point in time consists of its ordinal relationship (i.e. <, =, >) with its landmark values. The qualitative state of a parameter is given by this ordinal relationship and its direction of change, stated as inc (increasing), std (steady) or dec (decreasing). For example, a variable X described by the notation:

⟨(a,b),dec⟩ states that X has a value between the landmarks a and b, and is decreasing over time. The conception of time is different from that of the previous two mainstream approaches. Time is represented as a totally ordered set of symbolic time-points. The current time is either at or between these time points. Thus, time is described as an alternating sequence of points (t_i) and intervals (t_i, t_{i+1}). A special time-point, referred to as a distinguished time point, is a point at which something important happens, for example, a parameter passing its landmark value or reaching its extremes.

Constraints are two- or three-argument predicates on parameters. Three principal types of constraints are identified. The first are arithmetic constraints which correspond to quantitative arithmetic operations, e.g. ADD(X,Y,Z) corresponds to: $Z = X + Y$. This relationship must hold at each time point where a time point corresponds to a qualitatively distinct state of the system during which its behaviour is different from that of another state. The second type of constraint is a functional constraint which is defined by the forms: $M^+(Y,X)$ or $M^-(Y,X)$, meaning that Y is a strictly monotonically increasing or decreasing function of X respectively. $M_0^+(Y,X)$ and $M_0^-(Y,X)$ is the notation for the special case where $Y = 0$ when $X = 0$. The last type of constraint is the derivative constraint expressed by the general form: DERIV(Y,X), corresponding to the quantitative equation $Y = dX/dt$, i.e. Y is the rate of change of X at each time point. These constraints are designed to permit large classes of differential equations to be mapped directly into qualitative constraint equations.

An example may be used to illustrate how these constraints may be derived. Consider a container of gas being heated by a burner. The gas is at temperature T while the burner is giving off heat at a constant temperature T_s. Assuming that there is no heat loss, the rate of flow of heat into the gas (inflow) is a function of the difference between the two temperatures (ΔT). When $\Delta T = 0$, the inflow is assumed to be zero. The causal structure for this simple heat-flow system is shown in Figure 3.5. The differential

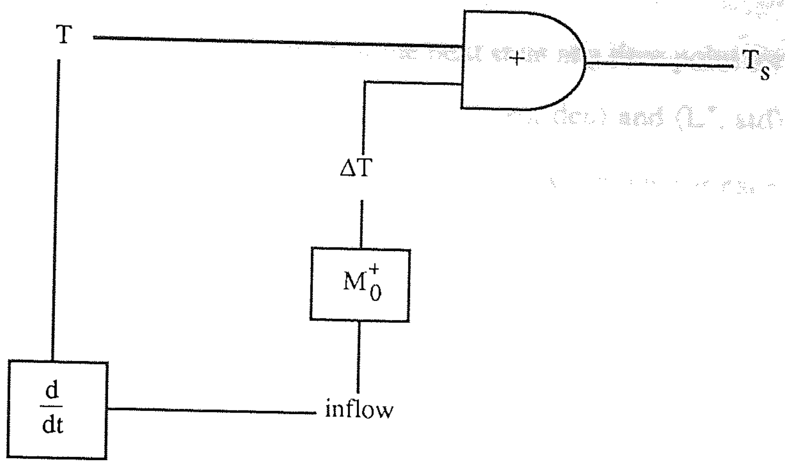


Figure 3.5 The Qualitative Causal Structure of a Simple Heat Flow System

equation that describes this situation is given as:

$$\frac{dT}{dt} = k(T_s - T)$$

This same information can be modelled approximately by the following set of constraints:

$$\mathrm{ADD}(\Delta T, T, T_s)$$

$$M_0^+(\mathrm{inflow}, \Delta T)$$

$$\mathrm{DERIV}(\mathrm{inflow}, T)$$

States of unknown parameters are derived by propagating known values through existing constraints. This propagation phase is complete when the direction of change for each parameter is known. In some instances, when the direction of change for a parameter is ambiguous, investigation of one state branches into three, one for each possible incremental value (each corresponds to an interpretation in the theory of Envisioning).

The qualitative changes possible for a changing parameter are governed by two sets of rules (Kuipers 1986, p. 300), one specifying all possible transitions from a time point to a time interval (defined in the P-transition table) and the other specifying all possible transitions from a time interval to a time point (defined in the I-transition table). Prediction is achieved by referencing these tables to produce the possibilities for each changing parameter. For example, the possibilities of the next state at a time point for a parameter V described by ⟨(0,∞), dec⟩ are: ⟨0, std⟩, ⟨0, dec⟩, ⟨(0,∞), dec⟩ and ⟨L^*, std⟩ where L^* is a (possibly new) landmark value. The sets of possible next values for each parameter are combined to form all possible next combinations. Suppose V has a derivative relationship with Y which has two possible next values. These two values will be combined with V's four possible values to form a total of 8 combinations which are then pruned by the propagation cycle: the rules for pruning are termed consistency filtering and pair-wise filtering. For example, since V has a derivative relationship with Y, the combination set of {Y⟨(0,∞), inc⟩, V⟨0, std⟩} will be eliminated since it is not possible for V to be increasing when its derivative Y is zero and steady. The result of the pruning then represents the alternative events that could actually occur next.

The novelty of this approach is that it does not rely on pre-specified 'structural descriptions' to provide information on all possible landmark values. It automatically generates some of these by noting when parameters 'collide', or when no changes to parameters occur, and proceeds to investigate behaviour at this point.

Once the next states are identified, the whole cycle of propagation and prediction starts again and it continues until some terminating condition is recognised e.g. a cycle, quiesence or intractible branching. In the case of intractible branching, 'syntactic transformation' rules (Kuipers 1984, pp. 199-200) may be applied to produce a new set of simplified constraints. The propagation-prediction process is then applied to this new set.

Thus, the reasoning process (sometimes referred to as Qualitative Simulation) produces a behavioural description of the system which consists of a finite set of time points representing all the possible qualitatively distinct states.

The concepts and ideas of the theory have been implemented as a system, commonly referred to as QSIM (Kuipers 1986). The project MODEL (Nicolosi &

Leaning 1987) re-implements the QSIM algorithm so that it runs on an IBM AT! The objective of this system was to develop a new schema for dynamic biological systems. The model is specified in terms of compartments, losses, fluxes and inputs. From this representation, the system generates constraints in the form acceptable to its version of QSIM which processes it together with initial values supplied by the user, to produce the tree of all possible behaviours. One of the intended applications of this output was to combine it with results of quantitative reasoning to produce medical diagnosis and treatment. However, no details of how this was to be done was given in the paper.

3.2 Comparison of Approaches

It is observed that there are activities which are common to all the major approaches in qualitative reasoning theory: finding the appropriate representations for describing the entities of interest and their relationships and for describing the concept of time (i.e. modelling aspects), specifying the inferencing procedure for deriving behaviour from the representations (i.e. prediction aspects) and generating explanations from the results of the inferencing procedure (i.e. interpretation aspects). Thus, the analysis will proceed along these lines.

3.2.1 Modelling Aspects

In the physical domain, entities of interest are particular properties of physical objects (parameters) e.g. pressure, level, temperature. The interesting features of these parameters are their absolute values and their derivative values. These values are qualitative in nature and correspond to some interval on the quantitative scale. However, there are no explicit guide-lines demonstrating how these intervals should be derived. It seems to depend on whether it would be 'useful' to have such an interval; whether the behaviour during this interval is of interest. Take the parameter 'temperature' where it seems intuitively appropriate to divide its quantitative scale into three intervals: $-\infty$ to 0^{o}C, between 0^{o}C and 100^{o}C, above 100^{o}C to $+\infty$. Such a distinction is useful since the substance (which must be water) that is described by this parameter changes form and behaviour considerably in the different intervals. The most commonly used intervals for derivatives are: $-\infty$ to 0, 0 and 0 to $+\infty$. QSIM's ability to detect new landmark values (values which delineate the quantitative scale) confirms how arbitrary the selection of qualitative values can be.

One of the ways in which relationships between parameters are modelled is as constraints. This is due to the nature of the domain area; physical laws dictate interdependencies of parameters on each other rather than a cause-effect dependency. For example, Newton's law: force = mass * acceleration in no way specifies which is the causal parameter. These constraints are termed variously confluences, qualitative proportionalities, arithmetic relations, functional relations and derivative relations. Another way to model relationships is as causal relations, the order being imposed by the designer of the model. This type of parameter relationship (influences) is only explicitly expressed in QP theory. The last way of modelling relationships are as conditional laws; inequalities which largely serve to define boundary conditions over which behaviour may change.

The notion of time in qualitative reasoning is closely allied to that of the notion of state. Different time points are distinguished when the behaviour in question changes. A state defines an operating region over which behaviour does not change. This operating region is usually expressed by inequalities between values i.e. state specifications, quantity conditions and inequality conditions. Thus, a time point is created whenever a state change occurs.

It would appear therefore that the modelling primitives from the different approaches seem to be fairly consistent to each other. What distinguishes them is how these are organised to reflect real-world systems. Envisioning takes a mechanistic view and uses the idea of a device as its central organising structure. QP theory uses views and processes while Qualitative Simulation does not provide such a feature. What then are the implications of having or not having such a facility? Firstly, an organising structure provides a framework for analysing a given situation. This is particularly relevant where the problem area is as complex as that of the physical world. In the absence of such a framework, the analysis and design effort would degenerate to that of trial and error. More importantly, an organising structure fulfils an essential role as a means of communication and control towards achieving the main goal of qualitative reasoning: specifying the set of core knowledge. Communication is facilitated since a common vocabulary is defined while control is exercised in that extensions and modifications to the original theory can be made within this unified framework. The tangible result is a common library of knowledge that could be accessed by interested parties. In the case of Envisioning, this library consists of component models with each component describing the behaviour of the component over different states. In QP theory, the library consists of views and processes providing information about relationships. In Qualitative Simulation, the lack of a definition of an analysis framework precludes the existence of some sort of library. As a practical consequence of the lack of a library, the user of QSIM will need to be a domain expert since he effectively has to supply the mathematical model. (It appears that users of systems built on the other two theories need only supply the system topology and some initial conditions.)

Of course, the advantages of imposing an organising structure can only be realised if the structure defined is flexible enough to cope with having to describe different aspects of a domain. Several researchers in the field (Bredeweg 1989a; Morgan 1988) are of the opinion that QP theory and the theory of Envisioning are in fact, complementary approaches. In some instances, it seems more natural to use the process-centred approach e.g. describing geological formations while in others, it is more natural to use the component-centred approach (especially where interactions between various materials in their bulk form is considered) e.g. describing electronic circuits. In fact, it seems that in certain situations, any of the three approaches may be used. Bonissone &

Valavanis (1985) show how the operation of a coffee-machine can just as easily be modelled using one approach as using the other approaches. The work of Bredeweg (1989b) has produced a single framework that integrates the different approaches which has proven to be useful in making the the similarities and differences between the approaches more explicit. His ultimate aim is to attempt to incorporate a higher level of reasoning (termed meta-level reasoning) which will enable the system to select and adjust its reasoning process depending on the current problem in hand. Thus, it would appear that, currently, there is no single modelling approach that is general and powerful enough to describe all the phenomena in the physical domain.

QP theory and the theory of Envisioning have very little to say about the abstraction of information from the real-world to the model i.e. how to ensure that the model is a good representation of the real life situation. Both these theories emphasise what should be contained in the library models. The guiding doctrine is the objective of ensuring that models are robust i.e. they must be able to function in novel environments.

De Kleer & Brown (1983a) assert that adherence to the principle of 'no-function-in-structure' will guarantee models that are robust. For example, given a low-level electronic description of how a capacitor works, a particular reasoning process should be able to infer how a filter would work. This principle however was found to be too impractical and was later modified to the 'class-wide assumption' principle which states:

> The laws for the component of a device of a particular class may not make any other assumptions about the behaviour of the particular device that are not made about the class in general. (de Kleer & Brown 1984).

A class of devices is determined by the assumptions those devices satisfy. These assumptions in turn outline the sort of theory necessary in order to be able to reason with the components. For example, the class of closed circuits satisfies assumptions about connection in loops and a theory based on current flow will suffice, whereas the class consisting of both open and closed circuits which satisfy the assumption that the context is electrical, will require a theory based on Ohm's law. A thorough investigation into the applicability of this principle can be found in Keuneke & Allemang (1989). These researchers conclude that the more completely satisfied the 'class-wide assumption' principle is, the more detailed the theory has to be in order to cope with the components specified i.e. these assumptions substitute for a more detailed description of the structure of the system, a view held by Iwasaki & Simon (1986). However, there are some instances in which even this modified principle cannot be obeyed. Some devices in themselves have no behaviour unless seen in some given context (e.g. beams of wood have no behaviour unless they are used as walls for example) while others have behaviour but their functionality is not apparent unless assumed to be in a certain context (e.g. the movement of air is important only in the context of a fan say).

The 'class-wide assumption' principle corresponds roughly to the use of simplifying assumptions in QP theory (Falkenhainer & Forbus 1988). Instead of trying to establish a universal (partially) specification as in the theory of Envisioning, QP theory acknowledges that multiple perspectives which may be incompatible need to be represented. For example, in some situations, a feed tank may be best viewed as an infinite capacity liquid source while in others, it should be viewed as a container which may be emptied. Consequently, the initial theory has been extended to include a new specification: the CONSIDER specifier which determines the details of the model to be considered (and therefore which may be ignored). For instance, within the context of the steam plant, the ability to selectively instantiate thermal properties is given by the description: CONSIDER (thermal properties). The thermal properties of an object will be instantiated when this CONSIDER assumption is believed. Representing simplifying assumptions imposes new responsibilities on the domain modeller: the model must be organised so that local decisions about relevance force a coherent subset of the model to be constructed i.e. if thermal properties are considered in one part of the model, then it must be considered in the connected parts.

Thus, it appears that defining appropriate representations that could cope with various aspects of the physical domain is still very much a research issue.

3.2.2 Prediction Aspects

All three approaches recognise that behaviours hold constant only within a particular operating region (in fact, the notion of time elaborated on previously is based on this premise). It seems logical therefore to investigate how behaviour within a state and how transitions between states are inferred.

A description of the behaviour within a state is given by the values of its parameters. Some of the values of these parameters may not initially be known. Because operations defined in the qualitative domain do not satisfy the axioms of field and ring theory in abstract algebra (see Tables 3.1 and 3.2), it is not possible to use the usual algebraic symbol manipulation strategy to solve for these unknown variables. Instead, a combination of constraint satisfaction and generate and test techniques are necessary to find all the solutions to a set of parameters (interpretations) which satisfies all the constraints. Multiple interpretations or ambiguity is an inherent characteristic of the basic qualitative mathematics. QP theory expands the value description to include signs and magnitudes for both the amount and the derivative of the parameter. But as Kuipers (1984) observes, in practice, QP theory does not specify arithmetic operations on numerical magnitudes.

A current state of behaviour terminates when the conditional laws defining it are violated. To determine when and how a particular behaviour terminates and proceeds to the next, a set of rules is used. This set of rules defines state diagrams, performs limit analyses and produces simulation trees. The specific rules given by the different approaches bear a strong resemblance to one another. The limit rule in Envisioning expresses the idea that is common to all: no state transition can occur unless some variable is changing. Another common view is that variables must change continuously i.e. a variable cannot move from - to + without passing 0. This is explicitly stated by the continuity rule (Envisioning) and implied by the I-transition and the P-transition tables (QSIM). There is also tacit agreement as to the order of changes i.e. which variables will change first, as witnessed by the definition of the equality change rule (Envisioning) and equality change law (QP theory). For example, it is stated that changes from equality (i.e. zero) occur before any other changes.

3.2.3 Interpretation Aspects

Interpretation involves transforming the results from solving the constraints and relationships into the language of the real-world system i.e. generating explanations. This process varies considerably for the different approaches and this is due to several reasons.

Firstly, it seems that the definition of causality is an intuitive one as far as the understanding of physical systems is concerned; what is termed a correct causal argument really represents tacit agreement as to what feels right. As Iwasaki & Simon (1986) have pointed out, human beings are able to assign causality to symmetrical equations. For instance, given the symmetrical qualitative equations, [s] = [i] and [i] = [l] where s is a switch (on or off), i is the current flow (flow or no flow) and l is a lamp (on or off), the causal explanation would be directed: $s \rightarrow i \rightarrow l$; if the switch is on, the current flows which in turn causes the lamp to be turned on.

Secondly, the results of the system depends on what has been modelled and how it is modelled. The theory of Envisioning categorically states that no notion of causality should be embedded in the construction of the component models (no-function-in-structure). The generation of causal accounts is derived by applying heuristic rules to the results of the system. The philosophical thinking behind the derivation of these heuristics are explained in the theory of mythical time and mythical causality. Thus, different causal accounts can be produced based on different premises, one of which should correspond to the user's account. QP theory, on the other hand puts forward the 'causal directedness' hypothesis:

> Changes in the physical situations which are perceived as causal are due to our interpretation of them as corresponding either to direct changes caused by processes or propagation of those direct effects through functional dependencies. (Forbus 1984).

Thus, assumptions need only be made about which processes are active and are therefore confined to certain variables as specified by the influences. Variables expressed in qualitative proportional relations should not be the subject of assumptions in building causal arguments. The third approach, the theory of Qualitative Simulation does not concern itself with generating explanations i.e. the interpretation of the results is left to the user. Recent publications (Kuipers 1987) however indicate attempts to extend this theory to cover causal explanation. The problem solving architecture which is tested in the medical domain includes a hypothesis-driven module which generates plausible cause-disease hypotheses. Each of the disease hypotheses is associated with descriptions of the physiological mechanisms. Qualitative Simulation is used to generate a description of all the possible behaviours of this physiological system which is matched against the hypothesis. The result is a rich description of both observable and internal parameters for a hypothesis.

The approach taken by Kuipers (1987) seems to be from a pragmatic view point without overdue concern as to defining the nature of causality. Morgan (1988) points out that there can be considerable effort wasted in the search for irrelevant and possibly non-existent causality in the physical domain since the human use of such terms is different from actual physical relationships.

3.3 Qualitative Reasoning Applied to the Social Sciences

In this section, the application of qualitative reasoning techniques to 'less-scientific' domains is examined; the first being the domain of macroeconomics and the second, the business domain. The idea of qualitative models is not new in economics. Samuelson (1947) in expounding his theory of 'calculus of qualitative relations' concluded that:

> purely qualitative considerations cannot take us very far as soon as simple cases are left behind. Of course, if we are willing to make more rigid assumptions either of a qualitative or quantitative kind, we may be able to improve matters somewhat.

With the resurgence of artificial intelligence techniques, there has been a renewed interest in the building of qualitative economic models. Indeed, Forbus (1984) expresses the view that QP theory should prove useful in reasoning about the economics domain in so far as differential equations are useful in describing the domain. However, caution is advised as there seems no real agreement on what mathematical descriptions are appropriate and hence, it would be difficult to judge whether a qualitative model is correct. The results of recent experimental work are presented.

3.3.1 Qualitative Reasoning in Economics

An important concern of economic theory is that of identifying equilibrium positions, be it in the commodity, money or labour market. To explain the meaning of equilibrium points, two other definitions need to be mentioned: endogenous variables and exogenous variables. Endogenous variable are variables that can be explained within the theory while exogenous variables are those that influence other variables but are themselves determined by factors outside the theory. For example, if there was a theory about the price of apples, then the price of apples will be an endogenous variable while the state of the weather which will influence the price of the apples is an exogenous variable. In the context of Keynes' theory of output and unemployment, consumption and investment are endogenous variables while government spending is an exogenous variable. An equilibrium point is defined when no more significant changes in the endogenous variables can be detected as a result of a change in its system's environment i.e. exogenous variables. New equilibrium positions may be established in response to changes in the exogenous variables exerting their influence on the endogenous variables. It should be noted that different theories may define different sets of endogenous and exogenous variables i.e. what may be seen as an endogenous variable in one theory may be taken as an exogenous variable in another.

FOG (Formal system for Order of maGnitude reasoning) applies constraint propagation techniques to an equilibrium model of commodity and labour markets. This model is described by a set of constraints; each constraint being a relation between variables (Bourgine & Raiman 1986). The relations defined by FOG are novel and differ from the traditional qualitative operators as they take into account the order of magnitude of the variable (for more details of this methodology, see Section 7.2). The values of the variables are derived through propagating the known values through existing relations. Sets of values are referred to as 'virtual points'. Some virtual points will satisfy some or none of the constraints. An equilibrium position is a virtual point at which all constraints are satisfied. A 'virtual path' defines all the intermediate virtual points between an old equilibrium position to a new equilibrium position. There may be many potential paths and rules are introduced to eliminate the undesired ones e.g. if the sum of the changes for the value of a variable is ambiguous. The identification of this path is further constrained by specifying when movements from one point to another can occur i.e. only when one more constraint can be satisfied. This virtual path is used to generate explanations of the market responses to a change in its environment e.g. a harvest failure resulting in a cut in the supply of commodities.

The first attempt at applying any of the classical qualitative reasoning approaches in a social-science environment is described by Farley (1986). This work builds on that proposed by Kuipers, with some modifications sufficient to represent the equilibrium-based framework of many economic theories and to produce the associated style of reasoning. In addition to the relations proposed by Kuipers (e.g M^+ and M^-), two other relations: $D^+(x,y)$ and $D^-(x,y)$ are defined. These indicate that the variable x responds directly to the change in y either positively or negatively i.e. the causal relationship is explicitly stated as y affects x. A set of equilibrium conditions are also added, which represent constraint relations that are satisfied at points of equilibrium. This enhanced formalism allows the qualitative simulation of the responses of a model defined by the classical macroeconomic theory of output and employment, in reaction to changes in prices and wages. Simulation begins with every variable at its initial equilibrium position. It proceeds with the introduction of the change in an exogenous variable e.g. prices. These changes are propagated through all relations other than the D relations. This state is complete when all values have been derived. To continue, the D relations are examined to see if they may propagate any effects; if so, the simulation continues. This 'D relation - other relation' propagation cycle terminates when an equilibrium (a cycle) is recognised.

A more recent effort (Berndsen & Daniels 1988, 1989) attempts to deal with feedback and causality within the Keynesian monetary model. They derive explanations about the behaviour of the model by investigating the movements of the endogenous variables between two equilibrium positions of the model. Kuipers' formalism is used to derive a set of constraints from the structural equations imposed by the theory. For example, the equation, $y = f(I)$ which states that national income (y) is a function of investment (I) is transformed into: $M^+(y, I)$. All values are initially set to their equilibrium values with the equilibrium position defined as the point where the money supply equals the money demand. A change in the money supply is initiated and the new values for the endogenous variables are then deduced for the next distinguished time point. The original I-transition and P-transition tables defined by Kuipers are combined into one table so that fewer transitions between equilibrium points are derived since they cover a interval to interval time period. The propagating-prediction cycle terminates on an equilibrium position being reached e.g. when the money supply equals the money demand. This same model was tested using other methodologies, namely, the theory of mythical time and causality (De Kleer & Brown 1984) and the theory of causal ordering (Iwasaki & Simon 1986). The authors' conclusion was that Kuipers's formalism provided a more intuitive notion of causality. It is difficult to tell from the literature available how different this approach is to Farley's and therefore it is not possible to question the necessity of the modification made in both cases.

3.3.2 Qualitative Reasoning in Business

Business decisions encompasses decisions made in all functional areas of a firm: marketing and sales, production, personnel, purchasing and stock, finance etc. Characteristic of decision-making in this domain is the need to resolve the interests of the different functional areas since in some instances, the goals of each function may conflict. For example, the sales department would like a high volume of stock to be held to reduce the loss of sales through a stockout while the finance department may prefer a low volume so as to release funds for more profitable ventures. These differences need to be resolved in a manner that best serves the firm's interests. Conflict analysis techniques can be used to analyse decision-making in such a situation. Woodward (1988) illustrates on the use of this technique on a two player perfect information model. Each player is asked to order a list of options that are open to all players. These preferences are then analysed and a ranking of outcomes is produced. This ranking is based on the strategy where one player's preferences will be maximised given that the other player cannot adopt a different strategy which would create a worse situation. These results are mapped against all possible sets of behaviour generated by Kuipers's QSIM system to produce a constrained set of solutions for a given decision to be made.

3.4 Summary

This chapter presents and discusses the seminal works in qualitative reasoning; it illustrates how qualitative models have been constructed and used to produce causal explanation using the different methodologies. The use of these models to perform trouble-shooting and prediction is not covered in the research; only the core issues of qualitative reasoning is considered since this effort represents an initial investigation. This chapter therefore provides some ideas on how the subject of qualitative financial models ought to be approached.

Although research in this area is still relatively young, successes of their application in the domain of physics, electronics and medicine have been claimed. However, it is still too early to say how successful these applications in economics and business are or can be; this research hopes to make a contribution towards making this evaluation.

4 Consolidating the Research Proposal

This chapter seeks to explore and discuss several issues relating to the viability of the proposed research. It establishes the fact that such a proposal is indeed feasible and presents a plan for managing and organising the project.

4.1 Case for the Research Proposal

It has been established in Section 3.1 that qualitative reasoning has been successfully applied to physical domains. There should therefore be no reason why it cannot be used in domains which are inherently more qualitative and imprecise, for example the financial domain. After all, it is part of our everyday language to hear some comment about firm A being a 'bad' risk or firm B making a 'big' profit.

The most motivating appeal of qualitative models is their ability to handle novel situations (i.e. robustness) since new situations and opportunities are an integral part of the nature of the financial domain. The ability to deal with a changing environment cannot always be predicted (and thus pre-encoded) and yet is vital for ensuring the firm's survival, allowing it to compete successfully in the market-place. It would appear that although there are attempts to define principles to ensure this (de Kleer & Brown 1984; Falkenhainer & Forbus 1988), the evidence suggests that these works are only initial efforts, with much more research needed before qualitative reasoning approaches can lay claim to the ability to construct robust models.

The second promise of qualitative reasoning approaches is the ability to construct models that can capture the basic cause-effect relations in a situation and therefore generate causal explanations. The identification of which events cause which others is much more of an issue in the physical domain where the behaviour of complex physical systems is typically determined by a large collection of simultaneous constraints. In financial domains, the coupling of cause and effects is looser and less well defined. Since the construction of causal explanations have been the subject of constant research and study, *real* causality (as opposed to mythical causality) is implicitly pre-defined in the models, examples of which are shown in Section 2.2.1. It seems therefore quite straight-forward to generate causal explanations for financial models. The challenge however is to ensure that the assumptions made about the model are kept separate so that when the assumptions changes, the explanations generated may be appropriately amended.

Qualitative models, however, have demonstrated abilities which can be exploited viz. the ability to generate all possible behaviours of the model automatically. This ability engenders the ability to infer if a particular behaviour is not achievable. Both of these abilities have their uses in financial decision-making, in determining viable courses of actions to take in order to achieve particular goals.

An examination into the use of qualitative models in economics and business proved to be inconclusive (see Section 3.3). This is because the work carried out has involved very recent research efforts with the result that very few details of them are available, and the models selected for illustration have been rather small and well constrained, typically involving 5-11 variables and 4-11 equations. Thus, there are two fundamental questions that still have to be answered. The first is: are the differences in the nature of the two domains, the physical on the one hand and the economics and business on the other, significant enough to invalidate the use of qualitative reasoning? The second question is: how different are the domains of economics, business and finance?

The domain of natural sciences deals with inanimate objects that are subject to natural laws. The social sciences, on the other hand, deal with human beings who have free will and therefore cannot be made the subject of inexorable laws. Does the lack of a stable response to a given stimuli mean that it is not possible to develop theories in the domain area? The answer is obviously no, as witnessed by the variety of theories developed in these fields (see Section 2.1.1). This is because observations can be made that are fairly stable for large groups e.g. buy when prices are low. However, although there is a proliferation of algebraic models (e.g. the NPV model in Section 2.2.1), there are few problems for which a global model exist. This stands in sharp contrast to certain problems in physics and engineering where excellent multi-level causal models exist. The absence of such models together with the fact that the laws are not inexorable does not invalidate the use of qualitative reasoning but instead demands that the use of qualitative reasoning and the interpretation of the results from executing the qualitative model be extremely carefully managed.

All current qualitative economic models take an equilibrium position as their starting point (see Section 3.3.1). Changes in the exogenous variables are introduced and a simulation of the responses of the endogenous variables is generated. Termination of the simulation occurs when another equilibrium point (either new or old) is reached. This characteristic is not so obvious or clear-cut in the business or financial domain, which makes it difficult to generate causal explanations within the qualitative model, as illustrated by the application in the business domain presented in Section 3.3.2. One possible solution is to incorporate heuristics about human behaviour; how this is to be done is discussed next.

A *quantitative* model in the financial domain does not capture all the heuristics that define the use of the model. This leads to the sometimes mistaken view that the domain area is under-constrained i.e. that anything can happen (Woodward 1988). On the contrary, the domain itself is quite well constrained; it is the models chosen to represent particular situations in the domain that are under-constrained and this largely due to the fact that an important set of constraints (i.e. heuristics) are excluded. One way of including heuristics is to use them as a post processor to the results of the qualitative model. The qualitative model generates all potential behaviours while the heuristics selects the desired behaviour (in much the same way as some researchers have used teleological reasoning to filter the results of qualitative reasoning). Such a method of incorporation should ensure a context-independent qualitative model which is able to perform under a wide variety of conditions. More significantly, the separation of qualitative reasoning and heuristic reasoning means that the interpretation of the model does not simply mean regurgitating the assumptions built in by the heuristics (see also Woon & Coxhead 1989b).

4.2 Research Methodology

Since it has been established that qualitative reasoning has a role to play in assisting decision-making in the financial domain, it would seem sensible to proceed by re-examining the theory in relation to its applicability to the domain. This task would be facilitated if a particular situation is selected to be modelled since this would provide a focal point for the discussion and permit illustrations to clarify the points being made. The situation chosen should satisfy certain criteria:

1. It should reflect a fundamental aspect of the domain. The reason for this is obvious: to ensure that results will be useful to all firms.

2. It should be extensible so that a range of simple to complex models may be constructed for it. One of the goals of the research is to produce a qualitative model of a real-life firm, since only then can a proper evaluation of the power of such models be carried out. An incremental model building approach with this target in mind ensures a systematic and comprehensive evaluation of the results from executing the models.

3. It should contain sufficiently diverse relationships to allow all aspects of the theory to be tested.

Such a situation is identified and introduced in Section 5.1. Funds flowing through the firm can be qualitatively simulated so as to produce changes in the various levels of financial resources (the corresponding quantitative analysis is given in Section 2.1.2). The level of these financial resources constrain the flexibility of the firm in responding to changes in its environment. How the firm finally reacts depends on what may be conveniently termed company policies and strategies since the decision may be a product of many decision makers (these strategies would make up what has been referred to as heuristics about human behaviour).

The conclusion(s) drawn from attempts to model this situation should be confirmed with the implementation of an experimental prototype. The emphasis of the prototype will be on generating the underlying qualitative model and solving it. Other basic features that should be provided are the facilities to accept specifications from the user, to perform some form of error-checking and correction, and to generate answers by referencing some canned text stored in the system. Although it would be desirable to have efficient and elegant algorithms, these are not the primary and overriding concern of the research project. The description of the implementation of such a system is given in Section 6.1.

To test the power and flexibility of the system in generating and solving qualitative models, models of different complexity and different types of data should be used in the experimental work and the results from these documented for analysis. Section 6.2 and Section 7.3 contain such accounts.

5 Funds Flow Model: A Qualitative Analysis

The first section in this chapter defines the features and characteristics of a funds flow model. This deliberation lays the foundation for the subsequent discussion on the difficulties of deriving the equivalent qualitative model and a possible satisfactory solution.

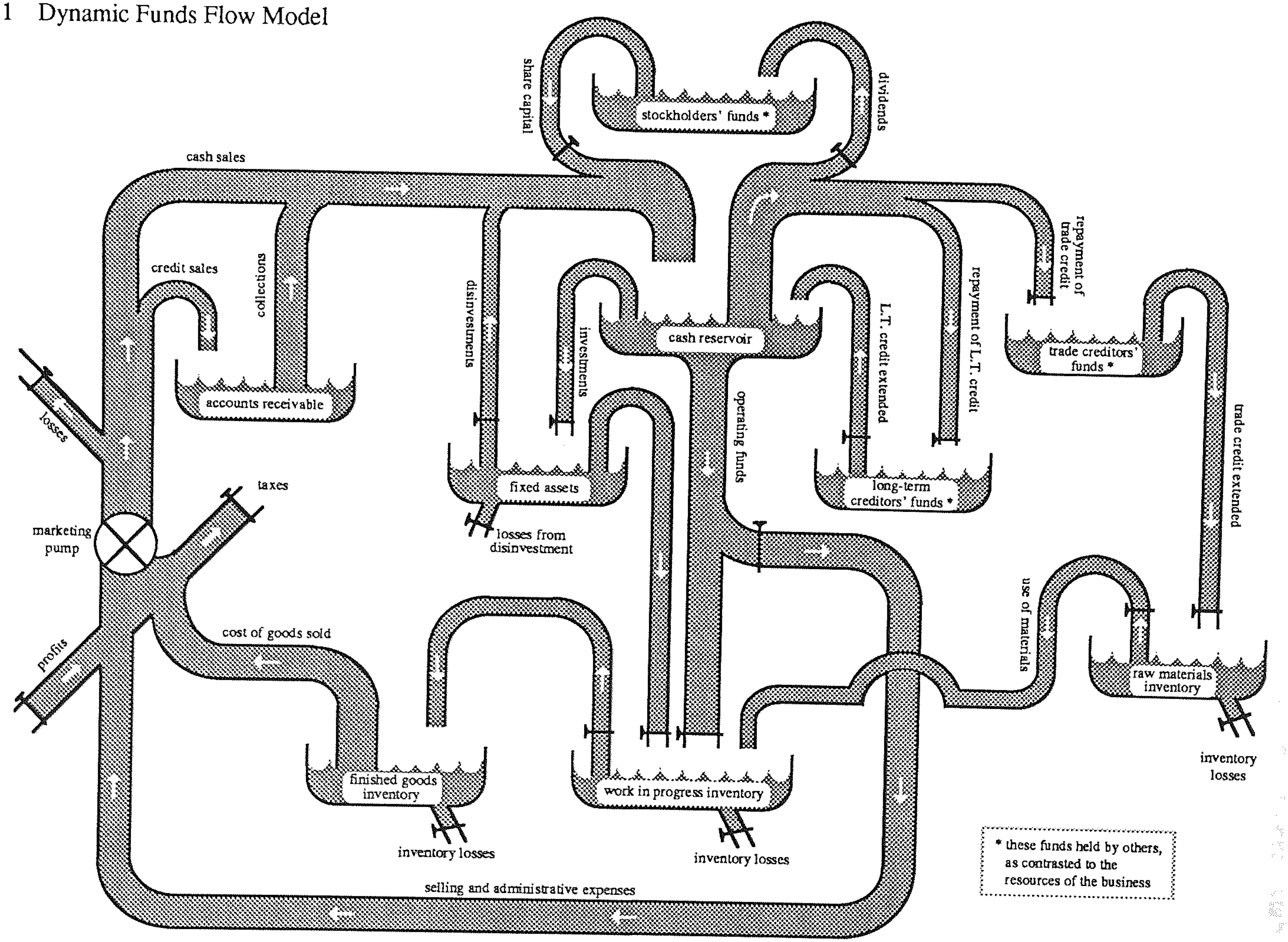
5.1 Defining a Funds Flow Model

Financial analysis is a very central issue in modern business decision-making, its underlying concern being to evaluate the economic condition of a firm. Such an exercise is undertaken for many and varied motives: to assist a prospective shareholder in reaching a decision regarding the purchase of shares in the firm, to assist a creditor in determining the financial viability of awarding a loan or to assist a manager in planning for investment, operations and financing decisions etc. The analysis task is, by and large, a judgemental process with each person having recourse to different sorts of information and a different understanding of analysis techniques.

One popular analysis technique involves analysing the flow of funds in a firm (Brigham & Gapenski 1988; Helfert 1978; Smith 1979) to see how funds have been acquired and how they have been utilised. The concept of funds is understood to mean all measurable resources, including cash. Figure 5.1 shows a model for a manufacturing firm (Helfert 1978); although all models illustrate the same fundamental concept, the model shown is particularly provocative in its depiction as it exhibits a strong resemblance to the fluid flow models that can be found in physical systems.

The normal activity of a manufacturing firm centres around transforming raw materials into a finished, saleable product. The firm may initially start off with investments from shareholders (share capital) and loans from financial institutions (long

Figure 5.1 Dynamic Funds Flow Model



* these funds held by others, as contrasted to the resources of the business

term credit extended). These funds will be used to mobilise all the activities necessary to carry out the firm's operations, such as the purchase of fixed assets (e.g. equipment), the purchase of raw materials, the hiring of the labour force (administrative expenses), advertising (selling expenses), and so forth. Once the infrastructure has been established, the raw materials purchased can be processed and sold. This sale generates funds enabling the purchase of more raw materials which can then also be processed and sold, thus maintaining the 'sale of goods - purchase of raw materials' cycle. Once this cycle is initiated, there is really no starting and stopping point.

Looking at the funds flow model in greater detail, goods produced by the firm are sold either for cash or on credit. A credit sale involves a receivable which, when collected, becomes cash. Raw materials, on the other hand, may be purchased on credit only (trade credit extended). A credit purchase involves a payable which becomes a drain on cash when it is paid. Raw materials within the system go through different stages of the manufacturing cycle before they are sold; costs that are incurred during these stages are allocated to them. These costs include not only the material costs but also equipment costs (depreciation) and labour costs (operating funds). In this model, selling and administrative costs are not allocated directly to the goods produced, although some firms may adopt this practice. If the proceeds from the sale of goods exceed their costs (i.e. raw material and processing) as well as that of selling and administrative expenses, then a profit is made for the period; if not, then there is a loss. Profits, together with new sales, are then circulated round the system.

Several interesting features may be identified in the model: the pump, the valves, the reservoirs and the draining pipes. The marketing pump stands as a surrogate for the complex set of interactions that typically occurs between the firm and its environment, resulting in its current sales. Therefore, factors such as how selling prices and sales volume are determined are not dealt with in the model. Other factors that are not considered are denoted by the valves which represent management's ability to control and regulate the funds at the points where they have been placed. For example, the valve setting at 'repayment of trade credit' symbolises management's inclinations to pay its trade creditors (of course, this could be due in part to the firm's ability to pay). These valve settings thus control the flow of funds through their associated pipes, influencing the level of funds within the tanks or reservoirs. These reservoirs represent the accumulation of funds that build up during the course of business activity, such as the accounts receivable reservoir and the cash reservoir. There are essentially two types of reservoirs: those containing funds that belong to the firm and those containing funds that are held by outsiders. Reservoirs containing funds that are the resources of the business may be referred to as asset reservoirs, examples of which are 'cash' and 'finished goods inventory'. Flows into asset reservoirs increase the level of funds in them, while flows out decrease their level. Reservoirs containing funds held by outsiders may be referred to as liability reservoirs, since these are claims that will have to be met in the future e.g. shareholder's funds, long term creditor's funds and trade creditor's funds. Since the measurement of funds is recorded from the firm's point of view, the liability reservoirs, in effect, hold negative levels. Flows into such reservoirs will reduce their level (i.e. reduce the negative level) while flows out will increase their level. Some reservoirs have draining pipes attached to them. These draining pipes denote losses to the firm e.g. debts that could not be collected become bad debts, or goods that do not meet the specified standards of quality become rejected and are counted as inventory losses. The valves on these pipes indicate management's ability to decide when to recognise these losses i.e. for the current period or future period. Thus, the model views the firm as a system of reservoirs and pipes through which funds are channelled, regulated by the positioning of the valves.

Variations of the model illustrated are possible. Different flow cycles may be constructed for different companies and industries to reflect the nature of the different activities of the firm. For instance, a high-street retail outlet will not have the related activities of the manufacturing process. Similarly, an outlet operating purely on a cash basis will not have the activities associated with debt collection included in the description of its model.

The funds flow model may be viewed as a static model or a dynamic model. In a static analysis, the net fund flows between two points in time are studied. These points correspond to the beginning and ending financial statement dates. Thus, the analysis portrays the net changes i.e. the sum of all changes that have occurred between these two dates. Quantitative values for some flows (e.g. sales, interest payments, selling and administrative expenses, and profit) can be directly derived from the income (profit and loss) statements since these describe operations over a period of time. Others are deduced by comparing the balance sheet figures over the two periods (balance sheet figures describe the firm's accumulated worth and debts since its inception). For example, the net increase (decrease) in fixed assets may be inferred by comparing the fixed asset values between the two points in time. Alternatively, detailed financial records e.g. fixed asset ledgers may be consulted to derive the individual values for investments, disinvestments and losses from disinvestments. In a dynamic model, the gross funds flow is studied i.e. all the changes that occur between the two statement dates. Although the analysis of the gross funds flow over time would be more revealing (and more importantly, more relevant to the real world), the financial information available constrains the analysis to the study of the static model.

5.2 Defining a Qualitative Funds Flow Model

The literature of corporate financial management has consistently reiterated the usefulness of a funds flow analysis. However, only computerised facilities providing quantitative analysis (such as that given in Section 2.1.2) is currently available. A comparison of such an analysis against the verbal account given in Section 5.1 serves to illustrate the deficiencies of quantitative analysis: the details that are lost, the implicit assumptions that might not be apparent to the users and the need for human interpretation of the results.

In order to construct a formal qualitative model for a given situation (e.g. the model in Figure 5.1), four main issues have to be addressed: identifying the primitives of the model, specifying the relationships between the primitives, describing the model in terms of the primitives and their relationships, and determining any assumptions that need to be made. In doing so, the adequacy of the current qualitative value and operations system is questioned and addressed (see also Woon & Coxhead 1989a).

5.2.1 Identifying the Primitives

The primitives in physical systems are the entities (e.g. water, springs) and the properties of the entities (e.g. pressure, level, temperature). In the funds flow model, interest is also focused on the variables identified in the system e.g. cash, profit, debt etc. Although each of these variables has several properties (e.g. liquidity, risks, costs), the analysis is largely concerned with only one property: that of amount.

How are the parameters (properties of variables) to be described? Forbus (1984) gives the most comprehensive description for parameters: the sign of the amount, the magnitude of the amount, the sign of the derivative and the magnitude of the derivative. The basic value set for these parameters is {-,0,+}. The sign of the amount can be used to deduce the behaviour of a component or a process. The sign of the derivative will indicate the direction of change and thus predict the next expected behaviour of the component or which process will follow. The magnitudes of the amount and the derivative perform the function of resolving ambiguous cases (see Table 3.4).

In physical systems, the sign of the amount of the variable (i.e the sign of the difference between the quantitative value and the landmark value which is taken to be the value zero) is used to indicate behaviour that is radically different from other potential behaviours. All radically different behaviours in a given context is therefore defined by the intersection of the possible signs (in this case -, 0 and +) for interesting variables. The funds flow model in Figure 5.1 has around forty variables defined; this would lead to 3^{40}

possible states which is a prohibitively large number of states to analyse. However, experience with physical systems shows that a large number of these may later be ruled out by constraints. A subtle difference in the nature of the two domains is that in the financial world, it might be said that the opportunity exists to support significant changes of behaviour rather than that significant behaviour occurs. Because of this, it is more appropriate to say that behaviour only changes when the analyst views some aspect of the company as inadequate. For instance, a firm making a borderline *loss* and a firm making a borderline *profit* can be considered as inadequate.

What yardstick(s) are used as tests of adequacy? To answer this question, it is necessary to examine the domain area to see the kinds of data the analyst typically uses and how these data are used in the reasoning process. Reasoning within the financial domain must include some form of value judgement. In financial analysis, quantitative values are not usually directly used for reasoning; there is a need to take into account factors such as inflation and variations in the sizes of companies. One way of doing this is by applying the technique commonly referred to as ratio analysis (mentioned in Section 2.1.2). An analyst typically compares a firm's ratio against some standard to derive an interpretation for some aspect of the firm. For example, if the firm's ratio of current assets to current liabilities is higher than that of the industry's average, then it may be said that the firm is well placed to handle emergencies like the unexpected calling in of debts. Bouwman (1978) from inspecting the protocols of his subjects, identified several main types of comparisons that are typically made:

1. Comparison over time. Results are interpreted in terms of changes in the values. Typical examples are: "output increased somewhat relative to last year", "output was up 20000", "output is about the same level compared to previous years", "output is way below the 1971 level".

2. Comparison with industry average. The comparison of single figure (ratio) with a given industry average. The results were characterised by qualifications like “above”, “below” and “equal” to industry average.

3. Comparison with an internal norm or rule of thumb. Evaluation is characterised by the implicit use of some rules which is not available in the financial information provided. For instance, subjects tend to hold that certain figures like profits and earnings have to remain positive. Results are expressed in terms like “good” and “bad” e.g. “inventory level is bad (= zero)”.

4. Comparison with a norm item. The identification of the norm item is peculiar to each subject and again, not available in the financial information provided; this knowledge is part of the subject’s model of the domain. Examples of these are: “the amount produced lagged behind the planned production”, “units sold is way behind demand”.

The concept of comparison over time is similar to that of working out the sign of the derivatives and will be discussed later. Looking at the remaining kinds of comparisons, it seems that in general, some norm is expressed against which comparisons are made. This norm may therefore be viewed as a landmark value. However, this landmark value might not be necessarily *zero*. Additionally, there is a need to accommodate the accounting convention used in recording transactions. Although these are recorded from the firm’s viewpoint, the financial statements and therefore the model, does not contain any negative flows, of which creditors and losses are examples. All this suggests that what is required are qualitative mappings for the positive quantitative space, with a provision of a norm i.e. landmark value. Figure 5.2 compares the proposed qualitative scale which is labelled as the set, {low,normal,high} against the conventional qualitative set. Although ‘normal’ is shown as a point value in the figure, it is also possible to conceive of it as corresponding to a range of real values. Similarly, although 'low' and 'high' are shown as corresponding to a range of real values, they may under certain circumstances correspond to a single value on the real-number line.

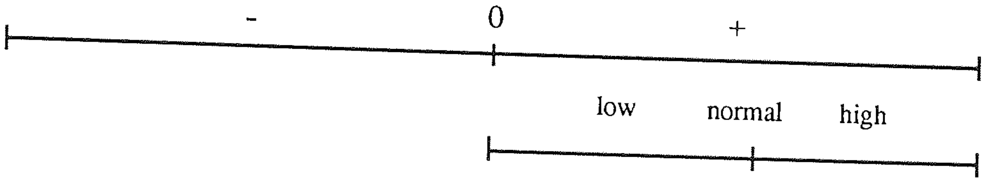


Figure 5.2 {low,normal,high} *vs* {-,0,+} Qualitative Value Sets

The conventional value set for the sign of the derivatives is also the set {-,0,+}. The sign of the derivative is used to determine that next state of the variable. If a variable is changing in a positive direction, this variable will eventually move onto the next value on the qualitative scale. For example, if the current sign of the amount of the variable is 0 and the sign of its derivative is +, then the expected sign of the amount of the variable will eventually reach a + value. This implies that the landmark value holds constant over time which it does, since it is *zero*. A look at the historical figures for industry ratios (landmark value) will reveal that these tend to fluctuate over time. For example, the profit margin (profit/sales ratio) of the Oil and Exploration sector in the United Kingdom dropped from 39.2 in 1984/5 to 34.5 in 1985/6 and to 21.4 in 1986/87 (courtesy of ICC Business Publications 1988). Because of this, although a firm's performance may improve over its previous year's, if this improvement is poorer than that for the industry as a whole, then it cannot be said that the firm's standing in the industry has been promoted. A clearer illustration of this phenomena can be further be made by considering a firm that has not improved its performance over its previous year's. However, if the performance for the industry as a whole, has consistently deteriorated, then the standing of the firm may be said to be enhanced. It is therefore not possible to take just the difference between the current value and the previous value of a variable in order to derive the sign of the derivative, since a positive derivative does not mean a potential enhancement in the firm's overall standing. Instead, a comparison of the difference between the firm's previous and present ratio and the difference of the industry average ratio for the same time periods has to be taken i.e. sign of the derivative = (firm's present ratio - firm's past ratio) - (industry's present ratio - industry's past ratio).

Thus, it can be seen that the derivative set for the funds flow model is not compatible with the amount set, as in the conventional approach. Since the interpretation of the derivative set is rather unusual, a full investigation into it will not be addressed by this thesis. Instead, only the amount set (i.e.{low,normal,high}), for which some principles exist, will be analysed.

5.2.2 Specifying the Relationships between the Primitives

Relationships in qualitative models have conventionally been expressed through the use of qualitative operators (see Tables 3.1 and 3.2). As the definition of the {low,normal,high} set differs from the traditional set, the operators will have to be re-investigated to see if they are applicable. To proceed, all variables will need to have their full quantitative value reduced to one member of the qualitative set {low,normal,high}. The qualitative value of a variable x will be denoted by the use of square brackets i.e. [x].

[x] [y]	low	normal	high
low	low	low	ambig
normal	low	normal	high
high	ambig	high	high

Table 5.1 Addition Operation: [x] ⊕ [y]

[x] [y]	low	normal	high
low	ambig	high	high
normal	low	normal	high
high	low	low	ambig

Table 5.2 Subtraction Operation: [x] ⊖ [y]

The first sort of relationship that needs to be expressed concerns how flows in and out affect the level of the reservoir they are associated with. The operators that express such relationships are the qualitative addition (⊕) and subtraction (⊖) operators. Tables

5.1 - 5.2 defines the operations. In certain cases, e.g. adding high and low, the result can be any one of high, normal or low, i.e. is ambiguous. The value, 'ambig' is used solely as an abbreviation for the expression 'high | normal | low'. These two tables are identical to the corresponding operations on the {-,0,+} set.

The next sort of relationship that needs to be considered are ratios which are used as a basis for comparisons. This implies the use of the qualitative multiplication (⊛) and division (⊘) operators. Tables 5.3 and 5.4 define these operations.

[x] [y]	low	normal	high
low	low	low	ambig
normal	low	normal	high
high	ambig	high	high

Table 5.3 Multiplication Operation: [x] ⊛ [y]

[x] [y]	low	normal	high
low	ambig	high	high
normal	low	normal	high
high	low	low	ambig

Table 5.4 Division Operation: [x] ⊘ [y]

Tables 5.3 and 5.4 are totally *different* to the corresponding operations on the {-,0,+} set. A flow that is low (i.e. below norm) when multiplied with another flow that is low (i.e. below norm) will give a resultant flow that is low. This is in contrast to the conventional set where - qualitatively multiplied with a - gives a +! It is also interesting to note that the tables for multiplication and addition are identical in the {low,normal,high} set, as are those for division and subtraction; subtraction is the inverse operation of addition and division is the inverse operation of multiplication in the conventional set.

Thus, the case for proposing a different value system for use in the financial domain is further strengthened by the differences in the results of performing various qualitative operations. The precise properties of this value system need investigation, since they determine how equations involving them ought to be written so as to express the exact semantics of any situation. Since qualitative addition and multiplication are identical, as are qualitative subtraction and division, it is usually only necessary to discuss addition and subtraction, with any conclusions transferred automatically to multiplication and division respectively. The qualitative value system put forward here has the following properties, which can be verified by the use of Tables 5.1 to 5.4.

(i) As in quantitative algebra, addition is a commutative operation, whereas subtraction is not, i.e. for all qualitative values [x] and [y]:

$$[x] \oplus [y] = [y] \oplus [x]$$

$$[x] \ominus [y] \neq [y] \ominus [x]$$

(ii) As in quantitative algebra, addition is an associative operation, whereas subtraction is not, i.e. for all qualitative values [x], [y] and [z]:

$$[x] \oplus ([y] \oplus [z]) = ([x] \oplus [y]) \oplus [z]$$

$$[x] \ominus ([y] \ominus [z]) \neq ([x] \ominus [y]) \ominus [z]$$

(iii) As in quantitative algebra, multiplication and division are distributive over addition and subtraction, e.g.:

$$[x] \circledast ([y] \oplus [z]) = ([x] \circledast [y]) \oplus ([x] \circledast [z])$$

However, the identity of multiplication with addition and division with subtraction means that qualitative addition and subtraction are also distributive over qualitative addition and subtraction, e.g. $[x] \oplus ([y] \oplus [z]) = ([x] \oplus [y]) \oplus ([x] \oplus [z])$.

(iv) The set of qualitative values, Q = {low,normal,high}, has an identity for addition and subtraction, viz. normal, since for all qualitative values [x]:

$$[x] \oplus \text{normal} = [x]$$

$$[x] \ominus \text{normal} = [x]$$

(v) Each element of Q does not have a strict additive or subtractive inverse element. Since as noted in (iv), normal is the identity for both operations, a strict additive inverse would require that for every [x], $[x]^{inv}$ existed such that:

$$[x] \oplus [x]^{inv} = \text{normal}$$

Table 5.1 makes it clear that this is not so. This is highly inconvenient as it appears to prevent the re-arrangement of equations, which generally involves the implicit addition of inverses in order to transfer terms from one side to another. One solution is to define the additive inverse as the negation operator (Table 5.5), as in ordinary arithmetic, and also extend the equality operator via Table 5.6 so that a value of ambig appearing on one side of an equation is equal to any value on the other side. A similar approach can be used for subtraction.

x	$\ominus$x
low	high
normal	normal
high	low

Table 5.5 Negation Operation: $\ominus$ [x]

[x] [y]	low	normal	high	ambig
low	true	false	false	true
normal	false	true	false	true
high	false	false	true	true
ambig	true	true	true	true

Table 5.6 Equality Operation: [x] $\circledequal$ [y]

Equations can now be solved in the usual way. For example, consider the equation:

$$[x] \oplus \text{high} \circledequal \text{normal} \tag{1}$$

There are two ways of solving this equation to find [x]. Firstly, each of the three possible values of [x] can be substituted into (1) in turn, checking which satisfy it. Only [x] = low does so, since the left-hand side of (1) is then ambig, which is qualitatively equal to the right-hand side normal, according to Table 5.6. Secondly, (1) can be re-arranged:

$$\begin{aligned} & [x] \oplus \text{high} \circledequal \text{normal} \\ \Rightarrow \quad & [x] \circledequal \text{normal} \ominus \text{high} = \text{low} \end{aligned}$$

Whichever method is used, the definitions of inverse and equality ensure that the same answer is obtained. However, since ambig has been taken to be qualitatively equal to normal, equations which would yield the same quantitative solutions can yield different qualitative solutions: in particular, ambiguity is possible.

To summarize: properties (i), (ii) and (iii) taken together mean that qualitative expressions involving $\oplus$, $\ominus$, $\circledast$ and $\oslash$ can be written as if they were normal quantitative expressions evaluating from left to right. To ensure the correct evaluation of nested expressions, parentheses may be needed when the operators $\ominus$ and $\oslash$ are used. Common variables in equations can be factored, since all the qualitative operators are distributive; this means that expressions may be simplified without any loss in accuracy. Property (v) however means that equations which are quantitatively equivalent are not necessarily qualitatively so.

5.2.3 Describing the Model

It is tempting to think that the formalism of QP theory (Forbus 1984) can be used to describe the funds flow model. This is in view of the fact that the exposition of this theory has been illustrated with examples of fluid flow systems on which the fluid flow model is based. However, a close examination reveals that these similarities are only superficial. The flow of funds around the model of the firm is not subject to physical laws; it does not consider gravity or pressure for example. The interaction of processes and objects do not necessarily result in new processes and/or new objects being created unlike events that occur in the physical world. For example, assuming that the collections from accounts receivable process is initiated, this would increase the amount of the object, cash (the reservoirs would need to be viewed as having infinite capacity). This change in the amount of cash does not automatically trigger off any other process e.g. repayment of trade credit etc. In fact, it is possible that none of the processes may be initiated. There is therefore not the continuous chain of processes and events that initiate one another, which is so useful in constructing convincing arguments and explanations in the physical domain. More significantly, it demonstrates how underconstrained the funds flow model is compared to applications drawn from the physical domain.

Conceptually, there are two levels of relationships shown in the funds flow model, of which only one is explicitly defined. This is the effect of changes in the amount of the variable on one other. The other relationship is not explicitly shown but is indicated by the presence of the valves and the pump. These valves and pump represent yet another important set of constraints on the functioning of the model; they provide a large part of the automatic triggering actions and reactions. For example, a firm whose priority is to upgrade its equipment (fixed assets), will increase the opening of the investments and the long term credit extended valve (assuming financing of the purchases is to come from long term debt) while keeping the other valves steady. Such actions result in triggering off the following chain of events: an increase in long term creditors funds leads to an increase in cash which leads to increase in fixed assets.

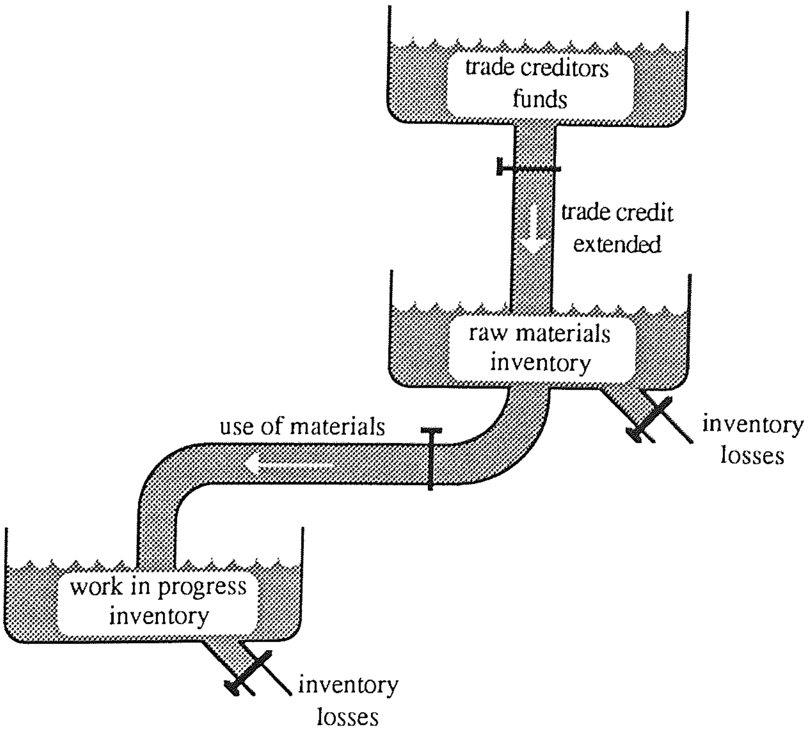


Figure 5.3 Raw Material Inventory Reservoir

It is possible that the funds flow model can be viewed as some sort of artificially engineered contraption. The theory of Envisioning (de Kleer & Brown 1984) has chosen engineered devices as its test-bed. Hart *et al.* (1986) suggest that the qualitative causal relations captured in the funds flow model can be abstracted and described using confluences. For example, consider the raw materials inventory reservoir in Figure 5.3. The value of this inventory is increased by purchasing raw materials (illustrated by the supplier extending trade credit to the buyer) and is decreased by using the material in the manufacturing process. Following the notation of confluences, this relation (ignoring the inventory losses) would be written as:

$$\partial(\text{use of materials}) - \partial(\text{trade credit extended}) + \partial(\text{raw materials inventory}) = 0 \qquad (2)$$

where the differentials are understood to represent qualitative changes. This confluence states that trade credit extended positively influences the use of materials, that the use of materials negatively influences the raw materials inventory and so forth. The general conclusion of Hart *et al.* is that if one confluence were to be written for each node in the model (see Figure 5.1), then these collectively would constitute a qualitative funds flow model. Very little is said about the relevance of the rest of the theory of Envisioning; in particular, it does not seem that the derivation of the confluences proceeded from identifying the components and the laws governing the behaviour of the components. Indeed, an analysis of the applicability of the theory reveals some problems. Suppose the components are taken to be: pump, pipes, valves and reservoirs. The behaviour of these components needs to be expressed in a fairly context-free manner to comply with the principle of 'class-wide assumption'. This is not possible since these components are *artifacts* that exhibit behaviour within an *artificial* context; the reservoirs need to be viewed as having infinite capacity, the behaviour of the asset reservoir is different from that of the liability reservoir although both are reservoirs with pipes leading in and out of them. Thus, references to pumps, pipes, reservoirs and valves are not to be taken à la de Kleer and Brown; they are merely convenient for associating meaning with the funds flow model given in Figure 5.1.

Qualitative Simulation (Kuipers 1984) seems to be appropriate since this approach does not impose any form of organising structure on the information to be modelled. A copy of QSIM was obtained and experimented with. However, the large number of relationships that need to be expressed using a binary relationship specification (e.g. M^+ and M^- operators) makes the system description very unwieldy since only two variables may be related with any given function. A more efficient representation would be to use the formalism of quantitative equations and transform these into qualitative equations. This transformation involves replacing every quantitative value with a qualitative value and every quantitative operator with a qualitative operator. However, subsequent investigations reveal a more serious problem than merely that of specification efficiency, namely, the unnecessary introduction of ambiguity into the system. This will be more fully discussed in Section 6.2.1.

What is the form of the quantitative equations for reservoirs? This depends on the meaning of the relationship that is to be expressed. The proceeding discussion concentrates only on asset reservoirs since liability reservoirs represent the converse situation. Any conclusions drawn from analysing the asset reservoir are also applicable to the liability reservoir, adjusting to achieve the converse effect.

For a particular asset reservoir, it is true to say that its change in level over a period of time is the effect of the accumulated inflows and accumulated outflows over the same period:

$$\text{end reservoir level} - \text{start reservoir level} = \sum_{i=1}^{n} \text{inflow}(i) - \sum_{j=1}^{m} \text{outflow}(j) \qquad (3)$$

where inflow(i) and outflow(j) should be read as accumulated flows over a particular accounting period. Since the initial interest is to investigate the level of the reservoir at the end of an accounting period i.e. end reservoir level, the start reservoir level may be taken as ‘normal’. Thus, the qualitative version of equation (3) may be written as:

$$[\text{end reservoir level}] \;\; \theta \; \sum_{i=1}^{n}[\text{inflow}(i)] \;\; \theta \; \sum_{j=1}^{m}[\text{outflow}(j)] \qquad (4)$$

which reads as the level being positively influenced by the sum of its inflows and negatively influenced by the sum of its outflows. However, it may be better to treat the qualitative equations as merely representing influences of one parameter on another rather than representing some underlying quantitative relationship. Therefore, the raw material inventory reservoir (given in Figure 5.3) will be described as:

$$[\text{use of materials}] \; \Theta \; [\text{trade credit extended}] \; \oplus \; [\text{raw materials inventory}] \; \ominus \; \text{normal} \qquad (5)$$

which states that if the use of materials is high and trade credit extended is low, then raw materials inventory reservoir must be low i.e. below the industry's norm. It must be emphasized that although (5) looks similar to (2), they have different meanings and are based on different understanding of the model; the confluence approach uses the conventional value set of {-,0,+} and describes values solely in terms of their qualitative *derivative* value whereas the proposed approach uses only the qualitative value set {low,normal,high}.

Equations need not be written for valves and pipes. Valves merely indicate the presence of external controls on flows; the decisions governing these controls are beyond the scope of the funds flow model. Thus, a valve on the purchases flow indicates the courses of actions open to a firm or identifies situations where the firm has some control over the decision to be taken. The amount of trade credit extended depends on both how much the supplier is able willing to supply and how much the firm is willing to purchase. Therefore, the valve on the trade credit extended flow indicates the partial ability of the firm to influence the decision. In other situations, the firm has strong control over the decision. For example, a firm is able to decide when to recognise a debt as being uncollectable (bad debts); bad debts are written off against profits of the period they are recognised in. Debts which are unrecognised as bad count as assets of the firm; of course, the limits to which a firm may refuse to recognise a debt as bad is governed by regulations. The absence of a valve indicates the inability of the firm to influence such decisions e.g. collections from accounts receivables. Pipes serve no function except to channel funds to and from the reservoirs. They have therefore already been considered in the derivation of the reservoir equations.

Lastly, an equation to express the function of the pump is needed. The pump represents the interface between the firm and its environment. Its function is to generate revenue in the form of sales that will allow the flow cycle to be maintained. This is shown in Figure 5.4 which is abstracted from Figure 5.1 (for simplicity, taxes are ignored). However, for the continued survival of the firm, it is not enough that sales is generated; a certain level of sales must be generated. In other words, the firm must seek to, at least, break even i.e. the value of sales must equal the value of goods sold plus the selling and

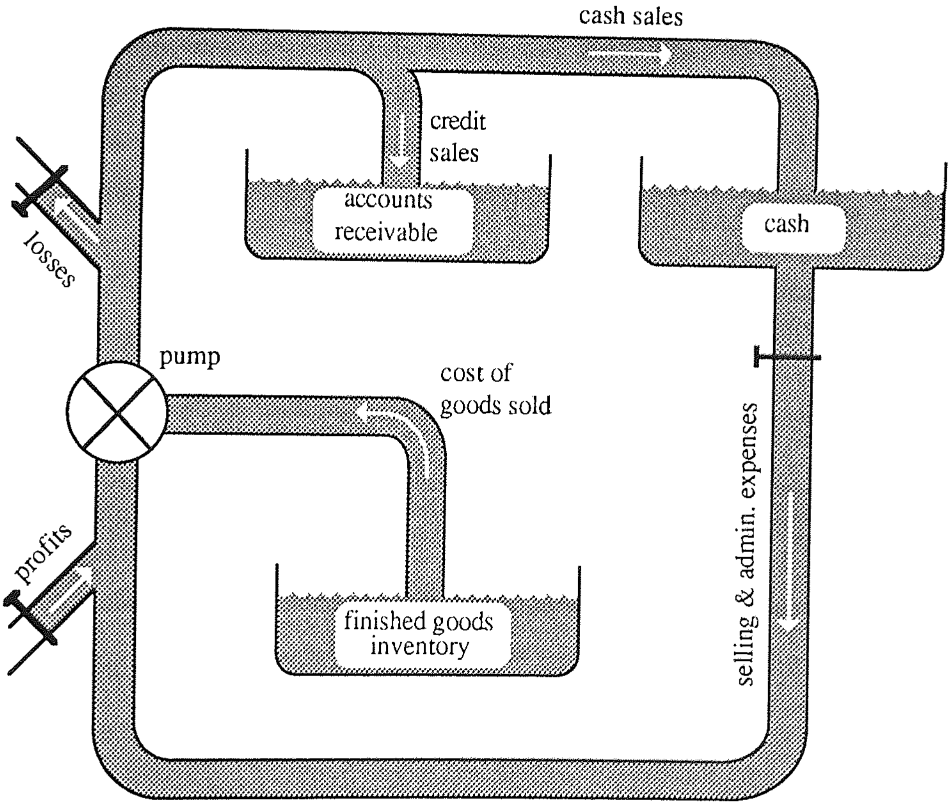


Figure 5.4 Flows through the Pump

administrative expenses. Levels of sales below the break-even point will result in the firm suffering a loss, which is shown as a flow out of the system. Levels of sales above the the break-even point will result in the firm making a profit, which is shown as a flow coming into the system. The equations describing the possible scenarios are:

[sales] ⊖ [cost of goods sold] ⊖ [selling and admin expenses] ⊖ [profit] ⊜ normal (6a)

[sales] ⊖ [cost of goods sold] ⊖ [selling and admin expenses] ⊕ [loss] ⊜ normal (6b)

[sales] ⊖ [cost of goods sold] ⊖ [selling and admin expenses] ⊜ normal (6c)

However, this is by no means the end of the story; there is still the question of identifying what the pump drives i.e. what management controls. In the case of valves, this is fairly clear-cut; a single valve controls a single flow through the pipe where it is placed. There are however many flows through the pump, for example, sales, cost of goods sold, selling and administrative expenses, profit and losses. Each of these will be considered in turn.

As it has been decided that the analysis will be confined to a purely static model, profit and losses are taken as the resultant effect of operations; they are treated as elements that cannot be controlled directly. There is a valve on the selling and administrative expenses which indicates management's ability to control this flow quite independently. The only flows left to consider are the sales and cost of sales flows. Sales is the result of the marketing effort of the firm; it seems plausible to say that the pump drives sales around the model of the firm. What about the cost of sales? The cost of sales is, in reality, an exercise in placing a value on the volume of the goods sold, with an aim of maintaining control over the operations of the firm. Sales can also be viewed from the same perspective i.e. it is an exercise to put a market value on the volume of goods transacted. Pricing policies of the firm determine this market value. Similarly, costing procedures determine the cost value on the same volume of goods. Seen in this perspective, the pump drives the volume of goods transacted around the model of the firm with sales values associated to them when they enter the system and cost values associated with them when they leave the system. Should this underlying meaning be reflected in the definition of the funds flow model? And if so, by what form of equation? This issue will be further explored in the next chapter on experimental work.

5.2.4 Determining the Assumptions

Several assumptions have been made in obtaining an appropriate description of the model. The following chapter analyses the results from executing the qualitative model. It therefore seems pertinent that these assumptions should be collected together and implications resulting from them reviewed.

Firstly, the financial information available restricts the analysis to that of a static model. This means that time lags and feedbacks, a nagging problem in the description of physical systems, can be ignored. Financial statements adopt the accounting principle of *allocating* and matching costs to the revenues that generate them. Thus, the profit or loss for the period is viewed entirely from a retroactive perspective.

Secondly, each firm is assumed to have only one pump i.e. one form of interaction with its environment. This may not always be the case since many firms, especially large corporations, own and manage diverse interests covering a wide range of industries. As an example, take Rediffusion in the United Kingdom, who not only dabble in the hi-fi market but also manufacture flight simulators. One pump is required for each different interest of the firm since the interactions will be different. Indeed, a more refined analysis might consider that a different pump is necessary for the different product lines (e.g. luxury *vs* economy range) of the firm.

Thirdly, valves are placed at points which are under the control of the management. So far, the view that has been taken is the profit (loss) is the *result* of operations i.e. there is no explicit valve. In reality, it may be the objective of the firm is to achieve a certain level of profit and thus it sets all 'valves' to achieve this. Similarly, if the firm is making a loss, then it might want to set the level of loss acceptable in the circumstances and have every other valve synchronised to meet this goal. The synchronisation and control of valves and the pump are effectively what drives the model. These however are not represented nor can they be represented within the funds flow model. Thus, instead of the active role, valves assume the role of relatively passive markers within the current context.

Lastly, the funds flow model is only able to depict flows and levels. Variables within it possess properties other than amount. Consider another property, liquidity. The degree of liquidity of the firm is essential to ensure the maintenance of everyday operations. Variables can be characterised by their relative degree of liquidity e.g. cash is the most liquid, finished goods inventory and accounts receivable less so and fixed assets even less. A firm might decide to improve its liquidity and as such will operate the appropriate valves to achieve this. However, this will only be interpreted *in the context of* the funds flow as an increase in the amount of cash (say), rather than an attempt to increase liquidity.

5.3 Summary

To illustrate the complexities that can be encountered in building qualitative models in finance, the funds flow model of a firm given in Helfert (1978) is considered. The qualitative reconstruction of this model provides the arguments and justifications for proposing some new concepts towards the theory of financial qualitative reasoning, namely, a new qualitative value set with its associated operations and a formalism for describing the relationships in the model. This chapter documents the theoretical foundation. In the next chapter, the truth of these concepts are tested.

6 Qualitative Flow of Funds: Experimental Work

This chapter begins with an explanation of how a system that is able to handle qualitative models, has been implemented. The implementation of the system was carried out using Quintus Prolog, Version 2.0 running on a VAX 8650 under the VMS Version 4.9 operating system and on a Sun 3/160 under the SunOS Release 4.0 operating system. The source code for the system amounted to ≈120k bytes*. Like all other programming languages, Prolog has its advantages and disadvantages; these will be discussed when the various aspects of the system are considered. This section is followed by an analysis of the results from a series of experiments that were conducted using the system developed.

6.1 Implementation: System Overview

Figure 6.1 (overleaf) shows the interactions between the five modules making up the entire system. These modules perform the functions of analysing and verifying the specification of the model (Structural Specification Analyser), generating the underlying qualitative equations (Qualitative Equation Generator), accepting and analysing the data (Data Analyser), solving the qualitative equations (Solution Generator) and generating explanations from the results (Explanation Generator). To give the reader a flavour of the system, a simple example is worked through; this is shown in Appendix E. However, the system is capable of handling more complex situations. The full range of the system's capabilities for each function will be discussed in greater detail in the following sections, and fully illustrated in the appropriate appendices.

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* The source code can be obtained by either writing to: Dr P Coxhead, Department of Computer Science and Applied Mathematics, Aston University, Aston Triangle, Birmingham B4 7ET or by sending an e-mail message via the JANET network to : coxheadp@UK.AC.ASTON.CLUST.

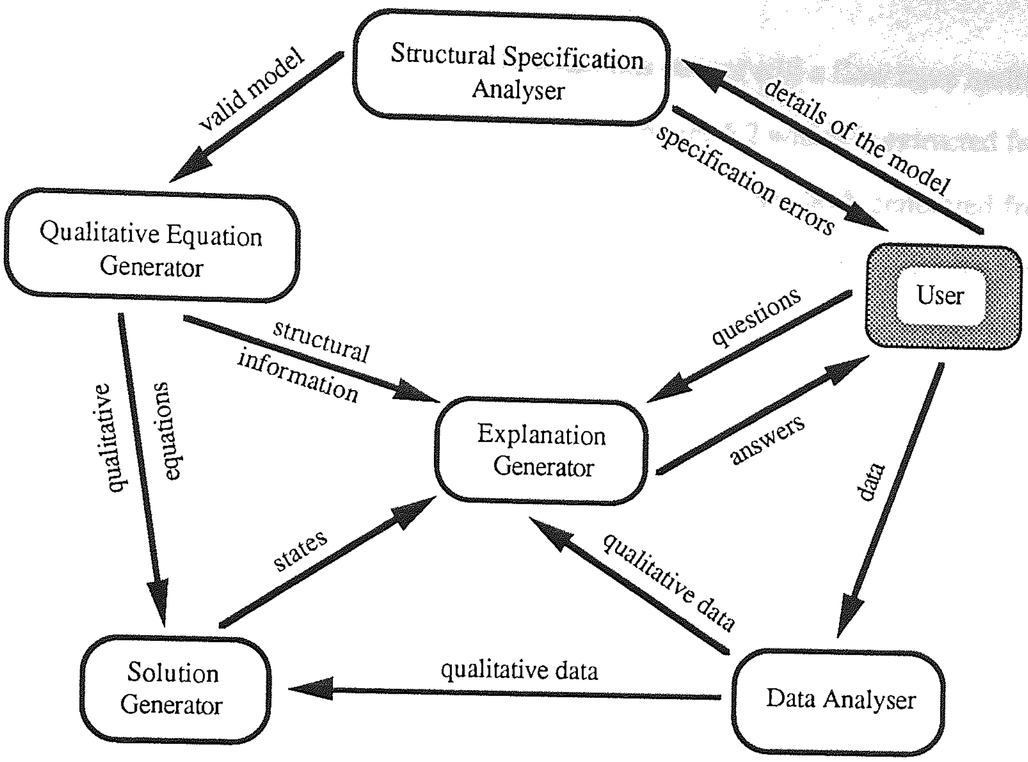

Figure 6.1 System Overview - Initial Version

6.1.1 Analysing and Verifying the Model

The first module accepts a structural specification of a firm's flow of funds model from the user in terms of pump(s), flows and reservoirs. In the current system, the assumption is that there is only one pump. Rules used in verifying and constructing the model are:

1. Sources and destinations are defined in terms of the pump, flows and tanks (reservoirs).

2. Multiple destinations and sources are permissible. A pump or a tank may have more than one flow running into it (i.e. many sources) and/or sustain more than one flow out of it (i.e. many destinations). A single flow normally originates from either a pump or a tank and terminates in either the pump or a tank i.e. it has only one source and one destination. Under certain circumstances, a flow may originate from another flow and/or

terminate in another flow. Only when this occurs will a flow have multiple sources and/or destinations. Looking at Figure 6.2 which is extracted from Figure 5.1, the credit sales and cash sales flows are both generated from the same pump. To represent such a situation correctly, a single flow, sales, should be the output of the pump which then subsequently divides into two destinations: credit sales and cash sales (illustrating the case of multiple destinations). In other instances, it may be desired that the input (i.e. all the costs) to the pump be taken as one flow. In other words, several flows (e.g. cost of goods sold, selling and administrative expenses) converge into one flow (e.g. total costs), illustrating the case of many sources.

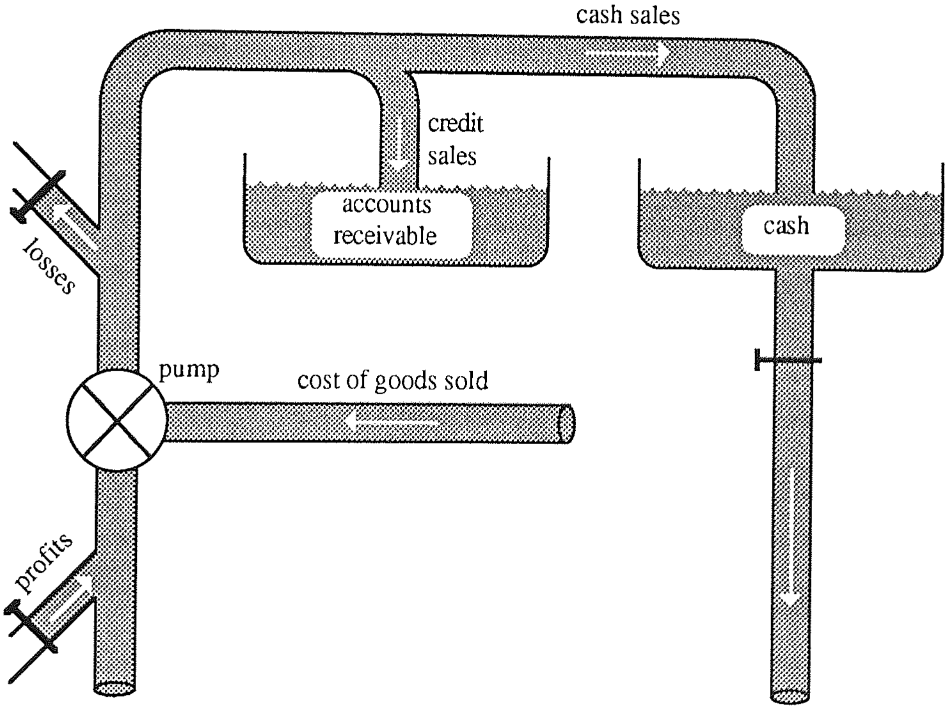

Figure 6.2 Sales Flow

3. A pump can only be connected to flows.

4. A tank can only be connected to flows.

5. A flow must always have a source and a destination.

A graphics interface would have been an extremely powerful tool for eliciting the necessary information. For instance, the use of Pro-Windows which provides a set of window manipulation predicates that can be fully integrated to Prolog would have resulted in a more exciting and interesting interface. However, since this was unavailable at the time and other windowing facilities posed severe integration problems, a simple query and answer session was implemented using the core language. Although the facilities provided by Prolog were adequate to the task, this proved to be a tedious and tiresome process, the result of which is clumsy to use. A typical interactive session (with user input in italics) looks like this:

Flow out of pump (q to end): *sales*
Flow out of pump (q to end): *q*
Destination for sales: *cash*　　　　Destination type: *asset tank*

The query and answer session is sequential. It starts from the initial source (i.e. the pump) and identifies flows out of this. These flows in turn, are queried for information on their destination(s). The user is then asked for information about the outflows from these destination(s). This destination-outflows query session ends when the model is complete i.e. all current outflows have the pump as their destination. This questioning approach precludes the existence of an isolated pump, isolated tanks and isolated flows. However, the input has to be further verified for circular flows. When this is detected, the user is shown the relevant structures and asked for modifications. If these modifications are permissible, they are integrated into the original specification.

The output of this module provides information for two subsequent modules, the Qualitative Equation Generator and the Explanation module. This information describes the characteristics of the variables (pump, tanks and flows), and the directional relationship of these variables to one another. Some sample inputs and outputs of this module can be seen in Appendix A.

6.1.2 Generating the Qualitative Equations

This module consults the information provided by the Structural Specification Analyser and generates a set of qualitative equations underlying the model. An equation is generated for each tank (reservoir) relating its inflows and outflows. The rules for generating the equations are:

1. Prefix an asset tank with a ⊖, all its inflows with a ⊕, to denote their positive influence, and all outflows with a ⊖ to denote their negative influence.

2. Prefix a liability tank with a ⊕, all its inflows with a ⊕ to denote their negative influence and all outflows with a ⊖ to denote their positive influence.

3. Prefix all inflows to a pump with a ⊖ and all outflows with a ⊕. The equation then has to be completed by considering the profitability of the firm for the period. A profit is prefixed with a ⊖, a loss with a ⊕ and a break-even situation will have neither variable included.

4. All inflows that merge into one flow are prefixed with a ⊕, the resulting flow being prefixed with a ⊖. Similarly, for a single flow that splits into many flows, prefix the split flows with a ⊕ and the original single flow with a ⊖.

To ensure that the equations do not contain a unary operator (i.e. begin with a minus operator), information on the inflows to a tank are parsed before all other information relating to the tank. The rule for generating the equation describing the pump has been included here for completeness; its generation is actually delayed until the data is entered whereupon the system will know if a profit or a loss has been made, thus generating the correct form of the equation (see equations 6a - 6c). This implies that although a static model is defined, the equations underlying it would have to be re-generated for each run of the system to reflect the different relationships that exist between variables at different periods of time; a firm may make a profit in one period and a loss in another. This is because the current system is unable to represent and handle complementary relationships within one model i.e. profit together with loss. A quantitative zero in the {low,normal,high} scale does not always map into the qualitative norm i.e. 0; consequently, the system is unable to infer what a quantitative zero profit means. In particular, it is unable to distinguish when the firm breaks even, resulting in neither a profit or a loss being made (thus inferring the use of equation 6c) and when the profit has not been made but this is the norm for the industry (thus implying the use of equation 6a).

6.1.3 Analysing the Data

The user may choose what types of data are to be entered into the system. The user may enter all the qualitative data directly in which case the system checks that none of the data contradicts the truth of the qualitative equations.

Alternatively, the user may enter quantitative values of the ratios for both the firm and the industry. Information on industry and public company ratios are published periodically and are easily available. One such publication in the United Kingdom is produced by Key Note Publishers who publish information on ratios classified by industries, ranging from the building industry to the aerospace industry to the retail outlets sector etc. If this option is chosen, the user has to specify relationships that cannot be expressed by the flow of funds model. These are accounting relationships which have been established by the financial and business community. For instance, current assets represents a classification for all assets that are convertible within the short term e.g. cash, stocks, short-term loans etc. Other common classifications are current liabilities which refer to all debts which have to be repaid in the short term, fixed assets, long-term liabilities etc (these classifications will hereafter be referred to as accounting variables). Analysts commonly use accounting variables in formulating ratios. A frequently used ratio is the liquidity ratio which is the ratio of current assets to current liabilities.

A simple conversion rule is used to translate the ratios into their respective qualitative values. This technique is adapted from the familiar concept of quartile distributions in the study of statistics. The values for all the firms are ordered and the middle range is selected as corresponding to the qualitative value, normal. Other qualitative values take their order from the interval identified. For example, supposing there were 9 firms with values that are distributed as follows: 1.2, 1.5, 3.7, 4.9, 5.5, 5.5, 11.8, 45.9, 55.0. Then the qualitative value low corresponds to $-\infty$ to 4.8, normal corresponds to 4.9 to 11.7 and high corresponds from 11.8 to $+\infty$. This is a very crude method which will doubtless draw criticism from practicing statisticians. However, the purpose here is merely to illustrate how it may be possible to convert quantitative values to its qualitative equivalents. Once converted to their qualitative values, each variable in the ratio may be assigned its qualitative value by looking up Table 5.4. As each variable participates in several ratios, these inter-relationships should constrain the value it may take. (For ease of reading, $\frac{\text{profit}}{\text{sales}}$ ratio will be written as the ratio of profit to sales.) Suppose data on the following ratios were given as:

1. ratio of profit to total assets = normal
2. ratio of profit to sales = low
3. ratio of sales to total assets = high

then the only results that will satisfy these three ratios (constraints) will be: [profit] = normal, [total assets] = normal and [sales] = high.

As a third option, the user may choose to enter *some* of the known qualitative values, allowing the system to infer the rest through propagating the known values through the equations or through using the quantitative-qualitative ratio values.

Lastly, the system allows the user to enter information about the desired values of the various ratios. Analysts would typically like to have a high ratio of profit to sales and a low ratio of interest to profit and a normal liquidity ratio. The user need not specify all the desired values; if a ratio does not have a specified value, the system associates the value normal with it. This information is used by the Explanation Generator when diagnosing the ratio profile of the firm.

A listing of all the different types of data that can be entered into the system is given in Appendix B.

6.1.4 Solving the Qualitative Equations

The technique used for solving a single qualitative equation is that of 'propagate and test' which has been mentioned in Section 5.2.2. To recap briefly, each possible qualitative value (i.e. low, normal, high) for the unknown variables is substituted into the equation to check which satisfy it. The result is sets of possible values. An alternative would have been to re-arrange the equation into the form: unknown variables = known variables and solve it. Both methods do yield the same qualitative solutions. Both methods are just as easily implemented in Prolog; the first method was implemented. This technique of 'propagate and test' is combined with the test of 'constraint satisfaction' in order to derive all the valid solutions to a set of qualitative equations. Two possible situations may result: a contradiction in a value previously derived for a variable is encountered or a restriction on the earlier derived value is possible.

An earlier derived value for a variable may be contradicted by subsequent equations (the equations representing constraints). For example, given the following set of equations, where [a] and [d] both are high and [x] is the unknown:

$$[x] \ominus [a] \ominus [d] \text{ ⊜ } \text{normal} \tag{7}$$

$$[b] \oplus [x] \text{ ⊜ } \text{normal} \tag{8}$$

Solving (7) would give [x] the value of high. If [b] were normal, then (8) would be contradicted since $\text{normal} \oplus \text{high} \neq \text{normal}$. When this happens, the candidate solution set {[a] = high, [d] = high, [b] = normal, [x] = high} is rejected as a possible solution set for equations (7) and (8). However, if the value of [b] were low, then the set {[a] = high, [d] = high, [b] = low, [x] = high} is a valid solution since $\text{ambig} \text{ ⊜ } \text{normal}$.

The possible values for [x] may be narrowed down by the application of subsequent constraints. For example, if [a] were low, [d] were high, then solving (7) would give [x] the value of {low,normal,high}. If [b] were normal, then the only valid value for [x] would be normal. Thus, the valid solution set would be {[a] = low, [d] = high, [b] = normal, [x] = normal}.

In solving any set of equations, it is unlikely that only one variable in an equation is unknown; it is possible that several variables will be unknown. In such cases, the system has to keep track of possible candidate solutions for the set of equations. Prolog's backtracking facility is an extremely powerful feature in ensuring painless constraint satisfaction since it can automatically be used to retract earlier derived solutions and to resume the process of 'generate and test'. However, this advantage is not achieved without a cost. Since the backtracking facility of Prolog ensures that every possibility is considered, this means that a run to completion might mean unacceptably long execution times. To reduce this execution time would require the development of intelligent search strategies which will limit and control the backtracking facility. This aspect was not investigated since this research has not yet evolved to the stage where the system will need to consider response time as an issue.

6.1.5 Generating Explanations

This module needs to interact with both the Structural Specification Analyser and the Solution Generator in order to be able to interpret the results in terms of the user-specified model. It also interacts with the user, in the form of a menu-type question and answer session. Again, as this system is meant to be a prototype, the form of interface was chosen for ease and speed of development. As the results are strung together using canned text, the actual answers produced are rather stilted. Where examples are given, the text has been slightly edited to give easier understanding. Samples of the raw output from this module is shown in Appendix C.

The system makes a cursory diagnosis by comparing the value of the firm's ratios to the preferred values entered earlier by the user. By considering the inter-relationships between the various variables, the system is able to trace the root cause(s) of the problem(s). For example, given the following ratios:

sales/stock is low
debtors/sales is low
current assets/current liabilities is low
quick assets/current liabilities is low

the system traces through the inter-relationships between the ratio and deduces the following set of values for the variables that is consistent with the given set of ratio values:

{debtors - low, stock - normal, sales - low, current assets - low,
current liabilities - low, quick assets - low}

The system then attempts to explain the cause of the situation by checking to see if an accounting relationship can be observed between the variables. In this case, it can, and the following diagnosis is offered (the underlying accounting relationship being given in italics):

> Because debtors is low
> quick assets is low, (*quick assets = cash + debtors*)
> Because quick assets is low
> and stock is inferred to be normal,
> current assets is low (*current = quick assets + stock*)

Thus, the root cause of the given situation is that debtors is low compared to the industry norm. This result can then be interpreted in terms of the flow of funds model to see which options the firm may take to correct the situation. Referring to Figure 5.1, two options are open: to increase the flows into the debtors reservoir (i.e. credit sales) or to decrease the flows from the debtors reservoir (i.e. collections). In order to decide which option to take, the user may query the system for the effects of different actions. The types of queries the user may make are:

1 What is the value of ‹variable›?
2. What is the value of ‹ratio›?
3. How was the value of ‹variable› deduced?
4. How was the value of ‹ratio› deduced?
5. How can ‹variable› be changed?
6. How can ‹ratio› be changed?
7. What happens if ‹variable› changes?
8. How can a particular profile be achieved?

The first two questions can be handled quite easily by looking up the relevant data maintained by the system. In addition, the system also maintains a trace of how these values have been derived; some of them could have been direct inputs from the user, others have been deduced by using information or a combination of information from structural, accounting and ratio data. These are used in answering Query 3-type and Query 4-type questions. How these deductions are carried out have been discussed in Section 6.1.3 and Section 6.1.4.

To answer a Query 5-type question (viz. how can ‹variable› be changed?), the system needs to determine the nature of the variable in question. The rules for generating explanations for the various types of variables are:

1. If the variable is a 'reservoir variable', explain the changes in terms of the flows into and flows out of the reservoir.

2. If the variable is the profit or loss variable, explain the changes in terms of flows into and flows out of the pump.

3. If the variable is a flow variable originating from another flow (main flow), explain the changes in terms of the main flow and any other flows originating from the main flow. For instance, in the case of the credit flow which together with another flow, cash sales, originates from sales, changes are explained in terms of changes in the main flow, sales, and changes in the other flow, cash sales.

4. If the variable is a flow terminating in another flow (resultant flow), explain the changes in terms of the sources of this flow. For example, in the case of costs (a flow that goes into the pump and is the resultant flow of selling and administrative expenses and cost of goods sold), its changes should be explained in terms of these two flows only.

5. If the variable is an accounting variable, explain the changes in terms of changes in its components. For example, changes in current assets will be explained in terms of changes in cash, stock and accounts receivables.

Each variable is traced to its related variables and explained in terms of them. In turn, these variables are traced to their related variables and explained in terms of them. This cycle terminates when the end of the chain is encountered i.e. the pump or a valve (flow over which the firm has control).

The answer to Query 6-type questions (viz. how can ‹ratio› be changed?) is quite straightforward. The system first identifies a set of values the numerator and denominator can have that will satisfy the required ratio value. For example, if the ratio of sales to stock is currently low and the user would like this to be improved i.e. normal, the possible combination sets are:

{[sales] = low, [stock] = low}
{[sales] = normal, [stock] = normal}
{[sales] = high, [stock] = high}

This set is then pruned by applying a simple transition rule to the current values of the sales and stock. In line with transition rules defined in other qualitative reasoning approaches, transitions in values are restricted to one-interval changes in either direction only: low ⇔ normal and normal ⇔ high. Thus, if the current qualitative value of sales and stock is low and high respectively, then the legal solution set will be {[sales] = normal, [stock] = normal}. To find out how this may be achieved, the user should use Query 5.

Query 7-type questions (viz. what happens if ‹variable› changes?), is the reverse operation of Query 5. An example of the output is:

If overheads becomes low and sales remains high, then profit will increase from low to normal

profit/sales ratio will be known to be low

interest/profit ratio will become normal

The only variables that may be changed are those flows over which the firm has control; flows totally controlled by outsiders may not be changed e.g. collections. In general, all changes are propagated in the direction of the pump. The propagation of changes terminates when the end of the chain is encountered i.e. the pump or a valve. The changes are also propagated to changes in the ratios resulting from changes in the various variables.

The last option (viz. how can a particular profile be achieved?) allows the user to specify the kind of ratio profile the firm would like. The system then attempts to show the events that need to occur to allow the achievement of this goal. The algorithm for producing the result is as follows:

1. For each ratio, derive the legal combinations of variable values. Constrain the total set of combinations by considering all other related ratios.

2. Identify the variables that can be changed by matching the 'new' values against the value derived from applying the transition rule to the current value.

3. Link together as far as possible, the variables that can be changed by considering their directional and accounting relationships. This is to ensure a coherent explanation which will only be given in terms of 'root' variables.

The profile specified by the user may not always be achievable given the present ratio profile of the firm. In this case, the user will be informed of the fact.

6.2 Experimenting with the System

This section reviews particular aspects of specifying models of different complexity to the system, starting with an simple initial model and progressing to more complex models until finally a real-life model is described. The discussion focuses on the underlying qualitative equations that have been generated and the results of solving these equations.

6.2.1 A Simple Model: The Corner-shop Newsagent

The main features of the business are that it is owned privately by a single individual, it trades solely on a cash basis, its premises are rented, and it handles homogeneous products (newspapers and magazines). The flow of funds model for a typical firm of this nature is shown in Figure 6.3.

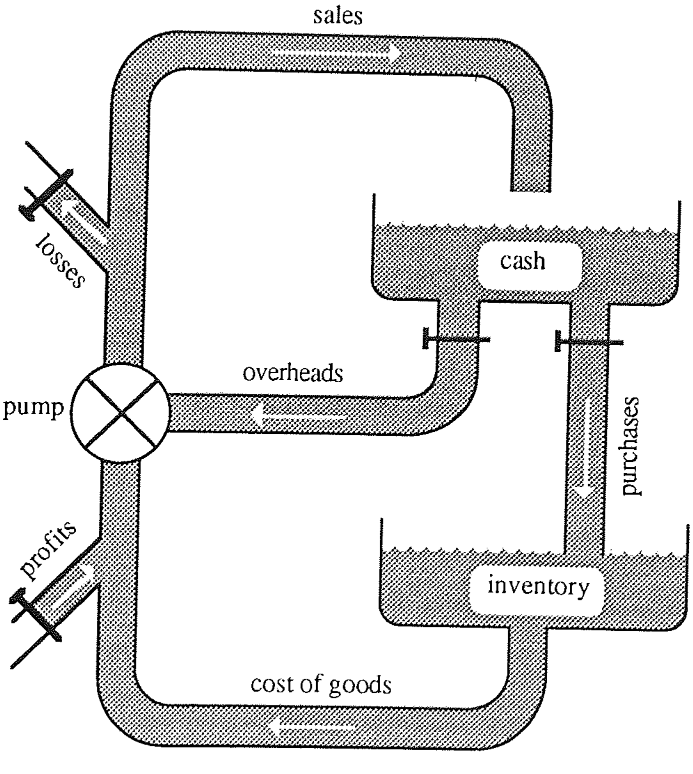

Figure 6.3 Hypothetical Newsagent's Flow of Funds Model

This model is the on-going model of the firm; the owner is not represented as it is assumed his involvement extends as far as providing funds to start up the firm. It is further assumed that all profits earned are retained within the business which is currently making a profit. Thus, the model will consist of a pump, two reservoirs and five flows (counting the profit and loss as one since they are mutually exclusive in any model) i.e. 7 variables. It will therefore be described by three qualitative equations, one for each reservoir and one for the pump:

$$[\text{sales}] \ominus [\text{overheads}] \ominus [\text{purchases}] \ominus [\text{cash}] \mathrel{⊜} \text{normal} \tag{9}$$

$$[\text{purchases}] \ominus [\text{cost of goods}] \ominus [\text{inventory}] \mathrel{⊜} \text{normal} \tag{10}$$

$$[\text{sales}] \ominus [\text{cost of goods}] \ominus [\text{overheads}] \ominus [\text{profit}] \mathrel{⊜} \text{normal} \tag{11}$$

The data used to drive this model was generated by the system trying various combinations of all qualitative values for all variables except for those of cash, inventory and profit.

There are 3^7 i.e. 2187 total possible different combination sets of values (which hereafter will be called states). Of these, only 517 are legal i.e. they satisfy equations 9 to 11. Thus, this solution space (about 24% of total possibilities) represents all the possible states of the firm making a profit. Of the 517, only 25 states have a unique solution i.e. one in which none of the variables in the set are ambiguous. Since the states are the basis for generating explanations, the ideal situation would be that only one state was found which was unique. When this does not happen, the next best alternative is to generate explanations only from the set of unique solutions, since explanations so constructed are apt to sound more 'positive' than those from ambiguous states where in some instances, these may degenerate to an 'anything can happen' situation. Thus, although both types of states (i.e. ambiguous and unique) are valid, interest in the first instance, is focused on the unique states.

In Section 5.2.3, the issue was raised of how the function of the pump ought to be described. Two options were suggested: the first was to describe the pump as driving the sales revenue and the second was to describe the pump as driving the volume of goods transacted. Hitherto, the model has assumed the first description. Subsequent runs were therefore made to test whether the second description might yield different results.

To describe the fact that the pump drives the volume of goods transacted, this variable must be explicitly introduced. There are various methods and techniques by which cost accountants arrive at a costing 'formula'. One simple method particularly suited to the operating environment of the newsagent of arriving at the selling price per unit of good is, to add a certain percentage (to recover overheads and make a profit) onto the cost price per unit of good. Thus, the total sales revenue would be a function of the volume of goods transacted and the selling price per unit of good while the total costs of the volume transacted would be a function of this volume and the cost price per unit of good. The qualitative equation to describe this relationship is:

$$[\text{sales}] \ominus [\text{selling price}] \circledast [\text{volume}] ⊜ \text{normal} \tag{13}$$

$$[\text{cost of goods sold}] \ominus [\text{cost price}] \circledast [\text{volume}] ⊜ \text{normal} \tag{14}$$

The new equations to be solved thus consists of equations (9) - (11), (13), (14). The new model therefore consists of 10 variables i.e. 59049 possibilities, making up 5 confluences. Again, the data used to drive this model was generated by the system trying various combinations of all qualitative values for all variables except for those of sales, cost of goods sold, creditors, cash, inventory and profit. Of all the possible states, 9451 are legal (about 16% of total possibilities). However, of these, still only 25 states have a unique solution!

Some of the solutions from this run are shown in Table 6.1 together with some examples of non-unique solutions. A close examination of the results revealed that

Variables\Case	1	2	3	4	5	6	7	8*	9*
selling price	high	high	normal	normal	high	high	normal	high	normal
cost price	normal	normal	normal	normal	low	low	low	normal	high
volume	normal	normal	normal	normal	normal	normal	normal	high	low
overheads	normal	low	normal	low	normal	low	normal	normal	high
purchases	normal	normal	normal	normal	normal	normal	normal	high	high
sales	high	high	normal	normal	high	high	normal	high	low
cost of goods	normal	normal	normal	normal	low	low	low	high	ambig
cash	high	high	normal	high	high	high	normal	ambig	low
inventory	normal	normal	normal	normal	high	high	high	ambig	ambig
profit	high	high	normal	high	high	high	high	ambig	ambig

* Non-unique solutions

Table 6.1 Some Solution Sets for the Funds Flow Model of the Newsagent

perhaps the equations were introducing ambiguity which is not part of the model. Consider case (8); the value of profit is ambiguous which has been derived by substituting qualitative values into equations (13), (14) and (11):

$[\text{sales}] \ominus \text{high} \circledast \text{high} ⊜ \text{normal} \Rightarrow [\text{sales}] ⊜ \text{high}$

$[\text{cost of goods}] \ominus \text{normal} \circledast \text{high} ⊜ \text{normal} \Rightarrow [\text{cost of goods}] ⊜ \text{high}$

$\text{high} \ominus \text{high} \ominus \text{normal} \ominus [\text{profit}] ⊜ \text{normal} \Rightarrow [\text{profit}] ⊜ \text{ambig}$

This is not entirely accurate since if volume is high and the difference between the selling price and cost price is high, then profit should be high since overheads is normal. This leads to the conclusion that the relationships expressed in equations (13) to (15) are not quite appropriate. An alternative approach to expressing the same idea would be to explicitly introduce and use the percentage added on to the cost price per unit of good to arrive at the selling price per unit of good i.e. markup:

$$[\text{markup}] \circledequal [\text{selling price}] \ominus [\text{cost price}] \tag{16}$$

$$[\text{markup}] \circledast [\text{volume}] \ominus [\text{overheads}] \ominus [\text{profit}] \circledequal \text{normal} \tag{17}$$

Resolving these equations (16) to (17), together with (9), (10), (13) and (14) yielded more constrained states. The number of legal states dropped from 9451 to 8555 and the number of unique states increased to 41.

Table 6.2 gives the summary of the results of the runs. Each run is described by a run number for easy referencing, followed by the set of qualitative equations used in it. The essential difference between each run is the description of the pump. In this first run, the pump is shown as driving the sales (its relationship to the cost of goods sold is ignored). The second and third runs considered the pump as driving the volume of goods; however, in each case a different equation was written to express this relationship, resulting in different conclusions.

Run Identification	Possibilities	Legal States	Unique States
Run 1 (9,10,11)	2187	517	25
Run 2 (9,10,11,13,14)	59049	9451	25
Run 3 (9,10,13,14,16,17)	59049	8555	41

Table 6.2 Summary of Experiments with the Simple Model

The results show that a simpler model with fewer variables, gives a smaller solution space as compared to a more complex description of the same situation. This suggests that together with each introduction of a variable, there must be the introduction of corresponding constraint(s) on the variable. If this is not possible, then the number of legal states will increase quite dramatically. In Run 2 and Run 3, three new variables were introduced: selling price, cost price and volume. However, there are no constraints placed on each of these variables thus leading to the large increase in the legal states. Further refinements of the model specification are therefore needed (see next section).

The results also reveal that it is possible to introduce an element of ambiguity to the model. If the model is expressed inaccurately (as in Run 2), states that ought to be ruled out exist as legal ambiguous states. The semantic meaning underlying each equation, therefore, needs to be carefully considered. This theme is returned to in the next chapter.

6.2.2 Refining the Specification of the Model

The first refinement attempted was to re-specify the equations using as minimal a set of variables as possible. As the set of equations in Run 1 is the minimal set (i.e. every variable is a 'primitive' variable), the initial refinement was only made on the equation set used in Run 3. The original set for Run 3 was:

[sales] ⊖ [overheads] ⊖ [purchases] ⊖ [cash] ⊜ normal (9)
[purchases] ⊖ [cost of goods] ⊖ [inventory] ⊜ normal (10)
[sales] ⊖ [selling price] ⊛ [volume] ⊜ normal (13)
[cost of goods sold] ⊖ [cost price] ⊛ [volume] ⊜ normal (14)
[markup] ⊜ [selling price] ⊖ [cost price] (16)
[markup] ⊛ [volume] ⊖ [overheads] ⊖ [profit] ⊜ normal (17)

This set was modified to specify all variables in terms of 'primitive' variables. For instance, sales would be eliminated and replaced by selling price and volume. The refined set of equations were thus:

[selling price] ⊛ [volume] ⊖ [overheads] ⊖ [purchases] ⊖ [cash] ⊜ normal (9a)
[purchases] ⊖ [cost price] ⊛ [volume] ⊖ [inventory] ⊜ normal (10a)
([selling price] ⊖ [cost price]) ⊛ [volume] ⊖ [overheads] ⊖ [profit] ⊜ normal (17a)

The result of this run, Run 3*, is shown in Table 6.2a. The results compare favourably against those of the original run (Run 3). The number of legal states has dropped quite dramatically, while the same number of unique states have been identified.

Run identification	Possibilities	Legal States	Unique States
Run 3 (9,10,13,14,16,17)	59049	8555	41
Run 3*(9a,10a,17a)	6561	2699	41

Table 6.2a Using the Refined Specifications

Another possible refinement that could be made concerns the use of quantitative information; the large number of ambiguous cases arises partly because quantitative information about the relative magnitudes of interacting variables has not been used either directly or indirectly. One way of attempting to include magnitude information is to use quantitative values of ratios. How such information may be translated to form additional constraints has been illustrated in Section 6.1.3. Subsequent runs using ratio information were made; the ratios used are those commonly available via published information.

The use of ratios necessarily entails the use of accounting information (see Section 6.1.3). The way this additional information is incorporated into the model has implications for the results. This goes back once again to the earlier observation that the degree of ambiguity is related to the number of additional variables that are introduced without supporting constraints. To illustrate this point, two other runs were made: Run 4 and Run 4*. Both runs assume that the model of the firm is that given by Figure 6.3 and in addition, that information on the following ratios are known:

ratio of profit to sales = high (R1)
ratio of sales to inventory = low (R2)

The ratio information uses sales as one of its components. Since sales is not a variable in the specification of the funds flow model, how can information about it be incorporated?

One way is to write a qualitative equation introducing sales, as in equation (13): [sales] ⊖ [selling price] ⊛ [volume] ⊜ normal. This, together with (9a), (10a) and

(17a) forms the equation set of Run 4. If this method is chosen, the algorithm for deriving the values of the variables are:

1. Each qualitative ratio is made up of a qualitative numerator, [x] and a qualitative denominator, [y]. For each known qualitative ratio value, all numerator and denominator combinations are derived from Table 5.4 (shown as [x]/[y]):

   <u>ratio of profit to sales:</u>

   (high/high), (high/normal), (high/low), (normal/low), (low/low)

   <u>ratio of sales to inventory:</u>

   (low/low), (low/normal), (low/high), (normal/high), (high/high)

   Note that a combination that yields an ambiguous result is deemed to be qualitatively equal to the known ratio value. For example, the combination value set for the ratio of profit to sales, (low/low) i.e. ambig will be qualitatively equal to the known value, high.

2. Derive solution sets (states) for all the variables (involved in the ratios), from the possible values derived previously. In this case, the states for {profit, sales, inventory} are:

   {high, high, high}
   {high, normal, high}
   {high, low, ambig}
   {normal, low, ambig}
   {low, low, ambig}

3. For each state, deduce the values of all unknown variables, using the qualitative equations.

The alternative is to handle and process the accounting relationships differently. This option is illustrated by Run 4* which consists of (9a), (10a) and (17a). The algorithm for deriving the values of the variables are as follows:

1. Generate a possible solution set for all variables. In this case, a possible state for all the variables in the system i.e. purchases, volume of goods, cost price, selling price and overheads are: {high, high, high, high, high}.

2. Verify these values to ensure that it satisfies the information known about the ratios i.e. derive the qualitative value for the two ratios from the solution set and check if these are qualitatively equal to the values given in (R1) and (R2). If the ratio variable is an accounting variable, then deduce its qualitative value by considering the qualitative values of other variables in the same accounting relationship. Sales, in this instance, is an accounting variable related to both selling price (which is high) and volume (which is high) and thus its value derived from both these values (high $\circledast$ high $\Rightarrow$ high).

   <u>ratio of profit to sales:</u>

   high/high $\Rightarrow$ ambig $\ominus$ high

   <u>ratio of sales to inventory:</u>

   high/high $\Rightarrow$ ambig $\ominus$ low

   States that do not satisfy (R1) and (R2) are rejected.

3. All the legal states for the model are thus derived by generating all combination of values for all the variables and verifying these against the known ratio information i.e. repeat Step 1 and 2 of this algorithm for all possible combinations.

Run 4* maintains the minimal set of variables in not introducing sales as part of its model. Rather it treats sales as part of the information that drives the model. The results of using the two different methods are shown in Table 6.2b. Although the results of these runs confirm the hypothesis that accounting and ratio information should be handled differently from information about the flow of funds, a better model to illustrate this point (since sales is strictly not an accounting variable) is given in the extended model described in Section 6.2.3.

Run Identification	Legal States	Unique States
Run 4 (9a,10a,13,17a,R1,R2)	4567	19
Run 4^* (9a,10a,17a,R1,R2)	2515	19

Table 6.2b Handling Ratio and Accounting Information

In summary, it can be observed that there are a large number of ambiguous states defined by the initial specification of model. Analysis of the results of the initial model lead to two types of refinements, namely the re-specification of the equations so as to obtain a minimal set of variables and the use of ratio and accounting information in such a

Run Identification	Legal States	Unique States
Run 1 (9,10,11)	517	25
Run 1^* (9,10,11,R1,R2)	437	11
Run 3 (9,10,13,14,16,17)	8555	41
Run 3^* (9a,10a,17a)	2699	41
Run 4 (9a,10a,13,17a,R1,R2)	4567	19
Run 4^* (9a,10a,17a,R1,R2)	2515	19

Table 6.3 Initial *vs* Final Specifications

way as to maintain this minimal set. Table 6.3 compares the results of the initial model against the results of the each refinement (the refinement runs are denoted with an *).

Run 1 represents the model of the firm where it is assumed that the pump drives sales. Since the equation set in Run 1 was the minimal set and since sales was part of the model, no refinements need to be made to it. Run 1* merely shows the result of using the ratio and accounting information as a means of constraint. Run 3 represents model of the firm where it is assumed that the pump drives the volume of goods transacted. Run 3* represents the initial refinement where the minimal set is used and Run 4* represents the situation when the second refinement was made, namely to incorporate ratio and accounting information while maintaining a minimal set of variables. The number of legal states has dropped quite substantially (from 8555 to 2515) in using the 'efficient' Run 4* set as opposed to the Run 3 set. This decrease has not been so noticeable in the case of Run 1. The effect of using ratio and accounting information on their own to constrain the solution space is comparatively modest, as observed by contrasting the results between Run 1 and Run 1*, and between Run 3* and Run 4*.

Two hypotheses suggests themselves: firstly, that there might be an operating threshold for the number of legal states for models of any complexity and secondly, it is possible that due to the simplicity of the model, the inter-relationships of ratios that can be specified are not complex enough to form stronger constraints. Consequently, more complex models had to be developed in order to test these hypotheses.

6.2.3 Extending the Model

The simple model was extended to include the description of the firm's relationship to its creditors (see Figure 6.3a). Equation (9) will need to be extended to form (18) so as include repayments (to creditors) and a new equation, (19), specified to define flows in

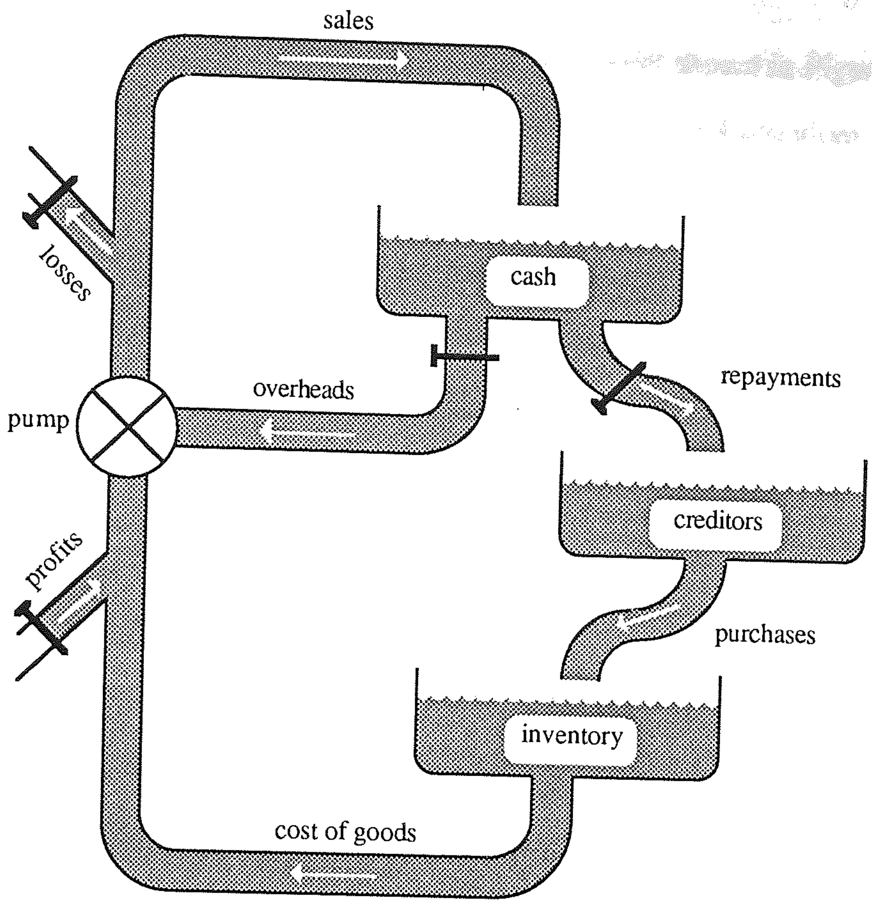

Figure 6.3a Extended Newsagent's Flow of Funds Model

and out of the creditor's reservoir:

[sales] ⊖ [overheads] ⊖ [repayments] ⊖ [cash] ⊜ normal (18)

[repayments] ⊖ [purchases] ⊕ [creditors] ⊜ normal (19)

Once again, the data used to drive this model was generated by the system trying various combinations of all qualitative values for all variables except for those of creditors, cash, inventory and profit. Three ratios were used as further constraints:

ratio of profit to sales = high (R3)
ratio of sales to inventory = low (R4)
ratio of current assets to current liabilities = low (R5)

where current assets is an accounting variable consisting of cash and inventory and current liabilities is an accounting variable, consisting solely of creditors in this case.

To summarise, the first run (Run 10) of the model shown in Figure 6.3a assumes that the pump drives the sales revenue. The following set of 4 equations are used in this run:

[purchases] ⊖ [cost of goods] ⊖ [inventory] ⊜ normal (10)
[sales] ⊖ [cost of goods] ⊖ [overheads] ⊖ [profit] ⊜ normal (11)
[sales] ⊖ [overheads] ⊖ [repayments] ⊖ [cash] ⊜ normal (18)
[repayments] ⊖ [purchases] ⊕ [creditors] ⊜ normal (19)

The second run (Run 20) assumes that the pump drives the volume of goods and the following set of 4 equations are used:

[purchases] ⊖ [cost price] ⊛ [volume] ⊖ [inventory] ⊜ normal (10a)
([selling price] ⊖ [cost price]) ⊛ [volume] ⊖ [overheads] ⊖ [profit] ⊜ normal (17a)
[selling price] ⊛ [volume] ⊖ [overheads] ⊖ [repayments] ⊖ [cash] ⊜ normal (18a)
[repayments] ⊖ [purchases] ⊕ [creditors] ⊜ normal (19)

The results of the two runs are shown in Table 6.4. They indicate that the first hypothesis (viz. there might be an operating threshold for the number of legal states for models of any complexity) is incorrect. The number of legal states has increased quite phenomenally when an extra set of relationships was specified (compare Run 10 with Run 1*, and Run 20 with Run 4*), the effect of introducing 'unsupported' variables being exponential. The implication for the second hypothesis (viz. ratios can be strong enough to form good constraints if their inter-relationships are sufficiently complex) is still

Run Identification	Legal States	Unique States
Run 10 (10,11,18,19, R3,R4,R5)	1903	37
Run 20 (10a,17a,18a,19a,R3,R4,R5)	11065	49

Table 6.4 Results of Using the Extended Model

unclear since the network of constraining ratios is relatively sparse. Therefore, the model was further extended to that resembling a model of an existing firm.

6.2.4 A Model of a Real Firm: Habitat Design

Some of the conclusions that have been tentatively drawn from analysing the simple models can now be confirmed with this experiment. A high-street retail store was chosen for this experiment because published data on the industry and individual firms in the industry is available and the reader does not need to have specialised knowledge about the industry to understand the workings of the typical firm.

A firm, Habitat Design, was picked at random for this experiment. By considering the published data and information, the author drew up the firm's flow of funds model as shown in Figure 6.4. The ten qualitative equations underlying this model are:

[credit sales] ⊖ [cash collect] ⊖ [debtors] ⊜ normal (20)

[purchases] ⊖ [cost of goods] ⊖ [stocks] ⊜ normal (21)

[repayments] ⊖ [purchases] ⊕ [creditors] ⊜ normal (22)

[fixed asset in] ⊖ [fixed asset out] ⊖ [depreciation] ⊖ [fixed assets] ⊜ normal (23)

[lt loan out] ⊖ [lt loan in] ⊕ [long term loan] ⊜ normal (24)

[lt liability out] ⊖ [lt liability in] ⊕ [other long term liability] ⊜ normal (25)

[st loan out] ⊖ [st loan in] ⊕ [short term loan] ⊜ normal (26)

[st liability out] ⊖ [st liability in] ⊕ [other current liability] ⊜ normal (27)

[cash sales] ⊕ [cash collect] ⊕ [lt loan in] ⊖ [lt loan out] ⊕ [lt liability in] ⊖
[lt liability out] ⊕ [st loan in] ⊖ [st loan out] ⊕ [st liability in] ⊖
[st liability out] ⊕ [fixed asset in] ⊖ [fixed asset out] ⊖ [repayments]
⊖ [overheads] ⊖ [other ca] ⊜ normal (28)

[sales] ⊖ [cost of goods] ⊖ [overheads] ⊖ [depreciation] ⊖ [profit] ⊜ normal (29)

Information about 13 ratios were given together with 10 other accounting relationships. These are listed in Appendix D. The initial run using this information was aborted, after

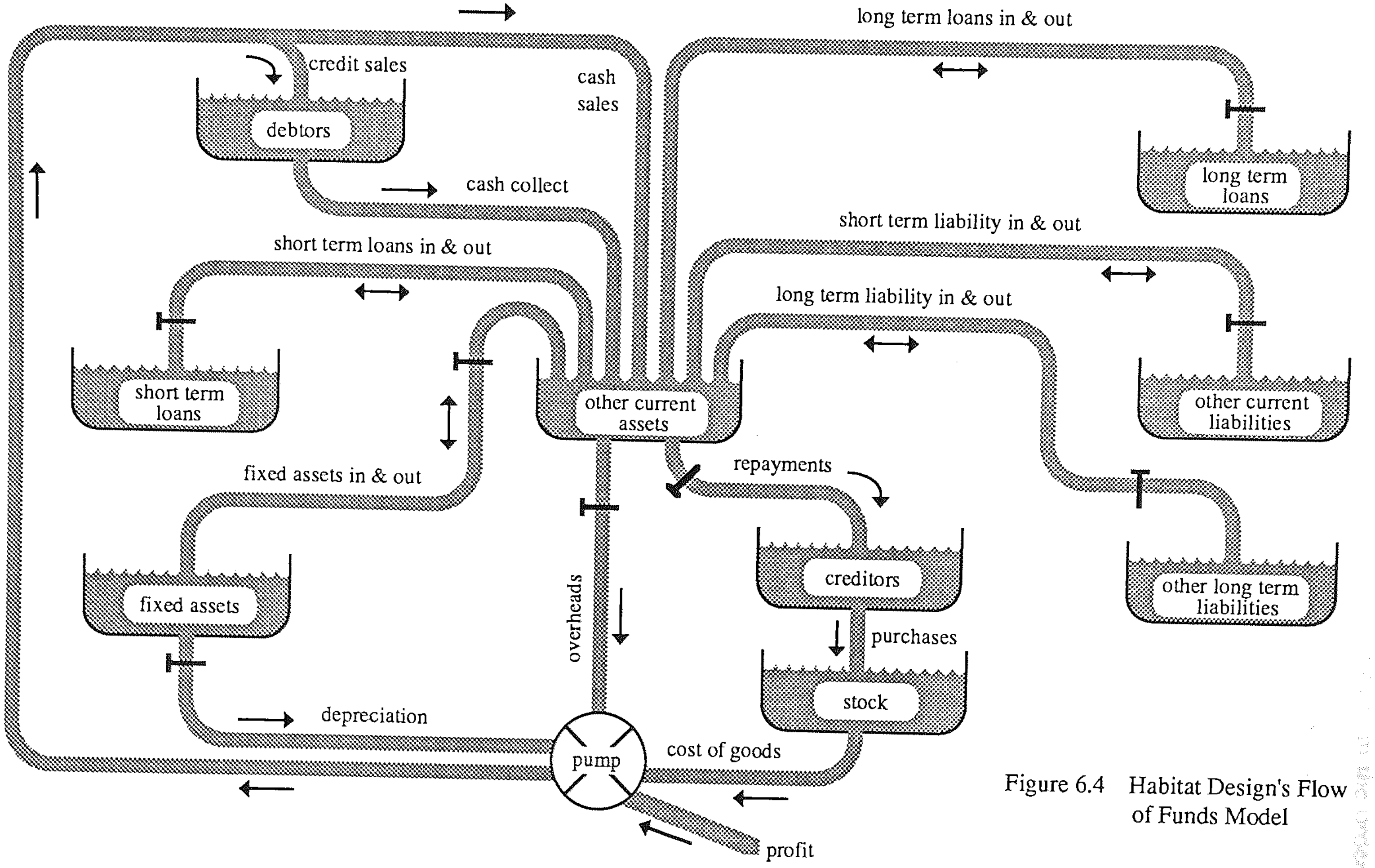

Figure 6.4 Habitat Design's Flow of Funds Model

several weeks of running on a VAX 8650 (this same run had previously crashed out on the Sun 3/160 after three days of running). In both instances, the problem was due to lack of memory space, hardly surprising as the total number of states is in the order of 3^{23} variables, ~ 8 billion possibilities. At the time of the crash, the system had identified about 3 million legal states. Thus, contrary to expectations, despite the provision of a more complex network of constraining ratios, the results of the run seem to suggest that the model is still underconstrained.

$\frac{\text{profit}}{\text{sales}}$	$\frac{\text{sales}}{\text{inventory}}$	$\frac{\text{current assets}}{\text{current liabilities}}$	Legal States	Unique States
low	low	low	1877	29
low	low	normal	1875	27
low	low	high	1873	25
low	normal	low	1599	24
low	normal	normal	1598	23
low	normal	high	1596	21
low	high	low	1903	37
low	high	normal	1903	37
low	high	high	1899	33

Table 6.5 Ratios as Constraints

Firstly, the ratios as a form of constraint on each other were investigated. For obvious reasons, Habitat Design's model is too impractical to be used for extensive testing. Consequently, further experiments to investigate the nature of ratio inter-relationships was conducted using the model shown in Figure 6.3a. The set of qualitative equations and the handling of the ratio and accounting information (given by Run 20) remained the same for all the computer runs; the only elements that were changed from run to run were the ratio values, a different combination of value for all ratios being specified for each run. Results of some of these runs are shown in Table 6.5. An analysis shows that the variation that in number of legal states does not vary substantially, the range being between 1559 and 1903 (about 20% variation). This implies that the inter-relationship of ratios do not place very strong constraints on each other so as to provide a containable number of solutions. Part of the reason for this is due to the imprecision of qualitative value set.

Secondly, an analysis was conducted to see how useful the equations were as a means of constraint. The equations are derived from the flow of funds model and consequently, require data which is not always published. In the 'toy' models used in Section 6.2.1 to Section 6.2.3, there is only ever one unknown in a single equation. This state of affairs does not always exist in more realistic models e.g. in equation (23), there will be three unknowns since only information on fixed assets is published. In fact, this situation seems prevalent in the real-world as indicated by the equations. In (22), only data on creditors is known while data on repayments and purchases is unknown while in (24) to (27), only the reservoir values are known. Data on flows in and out of these reservoirs are not known e.g. short term loan in and short term loan out. Thus, the equations are not able to form a strong network of constraints since data is not available for a large number of variables (incomplete information). This results in the enormous number of ambiguous legal states which might in fact be ruled out if more data were known.

6.3 Summary

This chapter begins by describing the details involved in implementing a system that will test the concepts outlined in Chapter 5. This is followed by a discussion about the results from the series of experiments designed to evaluate the usefulness of models built along these lines.

The initial experiments demonstrated that the equations have an important role to play in filtering out unobtainable states. Subsequent testing on a larger-scale model showed that this is only true provided enough qualitative values of the variables are known. It was also discovered that ratio constraints play only a marginal role in filtering out ambiguous states; this can be traced to the imprecision of the value set. These results suggest two possibilities. Firstly, it seems prudent to examine the nature of the interactions between the equations more closely since the results of Run 2 and Run 3 suggests that the ‘wording’ of equations has important consequences on the results of the model and secondly it seems that it might be fruitful to re-examine the data that is available to see if better use may be made of it to circumvent the imprecision of the value set. The results of examining these two possibilities are given in the next chapter.

7 Evaluation of Results

The conclusion drawn from earlier experimental work shows that ambiguity is a major problem. Indeed, it has been said that qualitative analysis is inherently ambiguous (de Kleer & Brown 1984). Thus, since the handling of ambiguity is a recognised and documented subject, this chapter begins by considering the current position in the field. Some of this literature has only been very recently available (i.e. those published in AAAI 1988), and as such, has not influenced the author's work to any extent. The ideas expressed in some of these papers however adopt a view in line with that of the author's; consequently, a detailed discussion of them will be postponed to the subsequent section which outlines the author's strategy and assesses the power of this scheme.

7.1 Ambiguity: Historical Perspective

Ambiguity may be defined in many situations: where the details of the information captured is incomplete, where not enough information is known or where the ordering of events is not known. The root cause of the first situation is that qualitative operators do not define a field and hence most of the usual theorems of Linear Algebra and Network Theory on which human intuition is based, do not hold. The second situation may arise due to the nature of the domain area and is thus a fact of the real-life situations. The last situation occurs because the concept of time in a qualitative world is also qualitative; time is conceived in terms of the ordering of events. However, since it may not be possible to know the ordering of all events, this ordering can only be partial.

In general, the three main approaches to qualitative reasoning do not handle the problem within the basic qualitative reasoning procedure. Although QP theory (Forbus 1984) stipulates specific data (i.e. the magnitude of the amount and the magnitude of the derivative) for resolving ambiguity, the system only seems to use information on the ordinal relations among quantities belonging to partially ordered quantity spaces rather than performing arithmetic operations on the numerical magnitudes. However, the incorporation of this information only partially solves this problem. The result is therefore seen to be solution sets, each of which can be identified with a different set of assumptions which may be implicit, as in QP theory (Forbus 1984), or explicit as in the theory of Envisioning (de Kleer & Brown 1984). It is generally agreed that some form of external evidence is required to resolve ambiguity, the most widely used of which is teleological i.e. derived from knowing the purpose of the device.

7.2 Resolving Ambiguity: Defining Extra-Mathematical Properties

The inability of classical theories to address the ambiguity issue fully has led to the search for strategies to resolve this question. One line of attack is to use extra-mathematical properties that have yet to be exploited. Proponents of this school of thought introduce the definition of new relations in an attempt to capture particular aspects of information lost in the traditional quantitative-qualitative transformation process.

Raiman (1986) proposes that information on the magnitude of the amount be extended to include knowledge on its order of magnitude. His system, FOG (Formal system for Order of maGnitude reasoning), was implemented to test this idea. (However, no details are given as to what is meant by a different order of magnitude.) The basic relations that are defined to capture the additional knowledge are:

1. A Ne B which stands for A is negligible in relation to B.

2. A Vo B which stands for A is close to B i.e. (A-B) is negligible in relation to B.

3. A Co B which stands for A has the same sign and order of magnitude as B i.e. if B Ne C then A Ne C.

The explanation of these operators is rather sparse; the author's understanding of it has been derived through scrutinising the worked examples provided. (In the examples which are provided for the sake of clarity, the assumption is that the real number line maps approximately into 10^x where x is taken to be the order of magnitude.) The Ne operator is used to distinguish amounts belonging to different orders of magnitude e.g. '1 Ne 1000'. Both the Vo and the Co operator consider differences within the same orders of magnitude only; the Vo relation seems to be a proper subset of the Co operator. An example will serve to clarify the definition of these two operators: if A = 800, B = 801 and C = 900, then it may be said that B Vo C and A Co C or as Raiman puts it, "Co is obviously less restrictive than Vo". FOG provides some 30 rules of reasoning about its basic relations, qualitative values, addition and multiplication. The application of these operators in an economic environment has previously been elaborated in Section 3.3.1.

A more rigorous approach along the same lines has been put forward by Mavrouniotis & Stephanopoulos (1987). Their reasoning scheme called the O[M] formalism is based on seven primitive relations among quantities. The basic primitive relations together with their equivalence to FOG relations are shown in Figure 7.1. The

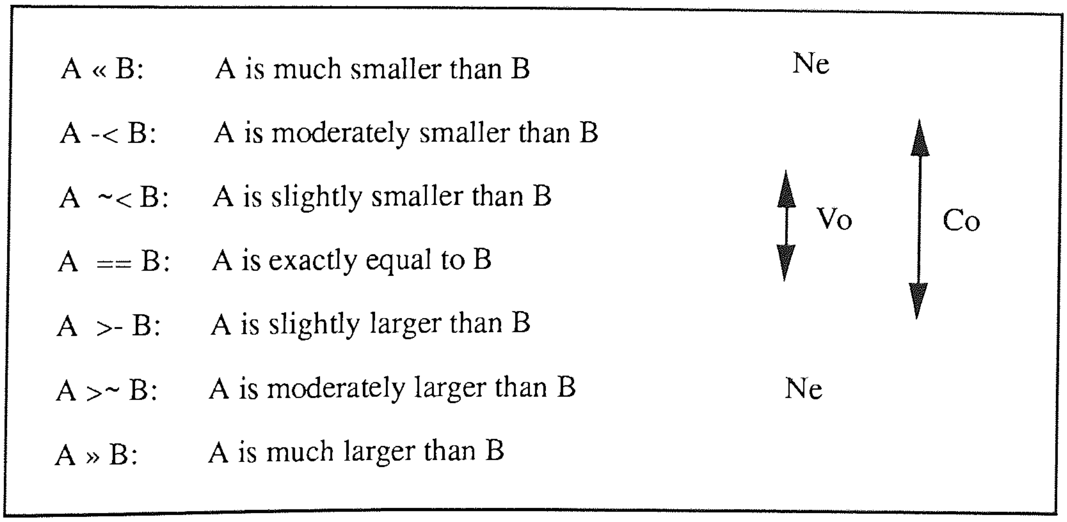

Figure 7.1 Basic O[M] Primitive Relations

system also defines twenty-one compound relations, a compound relation being an implicit disjunction of two primitive relations e.g. less than or equal to, which in O[M] formalism is «..==. Figure 7.2 shows the intervals for the relation A/B r_n 1; the intervals for the relations are taken to be symmetrical i.e. $e_3 = 1/e_2$ and $e_4 = 1/e_1$. The value of the parameter of e is dependent on the application domain. In the design of chemical processes, the designer tends to think of e as being between 0.05 and 0.20. On the other hand, the physicist would consider $e < 0.01$. Under these semantics, if A >~ B and B >~ C, the conclusion drawn will be A >~..>~ C. This interpretation is claimed to be too strict compared to human reasoning.

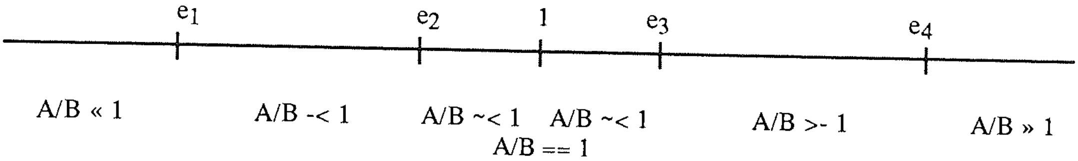

Figure 7.2 Strict Interpretation of Relation A r_n B

Thus, O[M] formalism replaces boundary points with intervals. Two sets of intervals are provided: a set of non-exhaustive intervals and a set of overlapping intervals. This, together with a heuristic that decides which interval to apply, is supposed to produce reasoning that closely resembles human reasoning. It can therefore be seen that the O[M] formalism shows how qualitative comparisons may be tied to a real number line.

Murthy (1988) draws together the different strands of work in the field of qualitative value sets. Each set of qualitative values that cover the entire number line is termed a Q-space. Four sets of Q-spaces that are useful in engineering problem-solving are identified; they represent a continuum of low to high resolution sets:

1. (-, 0, +) space which is identical to that specified by the theory of Envisioning (de Kleer & Brown 1984). This represents the lowest resolution set. The main problem with reasoning in this space is that the

addition of different signs results in ambiguity. This would be resolved if a move to a higher resolution Q-space were made.

2. (infinitesimal, 0, large) space which is identical to that in FOG (Raiman 1986). All relations expressed in Q-space 1 can be described in this Q-space; this Q-space effectively splits the positive half of the real number into two halves separated by a threshold i.e. a value that determines what can be termed a Vo or a Co relation. This threshold differs with the variables and the particular circumstances (e.g. whether two places are far apart depends on the mode of transport). Addition using this value set does not give ambiguous results since small influences are ignored with respect to large ones. It is significant however that the threshold changes during multiplication, in which case, ambiguity is possible:

   $a * b$ is large if a is large and b is large

   $a * b$ is small if a is small and b is small

   The product is ambiguous in all other cases.

   These ambiguities can be resolved using the next Q-space, Q-space 3.

3. $(y^{-z}, 0, y^{z})$ space which describes the relation between two numbers using some exponential function (y is the base e.g. 2 or 10 and z is an integer), which is used to resolve ambiguity in multiplication. If there is still ambiguity, there is a need to go to a finer level of resolution i.e. Q-space 4. It is possible to express all relations in Q-space 1 and 2 in this Q-space.

4. $(x * y^{-z}, 0, x * y^{z})$ where x is a number with n significant number of digits. This Q-space is the highest resolution set since as n approaches infinity, this Q-space approaches the real number line.

The four Q-spaces smoothly span the range from {-,0,+} set to the real number line. Analysis is performed at the lowest possible resolution set until ambiguities occur. When this occurs, the system moves from a Q-space with a lower level of resolution to that of a higher level.

The idea of ranking influences on a variable is not entirely new; Kosy & Wise (1984) develop a numeric measure ε to identify significant influences i.e. how much a set of variables affects a single variable, in the change between two contexts. If A is a function of B and C i.e. $A = fn(B,C)$ and the two contexts are 1 and 2 with $A_1 = fn(B_1,C_1)$ and $A_2 = fn(B_2,C_2)$, then B's influence on A is defined by $\varepsilon(A,\{B\}) = fn(B_2,C_2) - fn(B_1, C_2)$. The result is measured against some threshold value, which is empirically set, to determine its significance. The system, ROME, explains the value for that variable by tracing through the equations, collecting all influences that affect the variable and explaining the value in terms of the significant variables only. However, FOG and in particular, O[M] appears to be a more scientific approach. There are limitations to the usefulness of this technique, the most important of which is imposed by the large number of interactions between variables. Consider equation (28) which consists of fourteen interacting variables. There is every possibility that an ambiguous result will occur since this requires only two significant values to be of opposite signs. Another limitation is the assumption that all quantitative data is known. This might not hold true, especially if the analysis of the firm is taken by an outsider.

However, it seems possible that useful results could be obtained if knowledge of significant influences could be inferred and used by a qualitative reasoning system. Particularly appealing is the approach taken by Murthy (1988). Unfortunately, due to the very recent release of the paper and time constraints, this idea has not been pursued.

7.3 Resolving Ambiguity: Simplifying Equations

There are various ways of reducing ambiguity, such as the use of knowledge, heuristics and the use of quantitative data (variations of which were discussed in Section 7.2) and ultimately these will have to be used. However, it appears that the degree of ambiguity may also be affected by the way the qualitative model is expressed, i.e. the way in which the equations are written. Three papers (Dormoy & Raiman 1988; Raiman 1988; Williams 1988) recently published in the AAAI 1988 (available only in Spring 1989), express a similar opinion, albeit in more formalised terms. The discussion therefore proceeds by explaining the author's approach, drawing in similarities and differences from the other researchers at relevant points.

The anomalies observed during experimental work were first mentioned in Section 6.2.1 where the opinion was expressed that equations (11), (13) and (14) are not entirely accurate in portraying the profit derivation. The results from the experiments consistently show that care has to be taken when establishing new relationships; reckless introduction of new variables can have dire consequences i.e. unbridled ambiguity results. Thus, the suspicion was raised that the rule of generating one equation for each tank and for the pump is erroneous. Accordingly, a series of experiments were carried out to investigate the nature of the interaction of the equations, which bore out the suspicion. The conclusions of the results of these experiments follow (the unknown variables will be represented by [x] and [y]; other variables are to be regarded as known).

7.3.1 The Nature of Interaction between Equations

Firstly, it does not matter how a single equation is written. For example, given the values of [a], [b] and [c], precisely the same set of values of [x] satisfy all the alternative forms of the same 'semantic' equation given below:

$$[x] \circledequal [a] \oplus [b] \oplus [c]$$

$$[x] \ominus [a] \circledequal [b] \oplus [c]$$

$$\begin{gathered}[x] \ominus [a] \ominus [b] ⊜ [c] \\ [x] \ominus [a] \ominus [b] \ominus [c] ⊜ \text{normal}\end{gathered} \tag{36}$$

The evaluation of the equations proceeds as it does with normal mathematical equations. Thus, the ordering of items on one side of the equation is also irrelevant, e.g. equation (36) may also be written as: $[x] \ominus [b] \ominus [a] ⊜ [c]$.

Secondly, to minimise the loss of information, all calculations should be carried out as far as possible using quantitative values before converting to the corresponding qualitative values. This is due to the fact that information is lost whenever quantitative values are converted to qualitative values. In particular, $[a] \ominus [c]$ is only weakly qualitatively equal to $[a - c]$: for example, if $[a]$ = high and $[c]$ = high, $[a] \ominus [c]$ yields ambig, whereas if the quantitative values of a and c were used, the qualitative value of $(a - c)$ could be determined precisely. Williams (1988) quite correctly surmised that the crucial problem with standard approaches to qualitative reasoning is that they over-abstract, i.e. the replacement of every operator with the equivalent qualitative operator and every variable with a qualitative value leads to ambiguous answers.

Thirdly, the factored form of an equation should be used if one exists. For example, equation (38) will lead to less ambiguous results than equation (37):

$$[x] ⊜ ([a] \circledast [b]) \ominus ([c] \circledast [b]) \tag{37}$$

$$[x] ⊜ ([a] \ominus [c]) \circledast [b] \tag{38}$$

This is the result of the lack of a strict additive or subtractive inverse element with its consequent need for a weak equality operator to allow equations to be solved.

Fourthly, the simplification of a set of equations leads to less ambiguity if there are common items to be cancelled out. Consider the two equations:

$$[a] \oplus [c] ⊜ [x] \oplus [c] \tag{39}$$

$$[a] ⊜ [x] \tag{40}$$

They are not fully equivalent, and in particular (40) is less ambiguous than (39) because the common element [c] has been cancelled out. The underlying reason is that cancelling involves adding the inverse which in qualitative arithmetic may yield ambig:

$$[a] \oplus [c] \circledequal [x] \oplus [c]$$

$$\Rightarrow \quad [a] \oplus [c] \oplus [c]^{inv} \circledequal [x] \oplus [c] \oplus [c]^{inv}$$

$$\Rightarrow \quad [a] \oplus \{\text{normal, ambig}\} \circledequal [x] \oplus \{\text{normal, ambig}\} \qquad (39a)$$

Unless [c] = normal, $[c] \oplus [c]^{inv}$ = ambig, which means that (39a) is true regardless of the values of [a] and [x], i.e. the solution is [x] = ambig for any value of [a].

Next, it was discovered that the simplification of a set of equations leads to less ambiguity if unknown variables can be replaced by known variables so that there are no unknowns in the equation. Consider the two sets of equations:

(i) $[x] \circledequal [a] \oplus [b]$

$[y] \ominus [x] \circledequal \text{normal}$

(ii) $[x] \circledequal [a] \oplus [b]$

$[y] \ominus [a] \ominus [b] \circledequal \text{normal}$

The set of qualitative values of the four variables which satisfy both these sets of equations is the same. The reason appears to be that in substituting $[a] \oplus [b]$ for [x], there is still one unknown left. However, consider the sets of equations:

(iii) $[d] \circledequal [x] \ominus [a]$

$[b] \oplus [x] \ominus [a] \circledequal \text{normal}$

(iv) $[d] \circledequal [x] \ominus [a]$

$[b] \oplus [d] \circledequal \text{normal}$

In this case, set (iv) gives less ambiguous results than set (iii), as substitution leaves the second equation of the set with no unknowns. Thus, it seems advantageous to write equations so that where there is dependency, it is expressed in terms of a known quantity, rather than an unknown quantity.

Lastly, the experimental runs showed that the simplification of a set of equations leads to less ambiguity if unknown variables can be replaced by known variables, followed by cancellation of common variables. Consider the next two sets of equations:

(i) $[x] ⊜ [b] \ominus [a]$

$[a] \oplus [x] ⊜ \text{normal}$

(ii) $[x] ⊜ [b] \ominus [a]$

$[b] ⊜ \text{normal}$

In set (ii), [x] has been substituted and the common items have been cancelled out and this leads to less ambiguity. Substitution without any cancellation has no effect as in:

(iii) $[x] ⊜ [b] \oplus [c]$

$[y] ⊜ [x] \oplus [b]$

(iv) $[x] ⊜ [b] \oplus [c]$

$[y] ⊜ [b] \oplus [c] \oplus [b]$

Sets (iii) and (iv) produce an equal number of solutions i.e. valid values of the variables. Dormoy & Raiman (1988) also made a similar observation from which derived their Qualitative Resolution Rule; they see this situation as reflecting that of a system discovering global laws from local relations. The Qualitative Resolution Rule is given as:

Let x, y, z, a, b be qualitative quantities such that

$[x] \oplus [y] ⊜ [a]$

$\ominus[x] \oplus [z] ⊜ [b]$

If [x] is not ambig then $[y] \oplus [z] ⊜ [a] \oplus [b]$

Circumstances under which this rule should be applied are given; these are similar conditions to those pointed out previously: cancellation of common items must take place and unknown variables must be replaced with known variables.

7.3.2 Reformulating the Equations

These conclusions provide guide-lines in the formulation of equations to describe the flow of funds within a company. Attention is drawn again to the experimental models of the newsagent and the high-street retail store, described in Section 6.2.

Run 2 and run 3 illustrates the application of using the factored form of an equation. In Run 2, the equation set was:

[selling price] ⊛ [volume] ⊖ [sales] ⊜ normal (13)

[cost price] ⊛ [volume] ⊖ [cost of goods sold] ⊜ normal (14)

[sales] ⊖ [cost of goods sold] ⊖ [overheads] ⊖ [profit] ⊜ normal (11)

The profit was derived in effect, by substituting (13) and (14) into (11):

⇒ [selling price] ⊛ [volume] ⊖ [cost price] ⊛ [volume] ⊖ [overheads] ⊖ [profit] ⊜ normal (11a)

Given the the following values: [selling price] = high, [cost price] = normal, [volume] = high and [overheads] = normal, profit was incorrectly inferred to be ambiguous. Run 3, on the other hand, uses the following equation to derive the value of high for profit:

([selling price] ⊖ [cost price]) ⊛ [volume] ⊖ [overheads] ⊖ [profit] ⊜ normal (17a)

This is the correct result since the markup on the goods i.e. the difference between the selling price and cost price is high, the volume is high and the overheads are normal. Equation (11a) and (17a) is analogous to equation (37) and (38). Thus, factoring equations ensures that ambiguous results are the consequence of the inherent qualitativeness of the model, e.g. markup is high but the volume is low since there is no information on whether one will compensate the other.

Another situation for which the guide-lines may prove useful concerns that which involves a pair of flows that originate and terminate in the same tanks with each, however, flowing in the opposite direction to the other e.g. fixed assets in (i.e. the purchase of fixed assets) and fixed assets out (i.e. the sale of fixed assets). These flows will hereafter be referenced as contra-flows. Each of the following equations are examples of contra-flows which characterises the situation referred to as over-abstraction:

[fixed asset in] ⊖ [fixed asset out] ⊖ [depreciation] ⊖ [fixed assets] ⊜ normal (23)
[lt loan out] ⊖ [lt loan in] ⊕ [long term loan] ⊜ normal (24)
[lt liability out] ⊖ [lt liability in] ⊕ [other long term liability] ⊜ normal (25)
[st loan out] ⊖ [st loan in] ⊕ [short term loan] ⊜ normal (26)
[st liability out] ⊖ [st liability in] ⊕ [other current liability] ⊜ normal (27)

Another interesting aspect of these equations concerns the use of available published information; figures for individual contra-flows are rarely published. However, the figures for the gross changes in the tank (and consequently the net difference between the contra-flows) may be inferred by comparing the values of the tanks at two points in time (see Section 5.1). For instance, the difference in the value of long term loan at two points in time allows the inference for the value of ([lt loan out] ⊖ [lt loan in]) over the same period. Thus, it seems fruitful to replace the two contra-flows by a single flow denoting their difference. Thus, the respective modified equations would be:

[net fixed asset] ⊖ [depreciation] ⊖ [fixed assets] ⊜ normal (23a)
[net lt loan] ⊖ [long term loan] ⊜ normal (24a)
[net lt liability] ⊖ [other long term liability] ⊜ normal (25a)
[net st loan] ⊖ [short term loan] ⊜ normal (26a)
[net st liability] ⊖ [other current liability] ⊜ normal (27a)

In doing this, the set of variables defining the model is reduced thus achieving the objective of maintaining a minimal set of variables. However, these equations, (23a) - (27a), all assume that the net difference in flow is positive i.e. there is a net flow into the tank. This may not always be the case and under some instance, may cancel each other out. Thus, to describe all these possible scenarios, additional equations would need to be defined. For example, to describe the fixed asset relationship fully, two other equations need to be defined in addition to (23a):

[net fixed asset] ⊕ [depreciation] ⊕ [fixed assets] ⊜ normal (23b)

[depreciation] ⊖ [fixed assets] ⊜ normal (23c)

Equation (23b) describes the case where the firm is selling off more fixed assets than it is purchasing or replacing, while (23c) describes the case either where no fixed assets were bought or purchased during the period under review, or the amount of fixed assets disposed of matches the amount acquired. This situation is similar to the situation describing the profitability of the firm i.e. whether the firm is making a profit, loss or breaking even (see Section 5.2.3). This means that the generation of equations involving contra-flows will also be delayed until the user can supply information on it (rather than to generate it at the time of model specification - see Section 6.1.2). It must be admitted however that the corresponding equations for describing a net outflow in the case of (24) - (27) may not be needed since it is very rare for a firm to 'over-pay' their debts.

Habitat's financial statements under current review indicate the relationships expressed in (23a) - (27a). This means that equation (28) needs to be modified to form:

[cash sales] ⊕ [cash collect] ⊕ [net lt loan] ⊕ [net lt liability] ⊕
[net st loan] ⊕ [net st liability] ⊕ [net fixed asset in] ⊖ [repayments]
⊖ [overheads] ⊖ [other ca] ⊜ normal (28a)

The use of the modified equations (23a) - (28a) should result in a smaller set of legal states. This conclusion will be verified with a run, the results of which can be seen in the next section.

7.3.3 Solving the Simplified Equations

A new module, the Equation Simplifier thus interacts between the Qualitative Equation Generator and the Solution Generator (see Figure 7.3). This module takes the equations generated by the Qualitative Equation Generator and simplifies them according to the rules defined in Section 7.3.1. The algorithm for the simplification process is not particularly elegant or efficient, but it works for the cases presented to it. As an indication of the dimension of difficulty of this task, Williams (1988) makes use of Macsyma, a tested powerful symbolic algebra system in the implementation of his system. The construction of an efficient equation solver, in principle, constitutes yet another possible research issue.

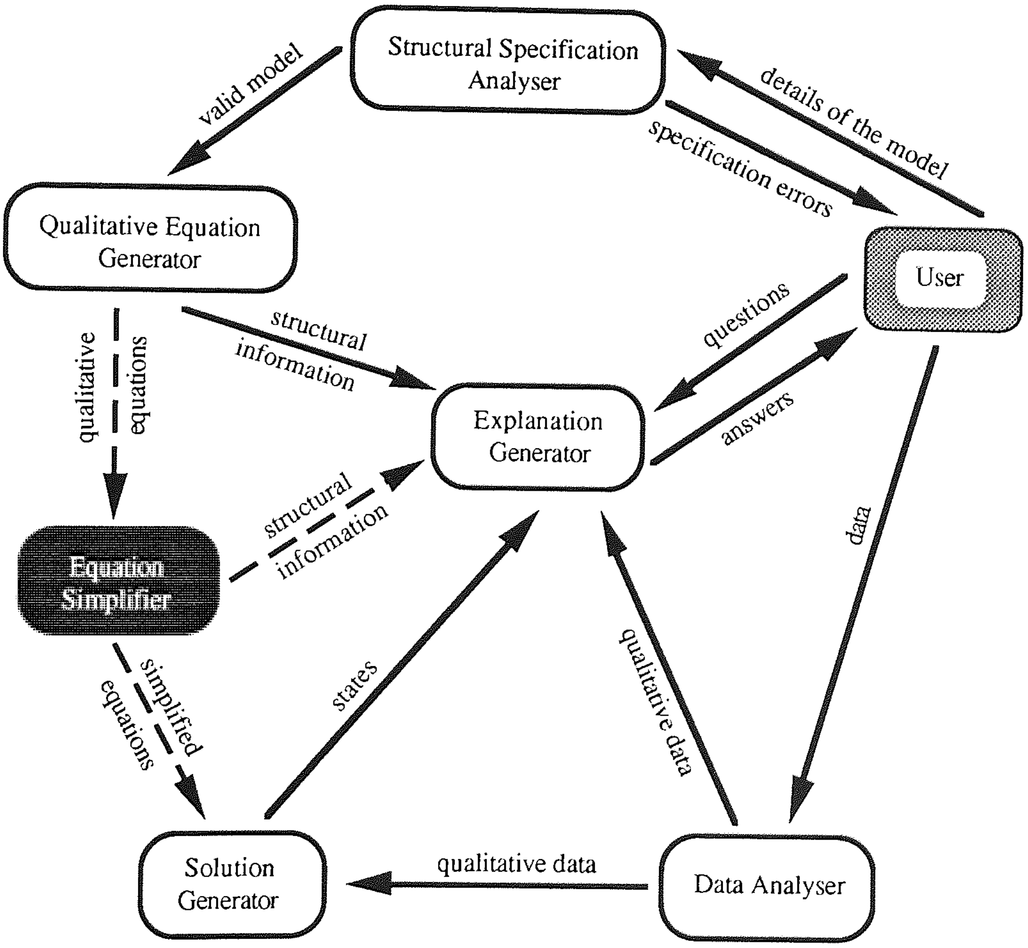

Figure 7.3 System Overview - Revised Version

The Equation Simplifier also needs to generate information to the Explanation Generator. For example, if the Equation Simplifier has replaced the contra-flows with a single flow, it would have to inform the Explanation Generator of this fact since the explanation would have to be given in terms of the given values of the two flows and the differences between them.

The simplified set of equations for Habitat Design is therefore:

[credit sales] ⊖ [cash collect] ⊖ [debtors] ⊜ normal (20)

[purchases] ⊖ [cost of goods] ⊖ [stocks] ⊜ normal (21)

[repayments] ⊖ [purchases] ⊕ [creditors] ⊜ normal (22)

[net fixed asset] ⊖ [depreciation] ⊖ [fixed assets] ⊜ normal (23a)

[net lt loan] ⊖ [long term loan] ⊜ normal (24a)

[net lt liability] ⊖ [other long term liability] ⊜ normal (25a)

[net st loan] ⊖ [short term loan] ⊜ normal (26a)

[net st liability] ⊖ [other current liability] ⊜ normal (27a)

[cash sales] ⊕ [cash collect] ⊕ [net lt loan] ⊕ [net lt liability] ⊕ [net st loan] ⊕ [net st liability] ⊕ [net fixed asset in] ⊖ [repayments] ⊖ [overheads] ⊖ [other ca] ⊜ normal (28a)

[sales] ⊖ [cost of goods] ⊖ [overheads] ⊖ [depreciation] ⊖ [profit] ⊜ normal (29)

The ratio and accounting relationships remain the same (see Appendix D). This time, the system managed to run to completion, after using 13 hours of CPU time on a VAX 8650 (or 3 weeks of elapsed time!). The number of legal states is 2374, of which none are unique. Despite this large number of states, the results are quite impressively sparse considering the large solution space (i.e. to the order of billions) and the fact that the previous run using equations (20) - (29) terminated abnormally (see Section 6.2.4). Having said that, there is still a large number of legal states which represents ambiguity which is inherent in the qualitativeness of the model; the proposed methodology has only succeeded in eliminating those superfluously introduced by the designer.

An interesting feature of the solution sets was the number of common values that each solution set had with the other. This led to the idea that the solution sets could be classified into two classes: one class for all values that are common to all candidate solutions and the second class, where the values vary i.e. attempt to collapse the sets. Only the latter set may then need to be focused on for further diambiguation.

7.4 Resolving Ambiguity: Collapsing Solution Sets

The objective of 'collapsing' the states is to identify a minimum representative set of values common to all solution sets. Table 7.1 is used to illustrate the strategy. Two sets may be combined if there is only one difference between them e.g. Set 1 and 3 can be added together to give {high, (normal,high), low}. The meaning of one difference must

	Short Term Loan			Creditors			Quick Assets		
Set	low	normal	high	low	normal	high	low	normal	high
1			✓		✓			✓	
2		✓				✓		✓	
3			✓			✓		✓	
4	✓					✓		✓	
5			✓	✓				✓	
6			✓		✓		✓		
7		✓				✓	✓		
8			✓			✓	✓		
9	✓					✓	✓		
10			✓	✓			✓		

Table 7.1 Sample Value Sets

be further clarified. Consider the following sets:

Set A {normal, high, low}
Set B {high, high, low}
Set C {normal, low, low}

Set A and B can be combined to form:

Set D {(normal,high), high, low}

But to combine set C into set D will be erroneous since the resultant set of Set E {(normal, high), (high,low), low) will imply the underlying set of:

{normal, high, low}
{normal, low, low}
{high, high, low}
{high, low, low}

which, when compared to the original set of {A,B,C} includes {high, low, low} although this is an invalid set. Thus, {(normal,high), (high,low)} is counted as more than one difference from {normal, low}. One difference therefore means a single difference for the entire sets to be compared.

A fundamental problem which seriously undermines this strategy is that the order in which these combinations are made affects the final result. Looking at a subset of the values given in Table 7.1 and concentrating on sets 6-10, there are two ways to produce the 'supersets'. One way is to combine 7, 8 and 9 to form a set, Set 11 {(low,normal,high), high, low}, and to combine 6 and 10 to form Set 12 {high, (low,normal), low}. These two sets, 11 and 12 cannot be further integrated and thus the final sets are:

Set 11 {(low,normal,high), high, low}
Set 12 {high, (low,normal), low}

Another way to combine the sets is to combine 6, 8 and 10 to form Set 13 {high, (low,normal,high), low} and to combine 7 and 9 to form Set 14 {(low,normal), high, low}. These two sets, 12 and 13 cannot be further integrated and thus the final sets are:

Set 13 {high, (low,normal,high), low}
Set 14 {(low,normal), high, low}

The final set of (13,14) is different from (11,12). So although it is possible in principle to classify the solution sets into two different sets, there seems to be again, a large number of such minimum sets depending on how they are combined. More work will be necessary to verify if this approach is worthwhile pursuing further.

7.5 Summary

The purpose of the research described in this chapter has been primarily to investigate various sources of ambiguity, starting from the initial specification of the model. The conclusion reached is that serious ambiguity may be introduced at this level; this has been borne out by various other researchers. However, having ensured that ambiguity arose from the situation itself and not the model, attention was focused on how this inherent qualitativeness could be handled. One approach of collapsing the sets into a minimum set that could be used to represent all solution sets was tried; more experiments will need to be carried out before a conclusion can be reached on how fruitful this approach may be. Another approach that seems promising, but was not tried, is to include information that will allow the system to differentiate between significant and insignificant variables. These two areas thus represent potential extensions to this piece of research.

8 Summary and Conclusions

The final chapter of this dissertation summarises the main conclusions of the research and evaluates how the effective the research has been in achieving its main aims. The chapter closes by suggesting areas in which future work might prove fruitful.

8.1 Summary of the Research

In Chapter 1, the goals of the research were stated as being:

1. To evaluate the flexibility and power of qualitative models.
2. To investigate the feasibility of constructing qualitative models in the financial domain.
3. To define the principles and methodology for the construction of such qualitative models.

The main method used to investigate the tasks set out by the goals was the construction of a system to implement some examples of qualitative financial models. However, some preliminary investigation was necessary in order to establish a sound theoretical foundation before the main body of work could be carried out. The conclusions of the preliminary analysis were:

1. Qualitative reasoning approaches have yet to prove that they can produce models which can perform in novel situations. However, there are aspects of the work which have proven to be useful, namely, the ability to generate and analyse all possible behaviours of the model automatically.

2. A new qualitative value set needs to be defined and together with it, a new set of qualitative operations to cope with the demands of the financial domain. The new value set is: {low,normal,high} and the qualitative operations are: ⊕, ⊖, ⊘, ⊛ and ⊜, which are the qualitative addition, qualitative subtraction, qualitative division, qualitative multiplication and qualitative equality operations respectively.

3. It is not always possible to derive the qualitative equations directly from quantitative equations. In the case of the funds flow model, the definition of the exact qualitative equations for describing the function of the various 'components' of a model have to be derived by analysing the verbal descriptions of the operations given in textbooks.

The major conclusions drawn from the main investigation were:

1. It is possible for a designer of a model to unintentionally introduce ambiguity that is not part of the model. However, it is also possible to design a system that will identify and eliminate ambiguity that occurs in such situations.

2. Models in finance display a severe lack of constraint when they are interpreted qualitatively. This is due to the fact that the heuristics to use and interpret them are not incorporated into the qualitative model.

3. More work is necessary to establish if qualitative reasoning approaches are indeed a fruitful avenue of exploration.

A full discussion of these conclusions will be presented in the following sections.

8.1.1 Useful Aspects of Qualitative Reasoning

The general consensus of researchers in the field is that:

1. Qualitative models can analyse their behaviour automatically.
2. Qualitative models can handle qualitative data.
3. Qualitative models can handle situations where all the data is not known.
4. Qualitative models are robust; they can perform correctly in novel situations.
5. Qualitative models can generate adequate causal explanations.

Section 3.1 presented the different algorithms for deriving all possible behaviours of a qualitative model. Each algorithm employs the use of qualitative mathematics i.e. qualitative values and qualitative operators. Although not directly stated, it may be inferred that the algorithms do not require all variables to have their values known; they will work when 'enough' values of variables are known. Thus, qualitative models do justify the claims that they can automatically generate possible behaviours, handle qualitative data and operate when not all information is known.

Two of the main objectives of qualitative reasoning approaches are to define a methodology to construct models that will operate in novel situations and to generate causal explanations. However, as the discussion in Section 3.2.1 pointed out, although efforts have been made to define principles which guarantee robustness (de Kleer & Brown 1984; Forbus 1988), there has not been any evidence of success in applying these to large-scale projects. More success appears to have been met in attempting to achieve the latter objective. Section 3.2.3 described the different, purely intuitive definitions of causality for the physical domain. Such a philosophical analysis is not necessary in the financial domain since some causal arguments are already embedded in the definition of the algebraic models (see Section 2.2.1). Thus, it seems fairly straight-forward to generate explanations from these.

Since qualitative models have demonstrated that they do indeed fulfil some of the promises they make, the question now is whether these features are enough to handle problems in the financial domain where the models are not sufficiently constrained (when compared to physical models) to give tractable answers.

8.1.2 A New Qualitative Value Set and Associated Operators

Section 5.2.1 established that the conventional qualitative set of {-,0,+} is not appropriate and argued for the definition of the new value set of {low,normal,high} on the basis of how analysts arrive at their evaluation of a firm. The definition of a new value set necessarily means the definition of a new set of operators. Since the use of this new value set and its associated operators will have implications on how the underlying qualitative equations for a model have to be expressed, the mathematical properties of these were thoroughly investigated (see Section 5.2.2).

What is apparent from the analysis is how 'weak' qualitative equations are compared to quantitative equations; this feature partly accounts for the large number of possible solutions derived for the models defined in Section 6.2 and Section 7.3. A close examination of these solutions showed that qualitative data on their own do not place sufficient constraints on the possible solutions, thus admitting ambiguous solutions which can in fact be ruled out if more precise data or additional data were used.

So while it has been shown to be true that using qualitative models, all possible behaviours can be uncovered, this analysis can only be useful if the number of potential behaviours is manageable. If the number of behaviours is very large, as shown when the model for Habitat Design was used as described in Section 6.2.4, then it is difficult to make sense of the analysis.

8.1.3 Derivation of Equations for a Qualitative Model

The model chosen for qualitative analysis is that describing the flow of funds through a firm. This description is given in terms of a liquid flow model i.e. pump, tanks, valves and flows.

Reasons why the mainstream approaches to qualitative reasoning could not work in this instance were given in Section 5.2.3; this can largely be attributed to the nature of the situation being modelled. The most promising line to take in describing the function of the components of the model points to a broad de Kleer and Brown style of specifying relationships. However, the specification of the functions of the components using this formalism is not as straight-forward as it was first thought to be.

Firstly, it is not possible to derive the qualitative equations directly from the quantitative equations (i.e. to replace every variable by a qualitative variable and every operator by a qualitative operator), simply because these do not exist. Secondly, the verbal descriptions of the situation are very imprecise; the problem of understanding such descriptions only serves to illustrate the flexibility of the human mind in handling imprecise information.

To ensure that the equations correctly reflect the underlying semantics, the descriptive accounts given in text-books had to be closely scrutinised for their meaning to derive the exact qualitative equations for describing the functions of the various components of the model, and the assumptions underlying these formulations.

8.1.4 Identifying and Eliminating Ambiguity

To verify the power of the qualitative models, a system was implemented which would execute example models so that results from them could be analysed. The system allows the user to specify the operations of the firm and the data (both quantitative and qualitative), and allows the user to query the system about the financial condition and performance of the firm: how this came about and how it may be improved. To answer these questions, the system not only has to generate the underlying qualitative model but also has to solve it. Section 6.1 presented the details of the system implementation.

The conclusion drawn from experimenting with different models and different types of data is that there is a lack of constraint involved in the model when it is interpreted qualitatively (see Section 6.2). This results in a prohibitively large number of possible solutions for any given model and is quite different from physical domains where the models are sufficiently constrained to produce useful answers. Several possibilities suggest themselves to alleviate this problem, one of which was to examine the nature of qualitative equations. This analysis given in Section 7.3.1 confirmed an early observation made in Section 6.2.1 that qualitative equations can introduce ambiguity which is not an inherent part of the model. The analysis also established the conditions under which ambiguity can be unknowingly introduced by the designer of the model and investigated the reasons for this to show how it can be eliminated. The original system was subsequently modified to include the facility for eliminating 'accidental' ambiguity.

8.1.5 Identifying Other Sources of Constraints

Although a substantial portion of ambiguity can be eliminated through the principles set out in Section 7.3.1, the results (i.e. number of possible states of the system) are still too large to be useful (see Section 7.3.3). This is because a large part of the constraints of the domain is embedded in the heuristics humans use to manipulate the model. Thus, in order to produce more constrained solutions, these heuristics will have to be incorporated into the computerised system. However, due to time considerations, this was not done and represents a possible extension to the current work.

Section 7.2 gave a review of the literature, concentrating on a particular aspect of qualitative reasoning: ambiguity, the bane of all researchers in the field. This review is relevant since any real attempts to use this reasoning style must find an answer to containing this problem and it allows the reader to make valid comparisons of the author's proposed solution.

8.2 Epilogue

It may therefore be said that there are differing degrees of success in the achievement of the objectives. A theoretical and practical investigation was carried out to analyse the power, flexibility and usefulness of qualitative models. This investigation produced evidence to show that the facilities provided by the technique will be useful to the extent that ambiguity does not feature prominently under the circumstances; unless and until ambiguity, an inherent feature of qualitative models, can be contained, the power and flexibility of these models in finance will be limited. It will be heartening to all future researchers intending to extend this thesis to know that there are several ways of placing additional constraints on the model and thereby containing ambiguity. These are discussed in the next section, under recommendations for future work.

The objective of defining the principles and methodology for constructing qualitative financial models has not been achieved, in view of the fact that it has not been possible to say unequivocally that qualitative models in finance are feasible. In retrospect, this objective was too ambitious. However, it was not immediately apparent at the time of stating the thesis proposal, after reviewing the literature of qualitative reasoning, that there are many fundamental questions for which current knowledge is not available or established. Only when attempts were made to apply the theory were such inadequacies revealed. Therefore, what the research has had to accomplish instead is a whole lot of 'ground-clearing' work which is essential if a solid base for research in the area is to be established.

The message that comes across clearly is that the field of qualitative reasoning is still in its infancy and that many more insights into this field will be needed before qualitative models can take their place as an established alternative to other types of models.

8.3 Recommendations for Future Work

It is difficult to know where to start; this research is essentially ground-clearing work and thus the possibilities for extending it are numerous. Some of the more interesting and realistic possibilities are to incorporate the better use of existing quantitative data and the use of heuristics.

The current qualitative value set only considers the amount of the value; the derivation of the incremental set as discussed in Section 5.2 would prove useful not only for disambiguation purposes but also to provide a richer description of the condition of the firm: one of the other established forms of analysis involves the comparison of the firm's financial statements over the years. Another aspect of quantitative information that has not been exploited is the order of magnitude information suggested by various researchers; especially appealing is the recent work by Murthy (1988). It would be interesting to see how this useful this technique would be in reducing the amount of ambiguity especially since the value set is different from the conventional set.

In contrast to quantitative models in physical domains, quantitative models in financial domains are not complete. This is because these models cannot capture the human aspects of the situation. Different persons not only interpret the models differently, they will also choose different models to help their decision-making function. It seems productive therefore to invest effort in defining various sets of heuristics, each representing a particular approach to decision-making. However, this study might be best undertaken by a financial researcher.

Another possibility is to carry on the investigation with more complex models, for example, involving the use of multiple pumps and considering other properties of the variables in the system like risk and liquidity.

Whichever approach is taken, the researcher can be assured that his work and his efforts can only go towards making a useful contribution to and advancing the knowledge and understanding of everyday phenomena in the commercial world.

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Appendix A

Sample Inputs to the Structural Specification Analyser

A.1 The inputs to two sessions are shown below. Each session begins with the user issuing the command "get_struct". The query, "controlled" elicits information as to whether the firm controls this flow i.e. is there a valve on the pipe through which the fund flows?

A.2 The model specified is that of the extended model given in 6.2.3 (see Figure 6.3a). It consists of a pump, 3 tanks and 6 flows (including profit/loss).

```
| ?- get_struct.
    Enter Name of flows out of pump (q to end): sales.
    Enter Name of flows out of pump (q to end): q.
    Enter Dest type(pump,flow,tank) for sales : tank.
    Enter tank type(asset,liability): asset.
                                            Name: cash.
    Enter outflows for cash (q to end): repayments.
                                            Controlled(yes/no): yes.
                  Outflow(q to end): overheads.
                                            Controlled(yes/no): yes.
                  Outflow(q to end): q.
    Enter Dest type(pump,flow,tank) for overheads : pump.
    Enter Dest type(pump,flow,tank) for repayments : tank.
    Enter tank type(asset,liability): liability.
                                            Name: creditors.
    Enter outflows for creditors (q to end): purchases.
                                            Controlled(yes/no): no.
                  Outflow(q to end): q.
    Enter Dest type(pump,flow,tank) for purchases : tank.
    Enter tank type(asset,liability): asset.
                                            Name: stock.
    Enter outflows for stock (q to end): cost_goods_sold.
                                            Controlled(yes/no): no.
                  Outflow(q to end): q.
    Enter Dest type(pump,flow,tank) for cost_goods_sold : pump.
```

A.3 The second model to be specified is a scaled-down version of Habitat Design described in 6.2.4. This model consists of a pump, 5 tanks and 12 flows (including profit/loss). An interesting feature is that it illustrates how the main inflow from the pump, sales divides into two flows, credit sales and cash sales.

```
| ?- get_struct.
```

```
Enter Name of flows out of pump (q to end): sales.
Enter Name of flows out of pump (q to end): q.
Enter Dest type(pump,flow,tank) for sales : flow.
          Flow (q to end): cash_sales.
          Flow (q to end): credit_sales.
          Flow (q to end): q.
Enter Dest type(pump,flow,tank) for credit_sales : tank.
Enter tank type(asset,liability): asset.
                              Name: debtors.
Enter Dest type(pump,flow,tank) for cash_sales : tank.
Enter tank type(asset,liability): asset.
                              Name: cash.
Enter outflows for debtors (q to end): cash_collect.
                              Controlled(yes/no): yes.
          Outflow(q to end): q.
Enter outflows for cash (q to end): repayments.
                              Controlled(yes/no): yes.
          Outflow(q to end): overheads.
                              Controlled(yes/no): yes.
          Outflow(q to end): fa_purchases.
                              Controlled(yes/no): yes.
          Outflow(q to end): q.
Enter Dest type(pump,flow,tank) for cash_collect : tank.
Enter tank type(asset,liability): asset.
                              Name: cash.
Enter Dest type(pump,flow,tank) for fa_purchases : tank.
Enter tank type(asset,liability): asset.
                              Name: fixed_asset.
Enter Dest type(pump,flow,tank) for overheads : pump.
Enter Dest type(pump,flow,tank) for repayments : tank.
Enter tank type(asset,liability): liability.
                              Name: creditors.
Enter outflows for fixed_asset (q to end): depreciation.
                              Controlled(yes/no): yes.
          Outflow(q to end): fa_sales.
                              Controlled(yes/no): yes.
          Outflow(q to end): q.
Enter outflows for creditors (q to end): purchases.
                              Controlled(yes/no): no.
          Outflow(q to end): q.
Enter Dest type(pump,flow,tank) for fa_sales : tank.
Enter tank type(asset,liability): asset.
                              Name: cash.
Enter Dest type(pump,flow,tank) for depreciation : pump.
Enter Dest type(pump,flow,tank) for purchases : tank.
Enter tank type(asset,liability): asset.
                              Name: stock.
Enter outflows for stock (q to end): cost_goods_sold.
                              Controlled(yes/no): no.
          Outflow(q to end): q.
Enter Dest type(pump,flow,tank) for cost_goods_sold : pump.
```

Appendix B

Sample Inputs to the Data Analyser

B.1 Four main types of data may be entered into the system: ratio information, accounting relationships, quantitative and qualitative values for variables.

B.2 The first session shows the user entering a series of qualitative values for the ratios. These will overwrite all those values that are currently held by the system from previous runs.

```
| ?- enter_qual_ratios.
   Enter ratio (q to end): profit/sales.
          Enter value(low,normal,high): low.
   Enter ratio(q to end): sales/inventory.
          Enter value(low,normal,high): high.
   Enter ratio (q to end): q.
```

The second session shows the user specifying a series of quantitative values for the ratios. If this option is chosen, then the user must also supply corresponding data for the industry. The system will convert the quantitative values for the firm into qualitative values, as specified in Section 6.1.3. This option will overwrite all existing qualitative ratio values.

```
| ?- enter_ratios_to_use.
   Enter ratio (q to end): profit/sales.
          Enter value for firm: 20.1.
          Enter value for industry:  [30.1, 55.1, 60.1].
   Enter ratio (q to end): sales/inventory.
          Enter value for firm: 32.1.
          Enter value for industry:  [20.1, 22.1, 23.0].
   Enter ratio (q to end): q.
```

Finally, the user may also enter desired qualitative values for the ratios; if these are left out, then the system assigns a desired value of normal to all desired ratio values.

```
| ?- enter_desired_ratio_values.
   Enter ratio (q to end): profit/sales.
```

```
        Enter desired value(low,normal,high): high.
Enter ratio(q to end): sales/inventory.
        Enter desired value(low,normal,high): high.
Enter ratio (q to end): q.
```

B.3 The user should enter the definition of the accounting variables used in the ratios. This is invoked by issuing the command "get_hierarchy_struct".

```
| ?- get_hierarchy_struct.
    Enter Class(q to end): quick_assets.
        Components(q to end): cash.
        Components(q to end): debtors.
        Components(q to end): q.

    Enter Class(q to end): curr_assets.
        Components(q to end): quick_assets.
        Components(q to end): stock.
        Components(q to end): q.

    Enter Class(q to end): total_assets.
        Components(q to end): curr_assets.
        Components(q to end): fixed_asset.
        Components(q to end): q.

    Enter Class(q to end): q.
```

B.4 The command "enter_qual_variables" allows the user to enter all or some of the qualitative values of the variables. These variables must have been defined either as part of the structure or as accounting variables.

```
| ?- enter_qual_variables.
    Enter variable (q to end): selling_price.
            Enter value(low,normal,high): low.
    Enter variable(q to end): volume.
            Enter value(low,normal,high): normal.
    Enter variable(q to end): q.
```

Appendix C

Sample Outputs from the Explanation Generator

C.1 The Explanation Generator is invoked with the command "explain". The system starts with an initial diagnosis. After the initial diagnosis, the user can query the system for more detailed explanations. Eight options are available to the user, each option has been reviewed in Section 6.1.5.

```
| ?- explain.
   Following ratios are unsatisfactory:

      interest/profit_bef_interest (low)
      sales/stock (low)
      debtors/sales (low)
      curr_assets/curr_liab (low)
      quick_assets/curr_liab (low)
      net_worth/total_liab (low)
      fixed_assets/total_assets (low)
      deprec/sales (low)

      These can be explained by the fact that:
         deprec is low
         fixed_assets is low
         net_worth is low
         debtors is low
         stock is normal
         sales is low
         interest is low

      Would you like to know why (yes/no): yes.
      Because
              debtors is low
      Then
              quick_assets is low
      Because
              quick_assets is low
              stock is normal
      Then
              curr_assets is low
      Because
              curr_assets is low
              fixed_assets is low
      Then
              total_assets is low
      Because
              interest is low
      Then
              profit_bef_interest is high
      Because
              net_worth is low
              curr_liab is high
      Then
              total_liab is low
```

C.2 The first two options are self-explanatory; the system merely retrieves the qualitative values of the ratios and variables.

```
Would you like to investigate further ? yes.
Enter any of following queries:

    1.      What is the value of <variable> ?
    2.      What is the value of <ratio> ?
    3.      How was the value of  <variable> deduced ?
    4.      How was the value of  <ratio> deduced ?
    5.      How can <variable> be changed ?
    6.      How can <ratio> be changed ?
    7.      What happens if <variable> changes ?
    8.      How can a particular profile be achieved ?
    9.      End of queries

  Enter Option: 1.
  variable ? sales.
  sales is low

  Enter Option: 1.
  variable ? cost_goods_sold.
  cost_goods_sold is low

  Enter Option: 1.
  variable ? profit.
  profit is high


Enter any of following queries:

    1.      What is the value of <variable> ?
    2.      What is the value of <ratio> ?
    3.      How was the value of  <variable> deduced ?
    4.      How was the value of  <ratio> deduced ?
    5.      How can <variable> be changed ?
    6.      How can <ratio> be changed ?
    7.      What happens if <variable> changes ?
    8.      How can a particular profile be achieved ?
    9.      End of queries

  Enter Option: 2.
  ratio ? profit/sales.
  profit/sales is high

  Enter Option: 2.
  ratio ? curr_assets/curr_liab.
  curr_assets/curr_liab is low

  Enter Option: 2.
  ratio ? sales/total_assets.
  sales/total_assets is high
```

C.3 How the qualitative value of a variable or ratio is deduced depends on what data was entered into the system. In some instances, it was user-specified i.e. given.

In others, the system had to derive these values; from existing ratio value constraints, from constraints specified by the equation, or from quantitative data.

```
Enter any of following queries:

     1.      What is the value of <variable> ?
     2.      What is the value of <ratio> ?
     3.      How was the value of  <variable> deduced ?
     4.      How was the value of  <ratio> deduced ?
     5.      How can <variable> be changed ?
     6.      How can <ratio> be changed ?
     7.      What happens if <variable> changes ?
     8.      How can a particular profile be achieved ?
     9.      End of queries

  Enter Option: 3.
  variable ? sales.
  sales is low as
    profit/sales is high             i.e low/low
    sales/total_assets is high       i.e low/low
    sales/fixed_assets is normal     i.e low/low
    sales/stock is low               i.e low/normal
    debtors/sales is low             i.e low/low
    deprec/sales is low              i.e low/low

  Enter Option: 3.
  variable ? fa_sales.
  fa_sales is ambiguous but the combined effects of fa_purchases, fa_sales is low
  Because
        cash_collect is low
        cash_sales is normal
        deprec is low
        fixed_assets is low
        ltloan_repaid is ambiguous
        ltloan_taken is ambiguous
        other_ca is high
        other_cl_repaid is ambiguous
        other_cl_taken is ambiguous
        other_ltliab_taken is ambiguous
        overheads is normal
        repayments is ambiguous
        stloan_repaid is ambiguous
        stloan_taken is ambiguous

  Enter Option: 3.
  variable ? curr_assets.
  Because
        stock is normal
        quick_assets is low
  Then
        curr_assets is low

 Enter any of following queries:

     1.      What is the value of <variable> ?
     2.      What is the value of <ratio> ?
     3.      How was the value of  <variable> deduced ?
     4.      How was the value of  <ratio> deduced ?
     5.      How can <variable> be changed ?
     6.      How can <ratio> be changed ?
```

```
    7.      What happens if <variable> changes ?
    8.      How can a particular profile be achieved ?
    9.      End of queries

 Enter Option: 4.
 ratio ? sales/stock.
 sales/stock is low as
   Company  ratio is more than 10% lower than the industrial median
    Company  ratio is 5.6
   The industrial median is 6.89999

 Enter Option: 4.
 ratio ? debtors/sales.
 debtors/sales is low as
   Company  ratio is more than 10% lower than the industrial median
    Company  ratio is 0.015
   The industrial median is 0.0799999
```

C.4 The system attempts to explain changes in terms of the structural flow model. If the variable is an accounting variable, then the explanation is given in terms of its relationship to variables in the flow model.

```
 Enter any of following queries:

    1.      What is the value of <variable> ?
    2.      What is the value of <ratio> ?
    3.      How was the value of  <variable> deduced ?
    4.      How was the value of  <ratio> deduced ?
    5.      How can <variable> be changed ?
    6.      How can <ratio> be changed ?
    7.      What happens if <variable> changes ?
    8.      How can a particular profile be achieved ?
    9.      End of queries

Enter Option: 5.
   variable ? selling_price.
   selling_price is ambig
     selling_price control is beyond the scope of this system

 Enter Option: 5.
 variable ? overheads.
 overheads is normal
 Up or down  value ? down.
 To get to the state of low
   overheads can be changed at management discretion, source is other_ca
     other_ca is high

 Enter Option: 5.
 variable ? credit_sales.
 credit_sales is low
 Up or down  value ? up.
 To get to the state of normal
   sales has to increase from low to normal
   cash_sales has to decrease from normal to low

   credit_sales is a branchoff from the main flow sales
   Because
```

```
          sales is low
          cash_sales is normal
 Then
          credit_sales is low
sales is determined by selling_price, est_volume
 selling_price control is beyond the scope of this system
 est_volume control is beyond the scope of this system

Enter Option: 5.
variable ? curr_assets.
curr_assets is low
Up or down  value ? up.
To get to the state of normal
  stock has to increase from normal to high
  debtors has to increase from low to normal
  other_ca has to remain high

  curr_assets is made up of stock, debtors, other_ca

  stock is affected by the changes in purchases, cost_goods_sold
   purchases is ambiguous
   cost_goods_sold has to remain low

  purchases can be changed at management discretion, source is creditors
   creditors is normal

  debtors is affected by the changes in credit_sales, cash_collect
   credit_sales has to increase from low to normal
   cash_collect has to remain low

   sales has to increase from low to normal
  cash_sales has to decrease from normal to low

  credit_sales is a branchoff from the main flow sales
  Because
          sales is low
          cash_sales is normal
  Then
          credit_sales is low
 sales is determined by selling_price, est_volume
  selling_price control is beyond the scope of this system
  est_volume control is beyond the scope of this system

 other_ca is affected by the changes in cash_collect, cash_sales, ltloan_taken,ltloan_repaid,
 other_ltliab_taken, other_ltliab_repaid, stloan_taken, stloan_repaid,
 other_cl_taken,other_cl_repaid, repayments, fa_purchases, fa_sales, overheads
  cash_collect has to increase from low to normal
  cash_sales has to increase from normal to high
 The combined effects of ltloan_taken, ltloan_repaid is ambiguous
 The combined effects of other_ltliab_taken, other_ltliab_repaid is ambiguous
 The combined effects of stloan_taken, stloan_repaid is ambiguous
 The combined effects of other_cl_taken, other_cl_repaid is ambiguous
  repayments is ambiguous
 The combined effects of fa_purchases, fa_sales has to remain low
 overheads has to decrease from normal to low

  sales has to increase from low to normal
 credit_sales has to remain low

 cash_sales is a branchoff from the main flow sales
 Because
          sales is low
          credit_sales is low
  Then
```

```
        cash_sales is normal
 sales is determined by selling_price, est_volume
 selling_price control is beyond the scope of this system
 est_volume control is beyond the scope of this system
 ltloan_taken is ambiguous
 ltloan_repaid is ambiguous

ltloan_taken can be changed at management discretion, source is long_term_loan
 long_term_loan is low
ltloan_repaid can be changed at management discretion, source is other_ca
 other_ca is high
 other_ltliab_taken is ambiguous
 other_ltliab_repaid is ambiguous

other_ltliab_taken can be changed at management discretion, source is other_ltliab
 other_ltliab is low
other_ltliab_repaid can be changed at management discretion, source is other_ca
 other_ca is high
 stloan_taken is ambiguous
 stloan_repaid is ambiguous

stloan_taken can be changed at management discretion, source is short_term_loan
 short_term_loan is high
stloan_repaid can be changed at management discretion, source is other_ca
 other_ca is high
 other_cl_taken is ambiguous
 other_cl_repaid is ambiguous

other_cl_taken can be changed at management discretion, source is other_cl
 other_cl is low
other_cl_repaid can be changed at management discretion, source is other_ca
 other_ca is high
 fa_purchases is ambiguous
 fa_sales is ambiguous

fa_purchases can be changed at management discretion, source is other_ca
 other_ca is high
fa_sales can be changed at management discretion, source is fixed_assets
 fixed_assets is low
```

C.5 This option merely tells the user what changes are required; the system does not attempt to verify if the changes proposed are possible.

```
Enter any of following queries:

    1.      What is the value of <variable> ?
    2.      What is the value of <ratio> ?
    3.      How was the value of  <variable> deduced ?
    4.      How was the value of  <ratio> deduced ?
    5.      How can <variable> be changed ?
    6.      How can <ratio> be changed ?
    7.      What happens if <variable> changes ?
    8.      How can a particular profile be achieved ?
    9.      End of queries

 Enter Option: 6.
 ratio ? sales/stock.
 sales/stock is low                    i.e low/normal
 Up or down  value ? up.
 To get to the state of normal
```

```
  sales has to increase from low to normal

Enter Option: 6.
ratio ? debtors/sales.
debtors/sales is low                     i.e low/low
Up or down  value ? up.
To get to the state of normal
  debtors has to increase from low to normal
  sales has to increase from low to normal
```

C.6 The system explains the effects of changes both in terms of the changes to the ratio profile of the firm and in terms of the funds flow model.

```
Enter any of following queries:

    1.      What is the value of <variable> ?
    2.      What is the value of <ratio> ?
    3.      How was the value of  <variable> deduced ?
    4.      How was the value of  <ratio> deduced ?
    5.      How can <variable> be changed ?
    6.      How can <ratio> be changed ?
    7.      What happens if <variable> changes ?
    8.      How can a particular profile be achieved ?
    9.      End of queries

Enter Option: 7.
variable ? sales.
sales splits into credit_sales, cash_sales
Need to specify which subflow is to be changed:
credit_sales is low
Up/down/none  value ? up.
cash_sales is normal
Up/down/none  value ? none.
Because
  credit_sales becomes normal
  cash_sales remains normal
Then sales becomes normal

If sales becomes normal
  and credit_sales becomes normal
  profit will increase from low to normal

  debtors will increase from low to normal

  profit/sales moves from high to normal
  sales/total_assets remains high
  sales/fixed_assets moves from normal to high
  sales/stock moves from low to normal
  debtors/sales moves from low to normal
  deprec/sales remains low
  debtors/sales moves from low to normal
  debtors/total_assets moves from normal to high

Enter Option: 7.
variable ? profit.
profit cannot be changed directly
variable ? stock.
stock cannot be changed directly
variable ? overheads.
overheads is normal
```

```
Up/down/none  value ? down.
If overheads becomes low
   other_ca remains high
   profit will increase from low to normal

   other_ca/total_assets remains high
```

C.7 Two examples are provided. In the first case, the desired ratio profile is achievable while in the second, it is not. The transition rule discussed in 5.1.3 determines the outcome of the request.

```
      Enter any of following queries:

          1.          What is the value of <variable> ?
          2.          What is the value of <ratio> ?
          3.          How was the value of  <variable> deduced ?
          4.          How was the value of  <ratio> deduced ?
          5.          How can <variable> be changed ?
          6.          How can <ratio> be changed ?
          7.          What happens if <variable> changes ?
          8.          How can a particular profile be achieved ?
          9.          End of queries

 Enter Option: 8.
Ratio (q to end)? sales/total_assets.
 Current value is low          New Value (low, normal, high) ? normal.
Ratio (q to end)? debtors/sales.
 Current value is low          New Value (low, normal, high) ? normal.
Ratio (q to end)? q.
This Profile will be achieved if
   debtors increases from low to normal
   sales increases from low to normal
   total_assets increases from low to normal

 Enter Option: 8.
Ratio (q to end)? sales/total_assets.
 Current value is low          New Value (low, normal, high) ? normal.
Ratio (q to end)? q.
This Profile will be achieved if
   sales increases from low to normal

 Enter Option: 9.


 Enter any of following queries:

          1.          What is the value of <variable> ?
          2.          What is the value of <ratio> ?
          3.          How was the value of  <variable> deduced ?
          4.          How was the value of  <ratio> deduced ?
          5.          How can <variable> be changed ?
          6.          How can <ratio> be changed ?
          7.          What happens if <variable> changes ?
          8.          How can a particular profile be achieved ?
          9.          End of queries

 Enter Option: 8.
Ratio (q to end)? sales/total_assets.
```

```
Current value is low          New Value (low, normal, high) ? normal.
Ratio (q to end)? q.
This Profile will be achieved if
  sales increases from low to normal

Enter Option: 8.
Ratio (q to end)? sales/total_assets.
Current value is low          New Value (low, normal, high) ? normal.
Ratio (q to end)? debtors/sales.
Current value is high         New Value (low, normal, high) ? normal.
Ratio (q to end)? q.


This Profile cannot be achieved

Enter Option: 9.
```

Appendix D

Habitat Design: Accounting and Ratio information

D.1 All figures are taken from 'Intercompany Comparisons: Retail Outlets' published by Keynote Publications Limited for the period 1981-1984.

D.2 The values for twenty-eight ratios for the 1982/1983 period are given. The values for the other firms in the industry are not given.

profit/cap_employ = 66.4
profit/total_assets = 25.1
profit/sales = 11.6
sales/total_assets = 2.2
interest/profit_bef_interest = 0
sales/fixed_assets = 5.6
sales/stock = 5.6
debtors/sales = 0.015
curr_assets/curr_liab = 1.0
quick_assets/curr_liab = 0.4
total_debt/net_worth = 0.7
net_worth/total_liab = 0.4
profit/net_worth = 66.4

curr_assets/total_assets = 0.61
debtors/total_assets = 0.3
stock/total_assets = 0.38
other_ca/total_assets = 0.20
fixed_assets/total_assets = 0.38
other_fa/total_assets = 0
curr_liab/total_liab = 0.62
creditors/total_liab = 0.22
short_term_loan/total_liab = 0.28
other_cl/total_liab = 0.12
total_debt/total_liab = 0.27
long_term_loan/total_liab = 0
other_ltliab/total_liab = 0
deprec/sales = 0.0001

D.3 The accounting variables used are defined as:

curr_liab = creditors + short_term_loan + other_cl
quick_assets = debtors + other_ca
curr_assets = stock + debtors + other_ca
total_assets = curr_assets + fixed_assets
net_worth = total_assets - curr_liab - long_term_loan - other_ltliab
cap_employ= net_worth + long_term_loan + other_ltliab
total_liab = net_worth + curr_liab + long_term_loan + other_ltliab
profit_bef_interest = profit + interest
total_debt = short_term_loan + long_term_loan

sales = credit_sales + cash_sales

Appendix E

Walkthough of the System

E.1 The model chosen as illustration is the hypothetical newagent's model given in Figure 6.3. A user interface has been added onto the original system for ease of use. The session starts by the user entering information on the structure of the model. A description of this process is given in 6.1.1.

```
Choose from following modules:

1.    Structural Specification Analyser
2.    Data Analyser
3.    Qualitative Equation Simplifier
4.    Solution Generator
5.    Explanation Generator
6.    End

Enter option: 1.


   Enter Name of flows out of pump (q to end): sales.
   Enter Name of flows out of pump (q to end): q.
   Enter Dest type(pump,flow,tank) for sales : tank.
   Enter tank type(asset,liability): asset.
                                            Name: cash.
   Enter outflows for cash (q to end): overheads.
                                            Controlled(yes/no): yes.
                Outflow(q to end): purchases.
                                            Controlled(yes/no): yes.
                Outflow(q to end): q.
   Enter Dest type(pump,flow,tank) for purchases : tank.
   Enter tank type(asset,liability): asset.
                                             Name: inventory.
   Enter Dest type(pump,flow,tank) for overheads : pump.
   Enter outflows for inventory (q to end): cost_of_goods.
                                            Controlled(yes/no): no.
                Outflow(q to end): q.
   Enter Dest type(pump,flow,tank) for cost_of_goods : pump.



   Explain how each of the following variables are derived:
     (in terms of external variables and operators)

   sales: selling_price * volume.
   cost_of_goods: cost_price * volume.


   Company made (profit/loss/breakeven)?: profit.
```

Based on the structural information provided, the system generates qualitative constraint equations. The way this is done is described in 6.1.2.

E.2 Once the structure of the model has been specified, the user will need to enter in data. The types of data the system can handle and use are given in 6.1.3. Here, we will suppose that we know that the profit/sales ratio is high and the sales/stock ratio is low and we would like the profit/sales ratio to be high and the sales/stock ratio to be normal.

```
Choose from following modules:

1.    Structural Specification Analyser
2.    Data Analyser
3.    Qualitative Equation Simplifier
4.    Solution Generator
5.    Explanation Generator
6.    End

Enter option: 2.


   Choose from one of the following:

   1. Enter qualitative values for ratios
   2. Enter quantitative values for ratios
   3. Enter desired qualitative values for ratios
   4. Enter qualitative values for variables
   5. Enter accounting relationship information
   6. End

   Enter option: 1.
   Enter ratio(q to end): profit/sales.
        Enter value(low,normal,high): high.
   Enter ratio(q to end): sales/inventory.
        Enter value(low,normal,high): low.
   Enter ratio(q to end): q.


   Choose from one of the following:

   1. Enter qualitative values for ratios
   2. Enter quantitative values for ratios
   3. Enter desired qualitative values for ratios
   4. Enter qualitative values for variables
   5. Enter accounting relationship information
   6. End

   Enter option: 3.
   Enter ratio(q to end): profit/sales.
        Enter desired value(low,normal,high): high.
   Enter ratio(q to end): q.
```

E.3 Once the structure of the model has specified, the user may request the system to 'simplify' the equations according to the rules given in 7.3.1. In reality, this process may be hidden from the user, but for the purpose of the research, it serves to illustrate one of its major findings i.e.that local generation of equations may introduce unintended ambiguity.

```
Choose from following modules:

1.    Structural Specification Analyser
2.    Data Analyser
3.    Qualitative Equation Simplifier
4.    Solution Generator
5.    Explanation Generator
6.    End
```

```
BEFORE :

fl_confluence(1,selling_price*volume-purchases-overheads-cash=0).
fl_confluence(2,purchases-cost_price*volume-inventory=0).
fl_confluence(3,selling_price*volume-cost_price*volume-overheads-profit=0).

AFTER :

fl_confluence(1,selling_price*volume-purchases-overheads-cash=0).
fl_confluence(2,purchases-cost_price*volume-inventory=0).
fl_confluence(3,a1*volume-overheads-profit=0).

equivalent(a1,selling_price-cost_price).
```

In this run, the system has simplified the third fl_confluence by factorising it. This is noted by the generation of the equivalent predicate.

E.4 Only when the data has been entered and the constraint equations describing the structure of the model verified and simplified, should the user request the system to solve the equations previously generated. The technique for solving the equations is given in 6.1.4.

```
Choose from following modules:

1.    Structural Specification Analyser
2.    Data Analyser
3.    Qualitative Equation Simplifier
4.    Solution Generator
5.    Explanation Generator
6.    End
```

```
Enter option: 4.

State: 1-1
profit - [low,normal,high]
inventory - [low,normal,high]
cash - [low,normal,high]
sales - [high]
purchases - [high]
overheads - [high]
cost_of_goods - [high]

State: 2-1
profit - [low]
inventory - [low,normal,high]
cash - [low]
sales - [low]
purchases - [high]
overheads - [high]
cost_of_goods - [high]

State: 3-1
profit - [low]
inventory - [low]
cash - [low]
sales - [low]
purchases - [normal]
overheads - [high]
cost_of_goods - [high]

State: 4-1
profit - [low]
inventory - [low]
cash - [low,normal,high]
sales - [low]
purchases - [low]
overheads - [high]
cost_of_goods - [high]


...........
```

Ideally, one unique state should be found, from which explanations can be generated. In this case, since there are 53 solutions (of which some are shown) , the user will need to identify which state is the most likely (the heuristics for selection represent yet another area for future work to be carried out on this research). Suppose that state 1-1 above was chosen:

```
Choose from following modules:

1.      Structural Specification Analyser
2.      Data Analyser
3.      Qualitative Equation Simplifier
4.      Solution Generator
5.      Explanation Generator
6.      End
```

```
Enter option: 2.

   Choose from one of the following:

   1. Enter qualitative values for ratios
   2. Enter quantitative values for ratios
   3. Enter desired qualitative values for ratios
   4. Enter qualitative values for variables
   5. Enter accounting relationship information
   6. End

   Enter option: 4.
   Enter variable(q to end): profit.
        Enter value(low,normal,high): high.
   Enter variable(q to end): inventory.
        Enter value(low,normal,high): high.
   Enter variable(q to end): cash.
        Enter value(low,normal,high): high.
   Enter variable(q to end): sales.
        Enter value(low,normal,high): high.
   Enter variable(q to end): overheads.
        Enter value(low,normal,high): high.
   Enter variable(q to end): purchases.
        Enter value(low,normal,high): high.
   Enter variable(q to end): cost_of_goods.
        Enter value(low,normal,high): high.
   Enter variable(q to end): q.
```

E.5 The explanations are based on the data entered and deduced by considering the relationships expressed by the qualitative equations, accounting variables and ratios (see 6.1.5). In this case, since the data provided has been very simple, the explanations offered are relatively unsophisticated.

```
Choose from following modules:

1.    Structural Specification Analyser
2.    Data Analyser
3.    Qualitative Equation Simplifier
4.    Solution Generator
5.    Explanation Generator
6.    End

Enter option: 5.

   Following ratios are unsatisfactory:

     sales/stock (low)

     These can be explained by the fact that:
        stock is high
        sales is high


   Would you like to investigate further ? yes.
```

```
Enter any of following queries:

    1.      What is the value of <variable> ?
    2.      What is the value of <ratio> ?
    3.      How was the value of  <variable> deduced ?
    4.      How was the value of  <ratio> deduced ?
    5.      How can <variable> be changed ?
    6.      How can <ratio> be changed ?
    7.      What happens if <variable> changes ?
    8.      How can a particular profile be achieved ?
    9.      End of queries

Enter Option: 1.
variable ? sales.
sales is high

Enter Option: 2.
ratio ? sales/stock.
sales/stock is low

Enter Option: 3.
variable ? sales.
sales is  given

Enter Option: 5.
variable ? cash.
cash is high
Up or down  value ? up.
To get to the state of high

  cash is affected by the changes in selling_price, volume, purchases, overheads
   selling_price has to remain high
   volume has to increase from normal to high
  purchases has to decrease from high to normal
  overheads has to decrease from high to normal


Enter Option: 6.
ratio ? sales/stock.
sales/stock is low                    i.e high/high
Up or down  value ? up.
To get to the state of normal
  sales has to decrease from high to normal
  stock has to decrease from high to normal

Enter Option: 7.
variable ? overheads.
overheads is high
Up/down/none  value ? down.
If overheads becomes normal
   cash remains high
   profit remains high


Enter Option: 8.
Ratio (q to end)? sales/stock.
Current value is low          New Value (low, normal, high) ? normal.
Ratio (q to end)? q.
This Profile will be achieved if
  sales decreases from high to normal
  stock decreases from high to normal
```