1986

A Visual Interactive Model For Corporate Cash Management

Drew Cunningham Parker

Abstract

The corporate cash management problem has been addressed extensively in the literature. Actual implementations, however, are scarce. After discussion of the reasons for these limited implementation successes with practising cash managers, a Visual Interactive (VI) Modeling approach was proposed. This approach attempted to integrate concepts from past VI Modeling applications, Decision Support Systems (DSS), and 'soft systems' theory. Visual Interactive Models (VIMs) have been credited by Operational Researchers with a strong implementation focus, but a general methodology for building VIMs did not exist. This thesis formalized a development approach for VIMs and evaluated the results based on a practising cash manager's problem. The resulting problem formulation and solution alogrithms differed from other cash management models in the literature, and the form of the VIM that resulted from this modeling approach differed from current applications. The results suggest that the proposed VIM building approach can derive an effective and implementable model. Further, this methodology offers support for complex problem situations including those where no physical picture of the system under study can be derived.

ISBN 0-315-29493-0

Abstract

The corporate cash management problem has been addressed extensively in the literature. Actual implementations, however, are scarce. After discussion of the reasons for these limited implementation successes with practising cash managers, a Visual Interactive (VI) Modeling approach was proposed. This approach attempted to integrate concepts from past VI Modeling applications, Decision Support Systems (DSS), and 'soft systems' theory. Visual Interactive Models (VIMs) have been credited by Operational Researchers with a strong implementation focus, but a general methodology for building VIMs did not exist. This thesis formalized a development approach for VIMs and evaluated the results based on a practising cash manager's problem. The resulting problem formulation and solution alogrithms differed from other cash management models in the literature, and the form of the VIM that resulted from this modeling approach differed from current applications. The results suggest that the proposed VIM building approach can derive an effective and implementable model. Further, this methodology offers support for complex problem situations including those where no physical picture of the system under study can be derived.

Acknowledgements

The work required to complete a Ph.D. requires a considerable commitment on the part of the candidate. It also, however, requires a commitment of at least equal proportion by many other people and institutions. This commitment involves expertise, time, money, and patience. Fortunately, my friends and family have accepted these requirements without demands for retribution.

The person who has made the most intellectual contribution to my education has been my thesis supervisor, Dr. Peter Bell. I have often made requests about getting something read over a weekend, or meetings at inopportune times to discuss something important about my progress. From our first agreement that he would supervise this work, he has proven a severe but constructive critic, a mentor, and a close friend. Among many other things, I hope he has taught me what is required of me by my students.

The intellectual stimulation and challenge offered by a doctoral programme is traded off against the emotional and financial difficulties of again becoming a student for a long stretch. My three best friends, Valerie, Elaine, and Mac, my wife and parents respectively, have allowed me to live with both of these difficulties through unquestioning support. They only ever insisted that I keep going.

I was fortunate enough to be accepted for my doctoral education from the University of Western Ontario, and must acknowledge the commitment that institution has made toward a Ph.D. programme. The faculty at large in the School of Business Administration are both aware of, and committed to, the support required to get a candidate through. The Business Faculty houses considerable expertise which was always there for the asking.

I have been financially supported by many people and organizations. I would like to thank Mr. John Luker for providing money for his granddaughter's education, and Valerie for choosing a slightly different investment. Mr. John Brent provides a doctoral fellowship through the Universty which I was awarded in my first year. The Ontario Graduate Scholarship fund and the Social Sciences and Humanities Research Council of Canada also supported my studies. Without this support, the process would have been considerably more difficult, if not impossible.

Finally, I would like to thank my fellow students in the programme. It is a small group of people becoming scattered all over the world, but we supported one another through a complex and difficult process. They are a diverse group, but were always willing and genuinely interested to provide feedback and help for the many activities we encountered. I hope we will stay in contact. My only regret is that we could never win a baseball game.

TABLE OF CONTENTS

TABLE OF CONTENTS
(CONTINUED)

LIST OF EXHIBITS

LIST OF TABLES

Chapter 1

Introduction

This thesis emerged from research into the utilization and effectiveness of visual interactive (VI) modeling, a new Operational Research (OR) problem solving methodology. This methodology was applied to corporate cash management, a problem area which offered a promising test site for the evaluation of a proposed visual interactive model building approach.

This thesis made contributions in three general areas. First, a novel methodology for the design and implementation of visual interactive models (VIMs) that integrated concepts from the literatures of VI modeling, Decision Support Systems (DSSs), and 'soft systems' theory was proposed and tested. The second contribution of this thesis was in the design of the VIM itself. Previous applications of VIMs were primarily iconic graphic models (where a physical process was represented graphically). The cash management problem investigated offered a complex decision environment requiring rapid communication of data and difficult implementation experiences - features which appear to point toward VI modeling as a useful problem solving approach. There was, however, no physical process which could be presented on a graphics screen, and therefore the VIM developed for this thesis used representational graphics exclusively. The third contribution area was the development of a novel formulation and solution of a corporate cash management problem. This new formulation arose through investigation of a practising corporate cash manager's problem situation.

Visual interactive modeling is a novel modeling approach which has been developed by Operational Research (OR) professionals over the last ten years (Hurrion, 1976; Bell, 1984). VI modeling makes use of an interactive computer graphics environment to facilitate communication among the modeler, the decision maker, and the model itself. This approach, which saw many of its initial successes in dynamic simulation models of physical systems (Fiddy et al, 1981; Hollocks, 1981; Hurrion, 1976, 1978, 1980, 1981, 1984; Hurrion and Secker, 1978), has been found valuable by many modelers to analyze and represent complex problem environments (Bell et al, 1984; Lyons, 1983). Experience with VI modeling, however, has illustrated that the underlying process involved in building and utilizing this type of model requires a problem solving approach which differs from traditional OR problem solving methodologies, such as those outlined by Wagner (1969) or Buzacott (1982).

To utilize the unique benefits of VI modeling, then, a new methodology needed to be developed. The developers and users of VIMs have, to a large extent, been practitioners (Parker and Bell, 1983) whose objective has been the development of a model for a specific problem environment. In this demand-pull evolution, practice has led theory.

Traditional OR modeling approaches have been under continual review (For example, Buzacott, 1982; Checkland, 1981). New approaches, such as a 'systemic' method of addressing a problematic situation have been proposed, developed, and evaluated. Application successes have been realized frequently utilizing VIMs (For example, Lyons, 1983; Hollocks, 1981; Hurrion, 1981; Kaufman and Hanani, 1981), but at the same time, research into the effectiveness of computer graphics as an aid for modelers or to decision makers has provided "equivocal" results (Ives, 1982).

Experience with VI modeling led to the proposal of a new formal approach for problem solving using VIMs, where the solutions to a problem could be mapped out prior to model development. This approach was novel in that, rather than concentrating upon problem definition as a first step (Wagner, 1969) or upon model development of a subset of the real world problem (Buzacott, 1982), the approach would seek to determine what the solution to the problem would look like in a graphics-oriented environment, and then build the model to provide the needed solutions. The first major effect of such a modeling approach would be the development of an implicit agreement between the modeler and the problem owner very early on in the problem solving process to verify that the problem being addressed was, in fact, a useful problem to solve. The second would be an increased interaction level between the modeler and the problem-owner throughout the modeling process so that model-validation could be an ongoing, integral component of the problem-solving process.

In this thesis this modeling approach is formalized and applied to a complex problem environment to gain insight into the effectiveness of the approach in a real-world problem situation.

Development and Evaluation of a VIM for Cash Management

Commercial VI modeling packages were originally developed in the United Kingdom to animate dynamic simulation processes (Hurrion, 1976; Fiddy et al, 1981), but applications other than simulation have also been successfully implemented (Chi and Hehnen, 1983; Lembersky and Chi, 1983; Babin et al 1982; Ambrosetti and Ciriana, 1983). In order to evaluate the effectiveness of the proposed modeling approach, a new application area was sought where the problem environment was complex enough to offer a suitable test.

Corporate cash management is an area where OR has developed a significant theoretical base, but very few reported implementations exist (Daellenbach, 1975; Bell and Newson, 1982). The corporate cash management problem is complex (Bell and Newson, 1982), and involves several decisions, which must be made in a dynamic environment. After several interviews with cash management executives and a senior banking official responsible for cash management programs, it seemed that a VIM could provide the kind of support for the decision process which practitioners were seeking. The task was then to develop a VIM to support the corporate cash management function utilizing the proposed novel modeling methodology.

The objectives of this thesis were to present the proposed problem solving methodology and to test its usefulness as a means to develop a modeling environment to support the cash manager's decision process. In order to accomplish this objective, a specific cash manager was selected who was responsible for a function complex enough to both test this approach and representative enough to offer generalizable results for both corporate cash management modeling and for the development of other VIMs.

Approach

Following site selection, an in-depth analysis of a firm was required in order to conduct the desired evaluation of the proposed model building approach. It was expected that the resulting model would differ somewhat from existing models, but that the problem addressed by this model would more closely represent the practising cash manager's problem.

The steps involved required that the firm be selected early on in the research, since managerial interaction was an integral part of the model-building process. Upon selection of the research site, the first model building phase commenced. This phase involved the development of computer graphics which represented an acceptable solution format for the model, and thereby served to structure the problem solving process.

The second research phase was the development of interactions to enable the computer generated graphics to support the cash manager's enquiries and requirements. The expected result of this modeling endeavor was an interactive model where a series of decisions derived through optimization of some objective function would be presented to the manager, but externalities to this structured formulation could be added into the model by the decision maker. In this approach, the proposed model would be designed to support the decision maker rather than automate some aspect of his function.

After the graphics and the interactions were developed, the next phase would be the development of the algorithms required to accomplish the optimization within the package. At this point, the required managerial interaction is minimized, but the graphics display the behavior of the model and become an integral part of the validation process. The final research phase was data collection. This approach consequently contained a risk of developing a model which required data that was unavailable. If this occurred, however, decisions could be made between modifications to the model to use only available data, or to attempt to collect the needed data. This tradeoff, however, provides additional information to the decision maker about the process under study. The steps of the approach are formally outlined in Exhibit 1, Chapter 4.

The final phase in this thesis was evaluation of the VIM.

This evaluation involved comparisons of past, manual decision making procedures to preliminary decisions provided by the model. The model's "decisions," however, were based on a narrow view of the problem, and it was expected that they would be modified by the decision maker to account for externalities which the model did not consider. Still, it was expected that the model could reduce total costs levied against the account after the interactive adjustments. This expectation was based on the changed nature of the decision making process with the use of the model. First, the cash manager had a starting set of decisions from which to determine his actual decisions about the cash management process. This saved time in both developing forecasts and in manually developing a feasible solution from which to judge alternative courses of action. Second, the model offered an interactive environment where several alternatives could quickly be considered without manually performing a series of tedious, repetitive calculations.

In summary, this thesis represents a model building exercise utilizing a novel problem solving methodology, and offers insight into the process and advantages of using VI modeling to provide decision support in a complex, managerial decision environment.

Chapter 2

The Corporate Cash Management Problem

The corporate cash management problem has been modeled extensively in the literature with limited implementation success. These cash management models (discussed in detail in Chapter 3) have incorporated various modeling techniques and assumptions. The practising Canadian cash manager faces a complex, dynamic problem environment with time-constrained decision making requirements. The corporate cash management problem to be addressed in this thesis is outlined in this chapter, followed in Chapter 3 by other researchers' problem definitions and solution approaches.

Cash management, as practised in major corporations involves: (i) gathering and interpretation of accounting information to determine the current status of the cash account, (ii) forecasting inflows and outflows to the firm's cash account over some decision horizon, and (iii) a decision making function: trading a reserve of cash in the firm's account against investment in interest earning instruments (Bell and Newson, 1982).

A cash manager makes four basic types of decisions: (i) when cash is to be injected into the account, (ii) when cash is to be withdrawn from the account and released to the finance function, (iii) when cash from the account can be temporarily invested in interest earning assets and later returned to the account, and (iv) when to change the cash management monitoring and decision making process responding to the dynamic nature of the cash forecasts.

To focus this research, the following terms are introduced:

Cash Forecasting is the projection of cash inflows and outflows from the firm's cash accounts before allowance for the cash management decision variables. Cash forecasts may be dependent upon managerial action: if, for example, action is taken to expedite the receipts of certain receivables, then a new cash forecast must be derived which incorporates the results of these actions.

Cash Management is used to include both cash forecasting and managing the decision variables directly related to the cash account. This task requires the estimation and monitoring of stochastic elements (such as time lags for receipt of payments and cheque clearings) and the management of controllable elements (such as disbursements and the term of short-term investments). The relationship between the stochastic and controllable elements is complex: if, for example, an unanticipated need for funds arose, a receivable (normally a stochastic element) may be expedited through a telephone conversation with a regular customer (thereby becoming a controllable element). Alternatively, a cash need could be met by delaying a disbursement; perhaps holding a large cheque out of the mail.

Through mechanisms such as those mentioned above, the cash forecasting process is managed by implementing changes to the cash flow projections that are determined to be possible. The evaluation process involves determination of which of these options is feasible, and what the effect would be of selecting from each of these options. Cash management includes the evaluation of, and selection from, these feasible options.

An option for a cash manager is the investment of funds from the cash account into short-term securities (such as negotiable bank instruments). Short-term is interpreted in this thesis to be a maximum of 30 days. Beyond this short-term horizon, investments are assumed to be dealt with by the finance function of the company, which is generally distinct from the cash management function.

Long-Term Financial Management excludes those functions denoted as "cash management" above, and refers to the function usually termed "finance." In this thesis, the finance department will be considered a separate entity and will be assumed to be a source or destination of funds external to the cash management system. This corresponds to the common situation in a major corporation, where cash management is generally a function of the treasury department, while the finance department evaluates longer term capital investments (Bell and Newson, 1982). These functions interact through the maturing and acquisition of long-term instruments only insofar as they transfer through a cash account.

The cash management function is concerned with minimizing bank fees, transaction costs, and the cost of short-term debt. These costs may be offset by investment in a short-term portfolio, while the reserves in the cash account have value in keeping the risk of exhausting immediate credit sources at an acceptable level.

In addition, cash management has a longer term dimension that includes the negotiation of banking arrangements, for example: an average compensating balance in lieu of fees, and the monitoring and manipulation of the cash forecasting procedures.

Modeling support for this decision environment must be both interactive and flexible. The dynamic nature of the problem demands a modeling system which provides aid in the analysis of the formal (or structured) elements of this process, but allows managerial intervention with the parameters of the model. The structured elements of the cash management process are amenable to formal algorithms and computerization since they require many repetitive calculations which can be prespecified. The combination and selection from among these options, however, requires managerial intervention with a model, since there are many contingencies in the cash management process which require expert judgement.

Potential Support for the Cash Management Function

The practising cash manager faces a dynamic, often ill-defined, multicriteria decision situation. Interviews with several managers suggested that their problem solving (or decision making) approaches were heuristic as a result of the rapidly changing decision making environment. The idea of a computer-based decision support system was generally met with favour, but some doubts were expressed: the timeliness of information required, the need to only spend small amounts of time dealing with a model, and the necessity for an ability to pose "what if" type queries. Typically, no more than a few minutes at a time on an ad hoc basis were available for decision making, although more time was available for the forecasting or evaluative stages of the task. The cash managers interviewed commonly spent more than an hour per day on forecasting and evaluation, and suggested that this was one of the critical components of their managerial task.

The Concept of Decision Support Systems (DSSs)

DSSs are interactive computer-based systems to assist a manager in arriving at solutions to a loosely structured set of problems (See, for example, Keen and Scott Morton, 1978). A structured decision is repetitive, fully quantifiable, can be completely anticipated, and is often referred to as "programmed;" but most managerial decisions have certain elements which require intuition and judgement. Keen and Scott Morton (1978) suggest, "The methodology used to develop a DSS is to work mainly from the manager's perspective and accept his or her implicit definition of which components must be left to personal judgement." (Op. Cit.). DSS can support the manager through a model of the structured elements of the problem environment, and can provide a framework for the manager to analyze various decision options. The DSS approach recognizes that certain types of problems cannot be solved or supported by predefined algorithms, but can be attacked through the provision of flexible models. Keen outlined a specific focus of a DSS by stating that: "None of them give 'the' answer but they respect the primacy of managerial judgement." (Keen, 1980).

Sprague and Carlson (1982) identify the components of DSS as a "dialogue component," a "data base," and a "model base." Similarly, a VIM is composed of a command structure and graphics which serve as the dialogue, or interface, component, with underlying data and model bases programmed into the model. Through this structure, a VIM could support the cash managment problem by providing forecasts and corresponding decision scenarios based upon algorithmically derived options. These scenarios could then be manipulated by the decision maker to arrive at a planning solution over the decision horizon.

The cash management problem is particularly difficult to capture using formal optimization techniques (although many authors have attempted this using a version of the "cash management" problem -- see Chapter 3). A quantifiable objective can readily be assumed based on cost and interest rate parameters, but it is complex to model all the tradeoffs that must be examined and considered by the practising cash manager. Possible tradeoffs include: differing cost structures at alternative banks (also dependent upon the ability of the firm's management to negotiate which is, in part, a function of their information base), differing interest rates for available term instruments, and the downside risk associated with cash forecasts. This risk can result from either forecast error, particularly an underestimate of inflows, or from unanticipated outflows.

A cash management decision support system, therefore, promises to be a useful problem solving methodology with the following three advantages: the ability to support a semi-structured decision process; the ability to provide an effective interface between the decision maker and the model; and the ability to rapidly communicate the outcomes of alternative strategies. The latter advantage can be further exploited through the use of a visual interactive model.

Visual Interactive Modeling

VI modeling is a relatively new technique, developed in the United Kingdom, that merges the power of computer graphic communication with an operational research (OR) model. VI modeling was developed by operational research practitioners who perceived a need for better communication between model and user (Donovan et al, 1969; Sulonen, 1972; Sohnle, 1973; Hurrion, 1976). The current state of the art in VI modeling involves modeling physical systems, such as assembly lines (Fiddy et al, 1981; Hollocks, 1983), or a transportation network (Fiddy et al, 1981; Babin et al, 1982). A visual model rapidly communicates overall status indicators of the modeled environment, and aids understanding of the workings of a complex model for non-technical users. "The power of VIPS (Visual Interactive Problem Solving) as a decision-making tool comes from the confidence in the model that grows as the manager sees the model confirm his understanding of the real system" (Bell et al, 1983).

VI modeling has been described as a DSS-like technique, where VI modelers model complex and often fuzzy problem situations (Bell, 1983). DSS, however, has evolved primarily from MIS (Keen and Scott Morton, 1978; Sprague and Carlson, 1982; Parker, 1983), while VI modeling has been largely developed by OR practitioners (Bell, 1984). Some OR practitioners have disputed the domain of DSS (Naylor, 1982) and suggested that they "... use techniques such as computer simulation, heuristic programming, and artificial intelligence to analyze and solve unstructured problems." (Op. Cit.), but both disciplines offer contributions toward supporting complex decision making processes. The approach outlined in this thesis merges these two developments, and offers a problem solving approach which employs the suggested benefits of VI modeling in a complex, loosely structured decision situation.

Checkland (1981) suggested that many "hard systems" approaches fail as a result of the "softness" of the real world "human activity system" being modeled. This complexity could help explain the lack of implementation success of cash management modeling approaches from the literature. The cash management problem has primarily been addressed by OR modelers as a hard systems problem. An objective funtion was defined and a solution technique developed to deal with this specific objective. DSSs offer a different focus to problem resolution which may be more suitable for the practising cash manager's problem. The complexities and rapid information communication requirements between a model to support corporate cash management and the decision maker led to the suggestion that a VIM, developed as a specific DSS, may provide the most benefit to a practising cash manager.

Chapter 3:

Cash Management,
Visual Interactive Modeling,
OR Methodologies,
And Decision Support Systems

The work in this thesis draws on previous work in three areas: cash management modeling, visual interactive (VI) modeling, and decision support systems (DSS).

CASH MANAGEMENT MODELING APPROACHES

Cash is often considered in the Operational Research (OR) literature as an inventory item, which stems from the appeal of applying inventory modeling approaches to a simple cash management problem. This appeal is the result of the apparent similarity between the cost elements involved in the cash management and inventory management processes: there is an opportunity cost of holding cash (lost interest revenue), a cost of being short (credit charges), and a cost of ordering cash (transfer costs) which may be fixed, variable, or both. In order to model the cash account as a classical inventory problem, however, restrictive assumptions must be made. Several formulations have appeared in the literature, where the simplifying assumptions typically involve the objective function (such as the minimization of transfer costs traded off against lost interest revenue: Baumol, 1959; Beranek, 1963; Archer, 1966; Girgis, 1968; Miller and Orr, 1966; Stone, 1972; Robichek et al, 1965; Orgler, 1970; Hausman and Sanchez-Bell, 1975), the "demand" function (inflow or outflow of cash through the account), the issue of controllability of this demand by the decision maker, and the independence of events across periods, particularly receipts and disbursements.

The idea of modeling cash as an inventory item was introduced by Baumol in 1959. Baumol's simple model was of a cash disbursement account where disbursements occurred as a steady stream and balancing inflows were either from a bank loan or the liquidation of an investment. Investments were held at a constant average interest rate, and there was a fixed fee for each transfer to the cash account. Given these problem parameters, Baumol derived a cost-minimizing order quantity through an economic order quantity (EOQ) model. In the optimal solution, transfer costs were traded off against the opportunity cost of prematurely removing cash from the interest bearing investments. Subsequent extensions of this model included allowing receipts during a period, and including a proportional component (variable cost) in the brokerage fee.

Commenting upon the applicability of the EOQ derivation, Baumol proposed that it: "is only a suggestive oversimplification, if for no other reason, because of the rationality assumption (i.e. the objective function) employed in its derivation. In addition, the model is static." (Baumol, 1959). His model was, however, a starting point from a discussion of the demand for cash by firms and served as a foundation for further research.

Beranek (1963) also argued that cash management could be supported through inventory modeling techniques. He identified differences between the cash management and inventory management problems by suggesting: "There is a critical distinction between the two problems: in the inventory problem it is the drain on inventory - i.e., the outflow from the reservoir - which usually occurs at random while the inflow of units to add to the stock of goods is controllable. In the cash balance problem these conditions are reversed: the cash inflow is largely random while the drain is controllable. Indeed, in more elaborate models we can even regard the drain as a random variable." (Beranek, 1963). Beranek expanded the inventory modeling approach to include shortage costs, but rather than defining them as the (expensive) cost of utilizing standby credit lines from the bank, he suggested: "the central elements of the 'short' cost are (a) amount of cash discount foregone and (b) deterioration of credit rating." (op. cit.). This definition of the "short cost" referenced a compensating balance requirement to offset bank charges, and Beranek suggested that a zero balance was often a credible minimum for the cash account.

In extending the model to a multi-period case, Beranek accommodated inter-period dependencies in the decision variables as a result of nonzero transaction costs, but the random elements of cash flow were considered independent across periods. The result of both model formulations was an EOQ for adjustments to the cash account; cash was assumed to be generated either from the liquidation of investments or from borrowing. Varying inter-term interest yields, however, were not incorporated into the analysis.

Archer (1966) followed Baumol's inventory approach, but considered the cash management problem as a problem of safety stock determination. In comparing the approaches, Archer argued: "This paper tends to be more operational than the Baumol or Beranek presentations and hence tends perhaps to lose some of the sophistication of the more theoretical models; it attempts to present a reasonably operational method for providing for cash balances for transactions and precautionary purposes." (Archer, 1966).

Archer's model also included the first acknowledgement that the cash management problem could include the risk preferences of the decision maker. Archer's model emphasizes the precautionary demand for cash resulting from the lack of synchronization between receipts and expenditures and for the speculative elements of cash flow, such as uncertainty in forecasts or fluctuating prices of a commodity to be acquired by the firm.

The approach taken by Archer involved evaluation of the cash balance random variable, and determination of a safety stock of cash as a function of the firm's willingness to accept a probability of "stockout." The model assumed a planning period of one month, but could be modified for any relevant horizon.

Girgis (1968) extended the development of inventory modeling approaches to support the cash management problem by concentrating solely upon cash outflows through analysis of a chequing account. The three cost functions considered were the opportunity cost of a positive non-interest bearing balance (holding cost), a shortage cost (standby credit charges), and transfer costs (from converting marketable securities).

Assuming "...that the net expenses in successive periods are independent identically distributed continuous random variables..." (Girgis, 1968), an optimal policy model was developed for an n-period horizon. The decision variable was the amount to be injected into or withdrawn from the chequing account at the start of each period.

Miller and Orr's (1966) cash management model extended Baumol's work. They agreed with Baumol's basic formulation for a cash account which grew or declined at a steady rate (e.g. "salary-earning households"), but suggested that Baumol's model "is much less satisfactory, both from the positive and normative points of view when applied to business firms ..." They proposed that a cash management model for firms would have to be able to accomodate both positive and negative drift to cope with uneven cash flows over time.

Miller and Orr assumed:

i: a two-asset setting (cash and an interest-bearing instrument),

ii: that transfers can be made at any time,

iii: a zero lead time for realization of transfers, iv: that there is an absolute minimum cash balance of zero (or some prespecified value),

v: that cash balances are generated by a stationary random walk, characterized by a sequence of (e.g. hourly) independent Bernoulli trials,

vi: fixed, symmetrical transaction costs.

The Miller and Orr objective function was: "the firm seeks to minimize the long-run average cost of managing the cash balance under some 'policy of simple form.'" Based on these premises, Miller and Orr developed a control-limit (h,z) model, where the cash balance was returned to some intermediate level (z) if it reached either the minimum bound (zero), or a derived upper bound (h). The model was also extended to account for non-zero drift.

Commenting upon the applicability of their model, Miller and Orr consider such complexities as asymmetrical transfer costs, and suggest that: "Such variations will certainly lead to more complicated control rules and change other matters of detail, but the general qualitative picture is unlikely to be much altered as long as the basic framework is maintained." Further, their assumption of the cash balance generating function "can hardly be defended as being literally descriptive. The size and timing of many of the important individual transactions comprising the cash flow are under the direct control of management (e.g., dividend payments). Other transactions are the fulfillments of past commitments (such as payments on trade accounts or tax payments). Even where genuinely random changes do occur they are usually superimposed on some systematic and at least partially forecastable movements (e.g., payroll disbursements)." The Miller and Orr model was the first of several portfolio models to be introduced from the financial management literature.

Stone (1972) extended the Baumol and the Miller and Orr models to incorporate other important aspects of cash management into a general modeling framework. He suggested that: "... a firm's net daily cash flow is lumpy, discontinuous, and partially known (forecastable) and partially unknown (stochastic)." The novel contribution of Stone's framework was the incorporation of look-ahead heuristics to accommodate both the maturity of short-term investments and other controllable adjustments to the cash account. The opportunity cost of excess funds above an average compensating balance, however, was ignored in this formulation by the assumption that: "... if at any time the firm maintains excessive balances, it can generally apply these balances to another period."

Robichek, Teichroew and Jones (1965) viewed the cash management problem as a more general resource allocation problem. From this point of view, they proposed a linear programming (LP) solution approach. This approach required several assumptions, most noteably: deterministic inflows and outflows, and deterministic costs of all financial alternatives. Transfer costs were not considered, but their model did include various management options (e.g. pledging accounts receivable versus extending a term loan as a source of cash), and the resulting model minimized interest charges levied against the short-term portfolio. A significant contribution of this model was the notion of shadow costs and sensitivity analysis: "Management may wish to choose a non-optimal solution because of some factor not included in the model." The authors proposed to cope with uncertainty by optimization of the expected monetary value (EMV) of the stochastic cost elements, and used multiple runs to derive a series of scenarios for sensitivity analysis to permit the consideration of risk.

Calman (1968) also viewed the cash management problem as one in which LP could be successfully employed, but concentrated attention on funds flow into a centralized clearing account. This approach was effective for the evaluation of certain aspects of American banking, where such facilities as lock-boxes compensate for the logistical cheque-processing problem. This approach, however, has limited Canadian application due to Canada's different banking structure.

Orgler (1970) proposed an LP formulation of the cash management function which stretched the planning horizon and reduced the discrete number of periods evaluated in previous models by modeling uneven time periods. Orgler "... maximizes the horizon value of net revenues from the cash budget over the entire planning period." Average compensating balance requirements were incorporated as a minimum required balance, and both fixed and variable transaction costs could be incorporated into the formulation. As in the Robichek et al. model, the input parameters, including forecasts, were assumed to be deterministic but the limitation of this major assumption was contested by arguing: "... the importance of uncertainty in cash management model's decision is relatively small due, primarily, to their short-range nature."

The cash management problem can be viewed as a dynamic allocation problem, and several dynamic programming (DP) formulations have appeared in the literature. Daellenbach and Archer (1969) proposed a model with similar objectives to Archer's earlier formulation (Archer, 1966) to determine an optimal cash balance for a bank, and suggested that this form of model "... could be adapted to any organization." Daellenbach and Archer assume independent, identically distributed cash flows, and include a minimum acceptable probability of stockout as the primary managerial input parameter. The model, which incorporates variable transaction costs, "... is formulated as a dynamic programming problem minimizing the sum of the variable transaction costs, interest cost on borrowings less returns on Treasury bill holdings."

Hausman and Sanchez-Bell (1975) formulated a similar DP model, again with cash flows assumed to be independent, indentically distributed random variables. Their model, however, incorporated an average compensating balance requirement, and explicitly allowed both fixed and variable transaction costs. They compared the results of the model to a two-sided (s,S) policy from a sample data base, and found significant cost improvement (18%) from their formulation. In their concluding remarks, the authors acknowledged that "... the corporate officer responsible for cash and earning asset transfers felt that major influences on cash flows were known to him through his general business experience. The current research has not shed light on the question of whether the latter factor can in fact dominate the actual results of a cash balance problem."

In examining the complexities of the overall cash management problem, Homonoff and Mullins (1975) suggested that a simulation model might prove the most useful:

"The simulation approach does not guarantee optimal results. However, it is flexible enough to include many real-world characteristics of liquidity management which cannot be incorporated into an analytical approach. It allows the manager's judgements and assumptions to be reflected in the model, and strategies for improving on performance of the simpler Miller-Orr model can be tested. The interaction of the manager and the model in determining the best values for the decision variables (h,z,etc.) gives the manager an intimate knowledge of the nature of the cash management problem."

In evaluating the research undertaken in working capital management, Knight (1972) suggested that: "Because of the uncertainties and complex interrelationships involved, analysis and optimization must give place to simulation and satisficing." He went on to conclude that: "The role of optimization is thus reduced to its use in supplementary studies outside the simulation or budget model (1) for suboptimizing purposes, (2) to develop or modify the model, or (3) for guidance in the final 'satisficing' judgement."

One of the few reported implementations of a formal cash management modeling framework was developed by Couturier (1973). He demonstrated that a systematic decision making process based upon a heuristic could show significant improvement over a practising manager's performance. He also showed that a model which incorporated a more complex description of the cash management process could outperform a simpler analytic framework (the comparison was against the Miller and Orr control-limit model). Using a semi-variance statistic, (Markowitz, 1959) to account solely for downside risk, Couturier's model incorporated projected inflows and outflows based on such parameters as sales and purchase forecasts (accounting for expected lags for cash realization based upon customer and supplier performance), and developed an optimal daily account activity plan for a one-year horizon.

The OR literature on the corporate cash management function acknowledges its complexity and suggests that it is difficult to provide effective modeling support. Many authors further acknowledge the difficulty of model development to accommodate and incorporate the expertise of a practicing cash manager. VI modeling is a relatively new modeling approach which includes the potential to deal with complexities of this type.

VISUAL INTERACTIVE MODELING IN OPERATIONAL RESEARCH

Computer graphics have become a common tool for the communication of certain types of data. Empirical or derived frequency distributions, transportation networks, and proportions of a population are commonly presented graphically. Managers viewing such presentations are very familiar with this medium. A different form of graphic application has been evolving since 1976 in the field of operational research (OR), and has the potential to have a powerful impact upon certain types of OR modeling. This technique, known as visual interactive (VI) modeling, combines the benefits of graphic communication, an interactive computing environment, and a mathematical model.

The roots of VI modeling stem from research into the use of graphic presentations to communicate status indicators in OR modeling. Visual interactive PERT/CPM, location selection, and routing models were developed in the mid 1970's (Bowen et al, 1978; Donovan et al, 1969; Garbini et al, 1983; Hurrion, 1976; Palme, 1977). Developments in visual interactive simulation started in the United Kingdom prior to 1976, and the technique rapidly evolved as practitioners further developed technical support packages for more general visual modeling.

Visual Interactive Simulation (VIS)

VIS is an interactive computer simulation technique that includes three basic elements: a Monte Carlo simulation modeling language, a graphics interface, and an interaction module. As a simulation runs on a host computer (which can be a time-sharing mainframe or a devoted microcomputer), a "smart" graphics terminal communicates with the host and displays status indicators of the simulated system's progression through time. The model may run in real time or at an accelerated time scale, depending upon the requirements of the end-user. The interaction module allows the experimenter/observer to change parameters of the system, or to call up summary statistics at any point during the model run. "The basic philosophy of the approach is that a decision maker/manager will be able to watch a simulation model of his problem situation develop through time. The decision-maker can watch the progress of the model and can himself contribute to the validation of that model. Hence, he will have more confidence in its use, because of his own participation." (Hurrion and Secker, 1978)

The effectiveness of VIS for physical systems modeling can be highlighted through a review of practitioner involvement in the development of the technique. VIS was first proposed to support production planning simulation models by R.H. Hurrion in a Ph.D. thesis in 1976 (Hurrion, 1976). British Leyland was, at the time, using computer simulation to evaluate alternative designs for an assembly plant for a new automobile. Recognizing the potential benefits of the newly-proposed technique, British Leyland set out to develop an application package to support their design project and constructed a series of FORTRAN subroutines to drive an intelligent graphics terminal. BL Systems, the OR consulting arm of the corporation, subsequently offered these routines as a commercial package called "SEE-WHY." (Fiddy et al, 1981).

At about the same time, British Steel Corporation developed a series of subroutines to graphically enhance their in-house developed FORTRAN-based simulation language (FORSS), and their OR consulting group, Business Science Computing, now markets the product under the names FORSSIGHT in Europe and WITNESS in North America (Hollocks, 1983). By 1982 there were claimed to be over 100 installations of these two products throughout the United Kingdom (BL Systems, 1984).

OPTIK, the third commercial VI modeling product, was developed by the independent firm of Insight International

Ltd. in the United Kingdom. This product was the first to extend the capability of a commercial VI modeling package through a family of related products. OPTIK11 is a VIS package which competes directly with SEE-WHY and FORSSIGHT, but it is an extension of OPTIK1, a graphics modeling language that allows a modeler to develop VIMs without the time dependent orientation of a simulation language. A third product, OPTIK2, is a relational data base.

Other visual interactive simulation models have appeared in North America (Kaufman and Hanani (1981); Chi and Hehnen (1983); Birtwhistle et al (1984)), but these developments tend to be very specialized, and are less suitable for general simulation modeling than the current U.K. offerings. Interactive graphic developments for the more popular North American high-level simulation languages have been hinted at, such as GPSS (General Purpose Systems Simulation) or SLAM, but few developments have yet appeared on the market. A new package, called CINEMA, was released in 1985 for VIS on an IBM Personal Computer AT by Systems Modeling Corp., which required specialized hardware and utilized the SIMAN modeling language. This package, however, is being modified and two new offerings (BLOCKS and PLAYBACK) are available for the IBM Personal Computer.

VIS products differ significantly from the 'playback'-type graphic enhancements that have typically been made to some of the predominantly North American simulation languages (GPSS, SLAM, Simscript, Simula, etc.). Some North American packages offer graphical summary statistics in representational format (such as pie charts, bar charts, and line charts), with options such as colors and resolution level, dependent upon the hardware employed. These graphics are, however, static: the simulation run must be stopped and a "snapshot" of the status of the system either saved or presented on a graphic terminal. These simulation graphics have the same general structure as the non-graphic models on which they are based, but have added the graphic routines for statistical output presentation.

VIS models employ two types of graphics: representational (described above), or iconic:

> An icon is a non-abstract representation of a physical entity and an iconic graphic model provides a schematic view of a process. For example, an iconic VI model of a steel mill could include icons representing blast furnaces, railway cars, desulphurizing ports, etc. displayed on a screen mimicking actual system operations during a model run.
>
> (Bell and Parker, 1984)

The major structural enhancement of a VIS model is the dynamic graphic representation. These graphics can be iconic, representational, or both on a single screen; they serve to open up the "black box" of a simulation model for a decision maker's observation, validation, and subsequent interactive experimentation.

This revealing of the workings of a simulation model provides several advantages for the decision maker, but often at a cost of increased modeling effort. Aside from the requirements of including detailed graphics programs in the model, aspects of the simulation which are to be displayed on the screen must represent the manager's view of reality, or the model may be deemed unrealistic and therefore unacceptable. A common practice in simulation modeling is to aggregate certain activities if they can be grouped without affecting the results, but this procedure will not prove viable if this aggregation is visible to an individual familiar with the process who monitors the simulation in order to validate the model. A compensating tradeoff, however, is the clarity of communication resulting from the display of the inner workings of the dynamic model. Assumptions can be clarified as the model is presented, and often modified in real time if they prove unsuitable. Further, the assumptions and characteristics of a simulation model can readily be explained through a dynamic representation of the system under study.

Visual Interactive Modeling

VIS applications were among the first interactive, computer-based graphic modeling applications within OR, but the benefits suggested by the creators and users of this technique are not exclusive to a simulation modeling environment. VI modeling, as used here, has become a more general description of interactive graphic modeling. Some VIM developments have evolved from VIS technology (Most noteably OPTIK11, Insight International Ltd.), but others have occurred independently.

Routing problems were one of the first non-simulation applications to be examined using interactive graphics, because of the easy association of these techniques to visual images such as maps and charts. Transportation networks are currently a major VI modeling application area (Babin et al, 1982; Lapalme, 1982; Fisher et al, 1982; Fisher et al, 1983), and similar routing problems have incorporated graphics at such major firms as Exxon (Lee and Singer, 1983).

Other VI modeling application areas include job shop scheduling (Hurrion, 1978), facilities layout (Lim, 1982), conveyor flow analysis (Lyons, 1983), multiobjective planning (Johnson and Loucks, 1980), statistical data analysis (Kolata, 1982), decision tree analysis (Parker, 1983), and log cutting strategy evaluation (Garbini et al, 1983; Lembersky and Chi, 1984).

Research into the effectiveness of representational computer graphics has found "equivocal" results (Ives, 1982), with some experimental support (Lucas, 1981; Lucas and Nielson, 1980; Remus, 1984). These experimental results, however, have been difficult to derive (Ives, 1982), and suggest a need for further research into the area. The MIS research in this area (Ives, 1982; Benbasat and Schroeder, 1977), however, has concentrated upon graphics as a display medium rather than the issues of graphics as an integral part of the modeling process itself. A road map, for example, is an effective display of a large amount of data, but it differs dramatically from the dynamic output of an interactive simulation model in real time as an example of visual modeling.

Offsetting these research results are the constantly increasing numbers of VIM applications, and new technological developments to further enhance the technique. Symphony (Lotus Development Corp, 1984), for example, is a new microcomputer software package that integrates a sophisticated spreadsheet package with a data base management system, a word processing package, and an interactive color graphics driver. This integrated package could be used to develop interactive graphic models for a personal computer.

As these packages and corresponding applications emerge, effective development techniques must be advanced to assure the usefulness of the technique. The screen displays of a visual model are integral components of the model itself. "The design of the VIPS (Visual Interactive Problem Solving) screen displays is critical to the success of the technique. The old adage 'a picture is worth a thousand words' seriously underestimates the information content of many computer displays. New formats are being designed to cram more and more information onto a single screen." (Bell et al, 1984). The problem solving approach employed, then, must be a major consideration in any VI modeling application.

OR METHODOLOGY - HARD VERSUS SOFT APPROACHES

Wagner (1969) suggested that "Model-building is the essence of the operations research approach." He outlined the OR approach as a four-step process:

1: Formulating the problem,

2: Building the model,

3: Performing the analyses, and

4: Implementing the findings and updating the model.

(Wagner, 1969)

This modeling process has been applied successfully to a myriad of problems, but is based upon the premise that the problem can be clearly defined, and that some form of objective function can be derived. Wagner does not, however, suggest that the steps form a discrete series. Other OR researchers, however, suggest that formulation of the problem itself should be an integral part of the OR modeling process (Checkland, 1981). Buzacott (1982) contends that different approaches can be characterized as "Operations Research," "Operational Research," and "Systemics." The former approach offers an absolute minimum amount of interaction between the modeler and the problem owner, while the latter two offer an evolution away from "academic respectibility" toward acceptance and implementability (Buzacott, 1982). He concludes: "Operational Research seems most appropriate for situations that repeat themselves from one firm to another ...

Systemics seems more appropriate for strategic questions, where the advantage of experience and knowledge lies with the manager rather than the OR man."

Checkland (1981), conversely, does not differentiate between OR and systemics. Rather, he differentiates between "hard" and "soft" systems approaches, and suggests: "... structured problems are what 'hard' systems thinking and most operational research are concerned with." (Checkland, 1981). Human activity systems are defined as hard or soft according to the amount of structure in the problem itself. Fully unstructured problems "... are conditions to be alleviated rather than problems to be solved." Checkland outlines the hard systems approach as that portrayed by Jenkins (1969) and the RAND Corporation, and constrasts this approach with a soft systems methodology, where the problem definition stage is an integral component of the process.

Academic contributions to the cash management problem express the objective as the minimization of expected account costs. The cost tradeoffs involve transfer costs of some form, holding costs, and often a penalty cost of stockout through forced borrowing. With this single, clear objective and some forecasting function, a formal model can be developed and tested under various assumptions. This framework closely follows a hard systems approach. Very few of these models have been implemented or developed using an actual firm's data, and the practicing cash managers interviewed expressed doubt about their applicability, particularly in the Canadian setting. Checkland and Buzacott offer insight into the reasons for the divergence between theory and practice. The problem addressed is that perceived by the modeler, with little reference in the definition stages to an actual problem owner. Given the nature of the cash management problem outlined in Chapter 2, definition of the specific problem to be addressed is a critical success factor for a practically useful, theoretically based cash management model.

Another OR modeling approach to support complex problems has been computer-based Monte Carlo Simulation. Simulation is a technique often used to build a model of a complex problem situation where an objective is difficult, or impossible, to derive: "Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system." (Shannon, 1975). Wagner, however, suggested that this approach was to be used "when all else fails." Shannon outlined the following stages for simulation model development:

1: System Definition,

2: Model Formulation,

3: Data Preparation,

4: Model Translation,

5: Validation,

6: Strategic Planning,

7: Tactical Planning,

8: Experimentation,

9: Interpretation,

10: Implementation, and

11: Documentation.

This process moves away from a formal problem statement, but emphasizes the definition, objectives, and scope of the problem situation to be modeled early on in the process. Simulation, then, remains a 'hard systems' modeling approach. It moves away, though, from the formalization of an objective function early in the model building process such as that outlined by Wagner (1969).

The evolutionary development process proposed for this thesis was similar to an Information Systems prototyping approach outlined by Earl (1978) and Naumann and Jenkins (1982). A prototyping approach necessitates that implementation issues be considered throughout the modeling process: "Prototyping stresses the interactions between the user, builder, and system. This emphasis alters the critical user skills and abilities that are required for successful implementation of information systems." (Naumann and Jenkins, 1982). The methodology developed for this model building approach closely aligned with this method, where a smaller application was first developed and evaluated, and then the full system was developed. It differs from many prototyping projects, however, since each phase of the model was developed for the full system. Naumann and Jenkins suggest that a prototyping approach holds a strong implementation focus; the approach to be outlined in Chapter 4 exploits the interactions between modeler and problem owner outlined as beneficial for implementation, but deviates from the steps of a prototyping approach. Naumann and Jenkins identify these steps as:

1. Identify the user's basic information requirements,

2. Develop a Working Prototype,

3. Implement and Use the Prototype System, and

4. Revise and Enhance the Prototype System.

Operational Research and Management Information Systems have often addressed similar problems, each employing its own orientation (Parker, 1983). Management Information Systems often employ a 'systems approach' (Ahituv and Neumann, 1982) methodology in a problem solving endeavor, and the emerging discipline of DSS offers the opportunity to integrate successes from each field to support a complex modeling environment. DSS has evolved from several disciplines (Keen and Scott Morton, 1978), with the mainstream research coming from the field of MIS (op. cit.; Sprague and Carlson, 1982; Parker, 1983). VI modeling practitioners, however, have primarily been OR modelers (Hollocks, 1981; Fiddy et al, 1981; Hurrion, 1976) and the resulting models are often considered as DSS products (Hurrion, 1985).

DECISION SUPPORT SYSTEMS

The concept of DSS has emerged formally since the late 1960's, when Dickson (1968) predicted a new "era" in computer-based managerial decision support. The emphasis of these types of systems was moving away from formal, structured problem support. Technology was a major factor, particularly the developement of on-line interactive computing. Scott Morton (1971) posed opportunities and problems for unstructured decision support, and Alter (1980) categorized their functions into workable areas for research.

The major focus of the DSS approach is supporting complex decision processes, particularly where solution procedures cannot be fully specified in advance: "Decision Support Systems (DSS) are interactive, computer-based aids to assist managers in complex tasks requiring human judgement. The aim of such systems is to support and improve a decision process." (Hackathorn and Keen, 1981). This interactive support, primarily on an ad hoc basis, suggests a fruitful avenue of research into the development of a visual interactive cash management model.

Many OR practitioners, however, hold a dissenting view of the potential offerings of DSS (Field, 1983; Naylor, 1982) Naylor (1982), for example, argues that OR practitioners: "... use techniques such as computer simulation, heuristic programming, and artificial intelligence to analyze and solve unstructured problems." (Naylor, 1982). He concludes that: "DSS is a redundant term currently being used to describe a subset of Management Science that predates the DSS movement." A major contribution of DSS, however, has been the exploitation of new technology, and upon developments toward a generalized problem solving approach for loosely structured problems (Parker, 1983).

Checkland's concept of structured versus nonstructured problems corresponds closely with the support for structured versus unstructured decisions outlined in the DSS approach. Keen and Scott Morton (1978) classify problems as structured, where an objective can be identified and the solution process specified fully in advance, unstructured: "An unstructured task does not permit programming; the objectives, trade-offs, relevant information, and methodology for analysis cannot be predetermined ..." (Keen and Scott Morton, 1978), and semistructured, where some element of a decision process is unstructured. The type of support that can be provided for a decision process, then, depends on the amount of structure which can be extracted from that process: "The process of making a completely structured decision is algorithmic; the process of making an unstructured decision is heuristic." (Ahituv and Neumann, 1982).

Sprague and Carlson (1982) further expanded the definition of DSS, and proposed an "adaptive design" approach to facilitate the development and implementation of a DSS. "The result is that the most important four steps in the typical systems development process -analysis, design, construction, implementation - are combined into a single step which in iteratively repeated."

INTEGRATING VI MODELING AND DSS IN A VISUAL INTERACTIVE DSS FOR CASH MANAGEMENT

The model building methodology proposed in Chapter 4 was the result of an attempt to integrate successes of current VI modeling applications with current DSS methodologies. Sprague and Carlson's adaptive design idea suggests an approach to develop a visual interactive model which differs from traditional practice. VI modeling has existed exclusively in the realm of OR, and the development of the screen displays and underlying models has been typically performed by model builders prior to presentation of the system to the manager. To adopt the systemic approach proposed by Checkland (1981) and Buzacott (1982), the problem owner should be involved very early in the design of the graphics which will represent the system (or process) being modeled. Once agreement has been reached on the 'visual model' of the system and how a decision maker should be able to interact with that model, then the parameters of the problem under study have been delineated and the actual model building phase (in the "model world" in Buzacott's taxonomy) can commence.

Visual interactive modeling, then, offers a novel problem solving approach which is a hybrid of OR, DSS, and Systems methodologies. Developing the screen displays is the logical equivalent of Wagner's "Formulating the Problem," since this activity abstracts from reality what the decision maker wants to work with. Building the algorithms becomes a subordinate task which has its objective to service the screens.

The cash management problem found in the literature represents a major simplification of the problem faced by practicing cash managers. Effective decision support for this function requires consideration of the 'softer' aspects of the decision environment. The approach outlined in this thesis is a problem solving methodology which emphasizes interaction between the problem owner and analyst through a VIM.

The potential to support the corporate cash management problem with a VIM led to the development of a novel methodology for VI model building. An objective of the application of this methodology was to effectively support the cash manager's decision process, and to thereby overcome the manager's lack of acceptance of cash management theory.

The function of a DSS is to interactively support, rather than replace or simply provide information for, a complex decision process. If a problem situation cannot be structured sufficiently to allow automation of the decision process, a DSS using a model-decision maker interface is a logical progression. In this case, the model optimizes the underlying "primary function" components (Checkland, 1982) which can be structured, while the interface allows the decision maker to address the softer issues.

Chapter 4:

A Proposed Four-Phase Visual Interactive Model Building Approach

The problem solving methodology for this thesis was a four-phase, staged development, consistent in nature with the "adaptive-design" approach outlined by Sprague and Carlson (1982). This approach differed from an information systems life cycle approach (See, for example, Ahituv and Neumann, 1982) or from more traditional OR approaches (Wagner, 1969; Buzacott, 1982) through its iterative approach, similar to a prototyping methodology (Naumann and Jenkins, 1982). Several researchers have suggested that VI modeling requires a distinct model building approach and problem owner/analyst relationship to derive the full benefits of the technique (Lyons, 1983; Bell, 1984). The model building methodology developed in this thesis followed from these propositions. The approach was designed to exploit the communication benefits of VI modeling more explicitly in the development process, and to provide commitment and validation from the decision maker at each phase of the model building process.

The four phases of the methodology were:

1: screen development -- communication,

2: the interface component -- interaction,

3: algorithm development, and

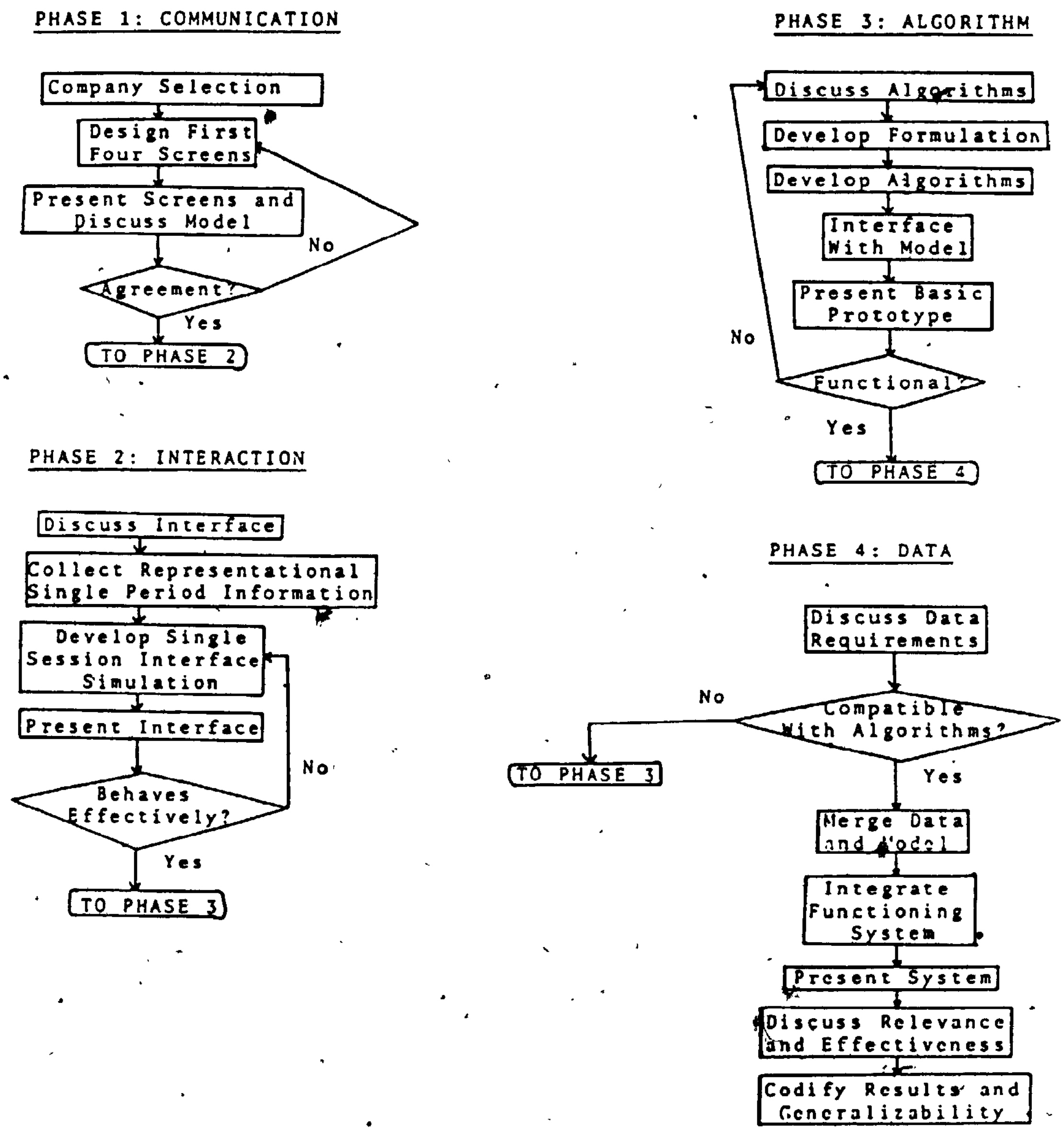
4: formal data collection.

The phases were interdependent, but this structure outlines the order in which components of the problem were specifically addressed. For example, the first phase will necessarily include a preliminary discussion of data analysis to determine the specific nature of the problem under study. Formal data incorporation, however, is the final stage. The end result of this approach is a modeling environment with all four elements integrated into one visual interactive, decision support system. A more detailed summary of the model development activities is presented in Exhibit 1.

The proposed methodology moves away from the more traditional optimization approaches to emphasize managerial relevance and implementability. This approach seeks to

EXHIBIT 1

DEVELOPMENT ACTIVITIES



accommodate, rather than attempt to incorporate, the unstructured complexities found in this problem. The cash management problem is dynamic and loosely structured. Cash managers require the ability to monitor and update their set of decisions as new information becomes available. By providing the ability to merge the model's information and the decision maker's judgement, the decision maker was expected to be able to improve on the manual decision process, and therefore willing to implement the model.

Phase 1: Screen Development -- Communication

Screen development was the first phase of the model building process. This starting point was chosen for three major reasons. First, practising cash managers (and most other managers) are unfamiliar, and potentially uncomfortable, with the concept of graphic modeling: for example, when asked if his function employed any graphics to help monitor cash over time (which would provide a starting point for initial screen development) a cash manager produced a hand-drawn trend display, but then suggested that this chart was solely for his own personal use to help monitor the performance of his unit. Second, VIM designers (for example, Lyons, 1983) have noted that the presentation of graphic models of processes unrelated to a manager's function was perceived as uninteresting and irrelevant, but the same managers were later impressed by a much simpler "mock-up" designed to graphically display some aspect of their specific problem areas. Third, and importantly, the selection and development of screens to suit a particular decision maker will dictate the form of the interface component. This will, in turn, largely determine the structure of the algorithms needed to support the interface that, in turn, will determine much of the data structure and data requirements. The entire process is conceived as iterative as, for example, tradeoffs are made between collecting data that has been determined beneficial for the model but is currently unavailable against the utility of some element of the model that relies upon that data.

After "fine tuning" the model, the end product is a DSS designed to suit the manager's problem, rather than a problem that can be defined to suit the model. The only data and algorithms employed will be those determined to be useful for the decision maker. The decision process under study is time constrained and complex, and the model must be simple to be usable and to provide reasonable response characteristics on a microcomputer application.

A visual interactive model can have several screen displays which can be interactively called during a model run, therefore the cash management DSS was designed to use more than one representation.

The following graphics were initially developed on paper:

1: An overall status display for a current month (a preliminary design for this screen is shown in Exhibit 2).

2: An overall status display for the past 10 days and next 30.

3 and 4: Displays of three trends: inflows, outflows, and overall balances.

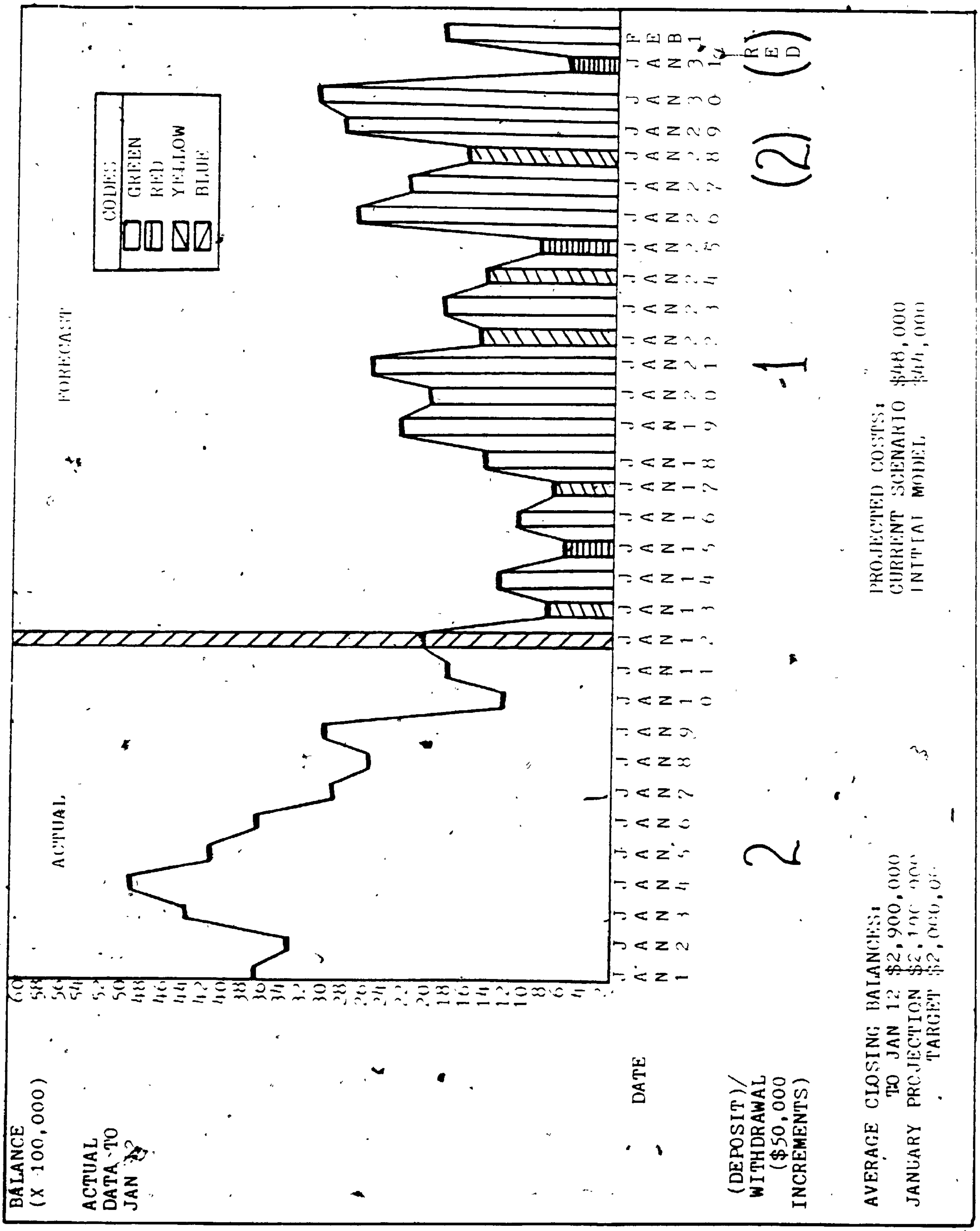
5: Summary display of model statistics and portfolio (non-graphic).

6: an interactive menu screen.

Additionally, a report-generating function was planned for the model. This function would provide hard copy for communication purposes after a series of decisions had been selected by the manager.

The design and subsequent selection of the screen displays is a critical element of this research. After these

EXHIBIT #2: OVERALL STATUS SCREEN
(PRELIMINARY)



initial screens were prepared, they served as the first contact issue for the field study, and were used to introduce the cash manager to the proposed system. Once the initial screens were developed to a point where they were acceptable to the decision maker, the problem under study became more structured and the next model building phase of the thesis could commence.

Phase 2: The Interface Component -- Interaction

The second aspect of the project involved a determination of the specific decisions that the cash manager makes, and how a VIM can support these decisions. Cost structures for the problem identified in the literature as cash management provide a starting point for modeling, but the process by which decisions were made needed much clarification.

The decision maker's problem-solving approach dictated several elements of the interactive component. It was hypothesized that both the format of the model and the decision process used by the cash manager would evolve with the close examination of the problem undertaken during model development.

To design the interface component, the screens and initial discussions with the manager were first studied. The decision maker began to interact with the model's "shell," and another iteration of screen and interface redesign took place. As the interface was merged with the screens, the manager began to interact with the model, and directed further developments through these "test flights."

Phase 3: Algorithm Development

The algorithms were to be developed to drive the graphics screens. In this methodology, the model building phase is largely structured by the selection of graphics screens and the interactions required of the model. The problem modeled according to this methodology may, in fact, be a subproblem of that addressed by the decision maker, but the interaction component was expected to allow for the incorporation of any externalities to the modeling process by the user. This phase required minimal input from the decision maker, since the output of the model was prespecified via the graphics screens.

Existing cash management models optimize some objective function and provide a solution to the problem as defined. The objective of this model as a DSS, however, seeks to provide a solution to a narrowly defined problem, but then offers this solution as a starting point for further interactive analysis by the problem owner.

Phase 4: Formal Data Collection

After development of the complete VIM, the data required to drive the model was examined. Consideration of the nature of the data required for the problem situation had been part of phase 1, but the formal requirements were yet to be determined. This methodology included the risk that some data element required for the model did not currently exist, but compensated by offering new information. If the problem as defined by the decision maker included data not utilized in the manual decision process, the opportunity existed for further refinement of the definition of the problem under study. This model building approach was iterative, since data elements not available at this point must either be collected, or the model modified to use available data. This decision, however, was made by the problem owner.

Rationale for the Novel Approach

VI modeling has evolved as much through a demand-pull evolution as a technological, or theory-push, evolution. The concept was initially operationalized by an academic (Hurrion, 1976), but has since been developed and refined largely by practitioners (Hollocks, 1981; Fiddy et al, 1983). Conversely, corporate cash management has not incurred the same theoretical - practical integration; the managers interviewed, for instance, were only remotely aware of any theoretical research that has been undertaken in the cash management area. They were all in agreement that any models they were aware of were inapplicable to the problem they dealt with.

This implementation weakness in cash management research corresponds closely with the strengths that have been claimed for VI modeling (Parker and Bell, 1983), and provides an opportunity to gain insight into both fields.

Today's computer technology supports the cash management function mainly through the provision of up-to-date information. Canada's major banks offer on-line query systems for corporate customers, through which account activity and current balances can be accessed by means of a computer terminal. Additionally, software packages allow the manipulation of information to provide reporting functions, including graphics, and data can be accessed through computer-based accounting records. The integration of forecasting, report generating functions, and some form of mathematical modeling, however, has not yet occurred.

The cash managers' task required that several activities take place in an extremely short time frame, and a modeling approach had to take account of this. Compounding this difficulty was the fact that the cash management process is dynamic. The model had to allow both the immediate manipulation and consideration of new parameters, and had also to provide immediate turnaround. It was this rapid communication and interaction requirement that led to the proposal of a VI modeling approach to support the corporate cash management decision process.

This research project, by examining the process of VI modeling, sought to provide evidence to standardize the process and to provide the benefits that have been alleged for this technique. Practitioners have anecdotal evidence (Lyons, 1983) where a VI modeling application provided identical conclusions to a previous OR report, but the findings were never implemented until the decision maker could "see" the results visually. VI modeling packages are now commercially available in North America, but the personnel responsible for their utilization tend to be OR specialists with training specifically in the programming and development of models, and not in the recognition of what should, or could, be enhanced through VI modeling. This research addressed these issues by examining the design process and the corresponding model requirements for a major VI modeling application.

VI modeling is gaining growing acceptance in OR and MIS, but current contributions tend to be specific projects (such as Patel, 1979). General VI modeling approaches have not yet been determined, and research to date has not provided a theoretical basis upon which to build (Ives, 1982). This thesis offers a model building approach to support the further development of VIMs as both an OR and DSS technique.

OPERATIONALIZATION OF THE RESEARCH PLAN

In order to develop a research plan to test the proposed methodology, several steps were taken. First, three cash managers and one cash management representative from a leading Canadian chartered bank were interviewed. The banking representative provided insight into the Canadian cash management situation as opposed to that of the United States where most of the current models had been developed. This information was useful for site selection.

To evaluate the proposed approach by addressing a representative cash management problem, a single site was required for development of the VIM. Model building required interaction with the decision maker at each phase of the project, so a research site had to be selected early on in the project. This site had to offer a suitably complex problem to test the methodology and to provide generalizability to other problem situations.

The company selected as the research site had to be a Canadian firm within the Canadian banking structure, and had to employ an identifiable cash management officer. Three firms were intially identified through a survey of Canadian cash management practices (Bell and Newson, 1984), and the cash managers of these firms were those interviewed. The firms were all large enough to provide the degree of complexity which would be representative of the problem outlined in the literature: a large Canadian insurance company, a major Canadian wholesale distributor, and a Canadian manufacturer and distributor of specialized industrial products. None of the cash managers interviewed utilized any formal algorithms to manage their cash account activities, and they all suggested that their major daily cash management function was the monitoring and forecasting of activities in the cash account. Other major tasks were identified as the negotiation and maintenance of banking arrangements and the consideration of alternative uses of short term residual cash.

While each cash manager expressed interest in the project, there was the important requirement of access to as yet unspecified confidential data. Additionally, significant time would be required on the part of the decision maker since the proposed approach required frequent interactions between the analyst and the decision maker. Each manager interviewed was asked about his willingness and capability to commit to such a project, and to provide data to evaluate the model. Final selection was made based on the manager who could agree to commit the time and provide the information needed for the project.

Before the final site selection was made, a search for confounding effects was made. If, for example, the company selected was in a state of change, such as merging with another company or realizing unusual growth or decline in its industry, results would be difficult to evaluate. The firm selected was in a stable economic situation, and did not foresee any signifigant changes throughout the duration of the project.

The selected company was a Canadian manufacturer and distributor of a line of industrial products, and was a wholly-owned subsidiary of a U.S. corporation. The subsidiary was, however, independent with regard to cash management and decision making, and the Canadian firm maintained its own Canadian banking arrangements. The company had sales of approximately $150 million annually, and was in a stable economic position. The cash manager was a senior executive officer of the Canadian company, and agreed to provide time and data as required for the project.

A tradeoff was made between generalizability and intensity of the model building project at this point. The objective of this thesis was to develop and evaluate a model building approach for VI modeling, so an in-depth project at a single site was selected as the appropriate research method.

The expected results of this model building exercise were that the proposed approach would offer an implementable product which could contribute to improved decision making on the part of the cash manager. Improved, in this case, could be interpreted as higher quality decisions -reduced account costs per unit of time; faster decisions of equal or better quality; and/or decisions made with greater confidence on the part of the cash manager through the examination of more alternatives or better support to calculate potential outcomes from any given decision set.

Current VI modeling projects have, to a large extent, related value to implementability. A strength that has been accredited to VI modeling is the ability to communicate the results of an OR study to the problem owner (Lyons, 1983; Bell, 1984). Research into the change in decision outcomes with the use of graphics has offered minimal support for the value of this technology other than as a marketing vehicle (Lucas, 1981; Lucas and Nielson, 1980), but current research suggests that VI modeling offers a new approach to complex problem situations (Bell et al, 1984).

Similarly, Keen and Scott Morton (1978) outline the difficulties of evaluating a DSS product, and suggest eight possible measures for evaluation: decision outputs, changes in the decision process, changes in managers' concepts of the decision situation, procedural changes, classical cost/benefit analysis, service measures, managers' assessment of the system's value, and anecdotal evidence. Evaluation of this model-building process included several of these issues. First, it was expected that the VIM which resulted from this approach would be deemed implementable by the decision maker with whom the project was undertaken. Second, the series of decisions offered to the manager by the model were expected to provide a solution which improved on those made manually. It was expected that the manager would change these proposed decisions to accommodate the elements of the problem not incorporated by the model, but that the total costs charged against the account would still be lower than those resulting from the manual decision process. Finally, a large part of the cash manager's task involves forecasting and calculating potential outcomes of decisions. The model automated several aspects of this task, and it was expected that less time would be required to make the necessary series of decisions. Rudelius et al (1982) stated several objectives for a DSS, including the ability to perform structured arithmetic calculations and understandability of the model's functions by users. The complex but routine calculations in the cash management function were an area where a computerized DSS could offer significant support.

The model which resulted from this modeling endeavor was not expected to automate the cash management function. The results were expected to be modified interactively by the manager after recommendations were made by the model. The final model was intended to offer a support mechanism for the decision maker, so that the 'softer' aspects of the decision environment could be incorporated. It was not expected that the VIM could incorporate all of the complexities of the cash management process.

After selection of the research site and preliminary data investigation, the next step was to develop the initial screens and use them to formally introduce the concepts to the problem owner. After obtaining agreement with the selected cash manager, account activity data was collected for a preliminary analysis of the cash account. It was then agreed that the analyst would develop the initial proposal for the project, and the analyst and manager would subsequently meet and commence the first proposed model building phase - screen development and graphic representation design.

Chapter 5

First Project Phase:

Initial Presentation of Graphics and Screen Development

The cash manager and analyst had agreed on the scope and objectives of this experiment and clarified the several distinct project phases. The first step, then, was to familiarize the manager with the available technology and the methodology to be used in this novel problem solving approach as a lead in to screen design. Since the demonstration of VIMs unrelated to a manager's task has been found ineffective (Lyons, 1983) and there was no existing VI modeling application that could be considered representative of the problem to be addressed, the initial presentation to the problem owner was a hybrid of three approaches.

First, the graphs and trend lines that the manager personally retained and updated were examined and discussed. These hand-drawn graphs provided an initial graphic format with which the manager was familiar and highlighted features of the problem that he considered important. The graphs showed daily closing balances, with the bank's average compensating balance (ACB) requirement superimposed. These displays highlighted surplus or shortage positions and were used to monitor performance and to evaluate the merits of decisions such as renegotiating ACB requirements vis-a-vis both fixed and variable bank operating charges. The manager had used these summaries to modify his ACB requirements prior to this study, and expressed confidence in his ability to use graphical summaries of large quantities of data to facilitate his policy decisions.

During this discussion, additional features of the cash management process were discussed. Of greatest importance to the cash manager were:

Daily closing balances, particularly for the month to date.

These were important to determine what levels of cash should be kept in the account for the remainder of the month, primarily to meet ACB requirements. These balances could then be traded off against other opportunities to use the current cash balance.

Projected daily cash activities for the remainder of the current month.

These projections were critical for the evaluation outlined above. There were, however, several components of inflows and outflows of cash, and it was suggested by the cash manager that an analysis of inflows and outflows separately would be a necessary part of a reasonable forecasting approach. For subsequent model development, further analysis of the components of inflows and outflows would be required.

Cheque volume for each day of the current month.

This parameter was used by the cash manager as a leading indicator of the variation in the remainder of the month's forecasts. It was compared to total amounts outstanding to anticipate the 'lumpiness' of the remaining cash outflows as cheques cleared the cash account. This was done through comparison of the total dollar value of outstanding cheques with the number of cheques outstanding.

Variability of the forecasts.

Several parameters contributed to the variability in the account activity forecasts, and this was an area where the cash manager's judgement was utilized most heavily. He considered the seasonality of elements within the forecast, past forecast accuracy, and recent price fluctuations in the raw material supply markets to determine how accurate the cash activity forecasts could be assumed to be.

Following this overview of the components of the problem, potential graphics screens were prepared on paper and presented to the manager at a second meeting. These screens had evolved from the graphics that the manager had been using, but were adapted to incorporate both the other parameters which had been discussed and the resolution and capabilities of the hardware to be employed. The manager's reaction to the preliminary status screen (Exhibit 2-1) was positive but brief (the examination lasted about two minutes for each proposed screen, and the manager offered opinions on his preference for the formats rather than suggestions to change any specific screen), until he was told that the data was derived from actual corporate data he had supplied earlier. He then took the graphs back to study for a significantly longer time interval, and asked a series of questions regarding the format of the graphs (e.g. scaling). These comments proved particularly helpful for the design of the initial computer-generated layouts. At the end of this discussion, the manager expressed interest in the continuation of the project and suggested that he could now more clearly see the potential benefits of this approach.

The third meeting, held at the computer facility, included the initial presentation of VI modeling to the manager, although both VI modeling and the particular problem environment had already been discussed.

There was no existing visual interactive financial model or a visual interactive model employing a similar form of representational graphics. Therefore, four models were demonstrated to illustrate VI modeling. The first two demonstrations were VIS applications: one an iconic model of a steel plant's railway car queueing system (Dofasco Lance Desulphurizing Plant Case, The University of Western Ontario), and the other a continuous flow model of a polymer production/distribution system (International Polymer Case, The University of Western Ontario). The objective of these demonstrations was to illustrate an overall VI modeling problem analysis approach, overview potential interactions and interventions with a VIM, and to highlight both the capacity and the limitations of this technology. The third model was a decision tree model (Ontario Brewing Company Case, The University of Western Ontario) used to demonstrate a form of representational graphic modeling. The final demonstration model was an interactive Gantt chart for a production scheduling problem written using the software package to be used for the cash management model.

When the manager was more familiar with VI modeling technology, six alternative cash management graphic screens were presented to him on the graphics terminal. These screens had no model driving them and the only interaction available was the ability to call another demonstration screen to be displayed. The data displayed was from the manager's firm so that scaling and format specifications could be included in the discussion. While the objective of this discussion was to select the screen(s) to be used in the model development process, the manager offered several suggestions which could not have been preconceived by the analyst. Axis labels were changed to be more readily interpretable, realistic minimum and maximum values established, and one screen was rotated ninety degrees (horizontal bars became vertical) so the problem owner would be readily able to evaluate levels at a glance. Colors were modified to be more meaningful and attempts were to be made to superimpose two graphs. Additionally, a bar graph to represent cheque volumes was added to a cash inflows and outflows display to allow heuristic evaluation of the forecasts.

The initial screen designs and proposed interactive capabilities were originally developed by the analyst, but the problem-owner completely redesigned the screens after sufficient exposure to the technique. Further, he suggested several revisions which could not have been preconceived by the analyst following the preliminary interviews.

Following completion of this phase, three major aspects of the project had been completed. First, the manager had expressed commitment to the project and agreed to the solutions, in the form of the graphics screens, which the system would provide. If the model could be built and validated by both the manager and the analyst, an implementable system should result. Second, the problem had been defined to a point where the algorithms and required analysis were clarified. By agreeing on the 'solutions' to the process, the problem was now more structured. The analyst's task, at this point, was to develop appropriate interactions so that the structured aspects of the problem, to be handled by the VI modeling system, could be developed. These interactions would also provide the cash manager with the capacity to impose the unstructured elements of his function on the model. This was the second phase of the model building process.

Checkland (1981) describes soft problems as ones "where goals are often obscure." The goals of this cash management modeling exercise remained unstructured, or 'obscure,' through the initial phase of the process. A shift from the soft systems approach to a more structured, hard approach, however, was a major objective of this first phase. The objective for this modeling approach was to derive a model which was valid to support the cash management problem that the decision maker faced. This objective required that the model achieve face validity (Kidder, 1981) from the cash manager to facilitate implementation. Face validation by the decision maker who would ultimately use the model was the first step in evaluating the usefulness of the model to support the cash management decision making process.

Validation and evaluation of decision support systems poses a difficult problem (Ives, 1982; Keen, 1975; Keen, 1981; Keen and Scott Morton, 1978) due to the difficulty to relate intangible benefits to somewhat more tangible costs. There were two major validating steps in this model building exercise. First, it had to be determined that the shell of the model, as it existed at this phase of the project, would be perceived as effective by the cash manager to support his decision making process. Second, the series of decisions which resulted from the completed model could be compared to past, manual decisions in terms of acceptability as judged by the cash manager, and in terms of costs levied against the account.

The model would initially offer a series of decisions which were based upon a narrowly-defined cash management problem. These decisions, it was expected, would show a cost improvement over manually derived decisions, but would be deemed unacceptable by the cash manager because the unstructured elements of the environment had not been considered. From this starting point, however, it was anticipated that an intermediate decision set would be derived through interaction between the model and the decision maker. This intermediate solution, should the model be effective, would offer both a cost improvement over the manual decision making process and an implementable series of account activity decisions.

This first phase was a critical success factor for the model. As the manager developed familiarity with VI modeling and the development process, he could then provide input to refine the model on an ongoing basis, rather than dealing with major revisions on presentation of the final model.

The model building approach differed from those in the literature as a result of this interactive problem definition step. It was also expected that the underlying mathematical models would differ from those previously developed. Buzacott (1982) differentiates between the "model world" and the "real world," and suggests that OR modelers frequently define the problem to be modeled without consultation from the problem owner. The result, he argues, is a model representing the OR analyst's definition of reality which can lead to a difficult validation and implementation process. He outlined an alternative model building approach entitled "systemics," where the problem owner's "definition of reality" is accepted completely as the situation to be modeled by the OR analyst. The flaw in this approach, he suggests, is that it: "... assumes that there are no objective facts." He concludes: "Since the OR man must adopt the manager's values, there is the risk that his OR will come to serve the devil." The model builder, however, must at least accept the preliminary problem definition from the decision maker, and it is the decision maker who must make the decision to implement the model.

The four-phase approach developed in this thesis differs from the discrete categories offered by Buzacott.

Employing the reported manager-analyst communication benefits of VI modeling (Lyons, 1983; Bell et al, 1984), this approach initially incorporates the manager's problem definition into the specifications for the model through design of the graphic representations of the 'solution' to the problem under study. Subsequent steps focus upon modeling the problem, as agreed upon, using the OR analyst's model building techniques to develop a model of the situation under study. Limiting assumptions required in the modeling process, however, are prespecified and agreed on by both the decision maker and OR analyst.

The next phase of this process was the integration of the developed screens into a computer graphic format and development of an interaction module to support the requirements which were now specified in detail.

Chapter 6

Second Project Phase:

Display Integration and Interaction Development

The second project phase, following the development of the screen displays, was to develop the interactive component of the model. The software package and hardware available included several functions which largely dictated the capabilities and limitations of this component. In addition, although the graphics displays had been defined by this point, changes were needed and details would have to be added to facilitate the required interactions. For example, colours selected would have to be reconsidered as the selected displays were merged together onto the graphics screen.

It had been determined in the first project phase that the manager wanted two major graphics displays. Several 'windows' on a single graphics screen were required to incorporate the display requirements. A window is a distinct graphic representation, such as a bar graph of account balances. While looking at a graphics display, several windows which comprise a single display screen can be observed simultaneously.

The first desired graphics window was a trend display of the closing account balance for each working day. This graph would accommodate both actual and projected balances and would scroll across a time line with dates labelled below the horizontal axis.

A critical objective of the graphics display was the ability to scan the forecast cash balances while simultaneously considering the variability of the forecasts, which translated to risk for the manager. Several methods to address this objective had been considered; for example, varying the width of the trend line according to the expected level of variation. This approach, however, made it difficult to determine the expected closing balances in highly uncertain periods due to the thickness of the line, and allowed only one threshhold level of variation to be displayed. The availability of eight colours on the ISC Intecolor terminal offered other informative, and useful, opportunities. It was decided to superimpose a multi-colour bar chart below the forecast trend line to display differing probabilities of cash stockout. This display would both highlight risk resulting from forecast variability, and serve to differentiate between forecast and actual data, since the area under the actual period trend lines would remain black.

After discussion regarding the display of forecast 'riskiness' with the manager, it was determined that there should be four threshholds highlighted. The first was to be a level of forecast uncertainty where the manager could be reasonably sure that the balance would remain positive.

The definition of 'reasonable' had been discussed with the manager at a preliminary stage in the development of the display, but there were two major factors which would have to be evaluated before values could be agreed on. The first were the extreme values of forecast variation, which had not yet been determined. These extremes would provide information on the usefulness of the forecasting approach to the manager. The closer together the extreme values were, the closer the threshhold values within this range could be. The second factor was the frequency distribution of the forecast variation within these ranges. For example, it would not be useful to use several colours if the forecasting technique used placed each day's forecast cash balance into the same category and hence only provided a one colour display. To be useful, there would have to be differentiation among categories, which was a direct function of the sensitivity of the forecasts themselves.

2

MICROCOPY RESOLUTION TEST CHART
NBS 1010a
ANSI and ISO TEST CHART No. 2

1.0 2.8 2.5 3.2 2.2 3.6 4.0 2.0 1.1 1.8 1.25 1.4 1.6

The second threshhold level was to be a warning of a cash stockout with some, as yet unspecified, probability. The third threshhold was a higher probability of a stockout, while the fourth was that of an expected negative balance. Color combinations to convey this information had been discussed, and the manager had made several suggestions during the final presentation of the second project phase. As a result, the colours green, yellow, red, and blinking red had been selected for the four 'forecast risk levels' in ascending order. Further, to maximize the information presented to the manager it had been agreed that, since a negative balance was considered both unusual and unacceptable, it would be represented as a red blinking zero point on the graph, for both forecast or actual days.

The vertical axis, which represented dollar balances in the account, could then be scaled from a minimum value of zero. To accommodate a maximum value, two alternatives were examined. First, relative scaling was considered. This would involve redrawing the graph each time any parameter was changed, since this might change the maximum value and the vertical scale may then have to be altered. The manager expressed concern that this approach would not provide comparisons across time periods, so a second alternative was employed - that of absolute scaling of the vertical axis. After examining several months of account data and discussing potential maximum account values with the manager, a reasonable maximum value was found. It was agreed that values above this level would be represented as a white blinking up-arrow in place of the trend line on the graph. White was selected since the colour of the trend line showing the closing cash balances was also to be white. A high cash balance was not considered as critical as a low or negative balance, so a change in colour from that of the trend line was unnecessary. It would typically, however, require attention and possible action by the manager so the blinking function was used.

The second graphic representation was a display of account activity for the same daily time horizon as the cash balance display. This graph highlighted cash deposits, withdrawals, inflows, and outflows as different series of coloured bars. While this graph would not highlight the same trends as the first display, it provided a rapid method of reviewing the components of the cash balance. A histogram of cheque volume was added to this display providing another item for the cash manager to use to heuristically evaluate the relative accuracy of the daily forecasts. The colour options employed were designed to facilitate maximum discrimination of the available colours among each displayed item. Some adjacent colour combinations, such as cyan and magenta, were more difficult to contrast than others, such as cyan and yellow, so the colours were reconsidered and modified once the complete screen displays were observed.

The daily detail required on the two displays and the resolution limitations of the graphics terminal meant that the number of days to be displayed at one time posed a difficult problem. As the number of days displayed grew, the amount of space available to present other information on the screen diminished. Conveniently, displaying a maximum of twenty-five days was technically viable given the other screen requirements, while the manager required at least one month's data to be simultaneously displayed. A twenty-three day display was agreed on which, since there was no account activity on weekends, was the maximum number of working days in any calendar month. Following design of the basic displays, attention turned to the interaction component.

The first interaction component to be designed was the interaction between the two main displays. It had been agreed that these graphs should be tied together logically, but the resolution of the graphics screen prevented display of both graphs simultaneously. There was also no apparent reason for the manager to need to access both displays at once, but rather, he needed to be able to refer to a particular position in time from one to the other. This required the interactive capability 'scroll' across the time line, and to 'flip' screens from one to the other at a selected point in time.

The primary function of these capabilities was the monitoring of account activities by the manager, who could peruse the cash balances display until a situation was found which required further investigation. With a simple interaction, he could then 'flip' to the cash inflows, outflows, and cheque volume display, which appeared in exactly the same space on the graphics screen, to break out the cash activities in the time period under study. The scrolling capabilities required that the horizontal axis (the time line) of each screen was tied together, so that screen flipping would result in the same relative time position for either display.

Upon completion of the interactions required to access the graphic displays, the next requirement was the ability to access exact numerical data values and to modify any desired aspect of the scenarios.

An interactive spreadsheet.

The manager needed to access the numbers behind the graphics display on an <u>ad hoc</u> basis. With this capability, anomalies discovered by examining the graphic displays could be analyzed in more detail to determine their exact composition, and the magnitude of each component. For example, if the cash balance display exhibited a sudden decline, the manager required access to the cash balance components to determine if the cause was an unusual inflow, outflow, withdrawal, or combination of these, and of what magnitude this was. The former requirement could be met from the inflows and outflows display, while provision of the latter required a spreadsheet. Discussing requirements for DSS design, Benbasat (1977) suggested that "... preceptive individuals should be given aids to summarize and filter data, such as exception reports and routines for determining patterns of given attributes over time. Receptive and maximal data user types should have a data-retrieval system with flexible and timely search capabilities to large data bases." The cash management problem imposes a need to scan large quantities of information rapidly and to examine portions of this information in detail. Depending on the decision maker's characteristics, a spreadsheet offered a tabular substitute for the detailed cash inflows and outflows graphic display. Decisions made by the manager, however, required numeric input which was also handled by this spreadsheet. To accommodate flexibility for the user, then, scanning capabilities were required for this display.

The spreadsheet would provide the manager with the ability to override the model's suggested decisions. He could also change a forecast using information unavailable to the model, or choose to modify a previously determined series of deposits or withdrawals.

The elements required for input or interaction within the spreadsheet were: the date, status (forecast or actual), receipts, disbursements, deposits, withdrawals, and cheque volume. Additionally, opening balance and values including high and low forecast estimates for receipts, disbursements, and the closing balance were displayed.

With the screen sensing capabilities of the software package, this interaction was feasible using cursor addressing to change a displayed value. To move the spreadsheet display to a new date, the manager could overwrite the displayed date and the spreadsheet would automatically move to the desired date. To modify a value in the data file, a similar technique was employed: the manager would overwrite the data item, and the model would automatically update the data file and corresponding screen displays on depressing the ENTER key.

Because of the limited resolution capabilities of the screen, the spreadsheet could not display the same time horizon as the graphic displays. Therefore, the spreadsheet did not scroll with the graphics displays. If a value was changed in the spreadsheet, however, the program would instantaneously update the graphics displays. This interaction offered two major advantages: first, the manager could scroll along the graphics displays without viewing a distracting changing spreadsheet (Additionally, the computational difficulties of synchronizing the scrolling to the spreadsheet would slow down the scanning capabilities somewhat). The second major advantage was an ability for the manager to modify the data file in one time period while viewing the impact graphically on a subsequent time period.

To differentiate the spreadsheet display from the adjacent graphic, the background colour was changed. It was decided that the displays which could be addressed via the cursor would have a yellow background colour while those which served as displays only would be on a black background. Additionally, numbers in the interaction displays (there were to be three) which could be changed by overwriting were to be red, while display-only values would be black. The spreadsheet, for example, was found to be of most benefit if it displayed not only the active day, but also the previous and subsequent working days. It then had three columns, the center of which was red on yellow which could be modified, while the other two days were displays only and were represented as black on yellow.

In addition to an ability to overwrite dates, a scrolling capability was built into the spreadsheet. This function would allow the manager to examine individual days in a critical period by scrolling day by day, changing entries as required to arrive at an acceptable position on the corresponding graphic display.

The second interactive requirement was a display of statistics to allow the manager to examine his banking position between any two dates. The manager often needed to calculate his average closing balance between specified dates to determine how the banking arrangements were being met by the current set of decisions and plans. To accommodate this requirement, a display was added which showed the required statistics.

A Display of Selected Account Statistics

The manager had negotiated an average compensating balance requirement with the company's bank; a common practice in the Canadian banking industry. In this type of agreement, the bank allows a portion of bank charges to be offset by a guaranteed minimum average monthly balance in the account. There is, however, an informal understanding between the parties that the balances retained over the weekends during each month will not deviate 'significantly' from the overall average balance. Further, the average balance is expected to remain relatively constant over time, rather than being 'padded' by large deposits at the end of each month to meet the requirement. In the event that the average balance does not meet the specified requirement, there is a 'deemed loan' at a reduced corporate lending rate automatically charged to the account. Should parts of an implicit agreement not be met, such as the weekend requirement, the bank was free to renegotiate this average compensating balance agreement at any time. The existence of informal agreements like this was one of the major complexities not accounted for by previous cash management models.

Rather than attempt to incorporate a flexible, dynamic constraint into the model, it was decided that prominent display of the statistics on which this agreement was based would be most appropriate for the cash manager and became the third major display and interaction area.

The balance statistics display showed a starting and ending date provided by the manager. Once these dates had been selected, the average closing balance in the period selected and the average weekend balance were displayed. These values could be examined alongside the closing balance display to evaluate the account's compliance with the banking arrangements. Additionally, total cheque volume between the chosen dates was displayed. This display would also be automatically updated as a value in the spreadsheet was changed.

The basic command window.

The software package structure allowed movement from one interaction window to another via commands entered in a command window. Since the model would be employed for several different activities (Such as scanning the cash balance, examining items in the inflows and outflows graphic, examining numerical data values in the spreadsheet, changing values in the spreadsheet and viewing their effect upon subsequent balances, and examining balance statistics over specified time periods), several macro commands were designed to allow movement into and around the window areas corresponding with these activities. The objective of defining these commands was to make them as obvious as possible while remaining simple and easy to remember. The commands initially developed were: DRAW - to redraw the screen, MODIFY - to allow access to the spreadsheet window, UPDATE - to allow access to the spreadsheet window at the first forecast date (to facilitate data updating over time), and BALANCES - to allow access to the statistics window. The first three letters of each command were sufficient for execution. Additionally, in the event that a command was forgotten, any command entered which included a question mark would bring a menu summarizing the available commands into the command window. The available commands are detailed in Exhibit 3.

Presentation of the VI Model's 'Shell'

The presentation to the decision maker on completion of phase two occurred at the computer site. The modeler and the manager had been in frequent communication regarding the modifications and tradeoffs required during the development of the package, but the product itself was significantly different from the graphics 'slide show' that

EXHIBIT 3:

THE INTERACTION COMPONENTS

COMMAND	FUNCTION	USER TASK(S)	MODEL TASK(S)
UPDate	ENTER SPREADSHEET AT FIRST FORECAST DAY	ENTER ACTUAL DAY'S ACCOUNT ACTIVITIES	UPDATE FORECAST PARAMETERS UPDATE DECISION RECOMMENDATIONS UPDATE BALANCES
MODify	ENTER SPREADSHEET AT DATE LAST MODIFIED (OR FIRST DATE)	CHANGE AN "ACTUAL" VALUE (ERROR CORRECTION)	UPDATE FORECAST PARAMETERS UPDATE DECISION RECOMMENDATIONS UPDATE BALANCES
		CHANGE A FORECAST VALUE	UPDATE DECISION RECOMMENDATIONS UPDATE BALANCES
		CHANGE A DECISION	FREEZE DECISION RECOMMENDING SUBROUTINE FROM CURRENT DAY BACK UPDATE BALANCES UPDATE SUBSEQUENT DECISION RECOMMENDATIONS
BALances	ENTER BALANCE CALCULATIONS WINDOW	ENTER "FROM" DATE AND/OR ENTER "TO" DATE (OR "END" FOR END OF CURRENT MONTH)	CALCULATE AND DISPLAY: -AVERAGE DAILY BALANCES -AVERAGE WEEKEND BALANCES -TOTAL ACCOUNT COSTS (ACTUAL OR PROJECTED) -TOTAL CHEQUE VOLUME

EXHIBIT 3 (CONTINUED)

COMMAND	FUNCTION	USER TASK(S)	MODEL TASK(S)
REPort	GENERATE HARD COPY OF BALANCES FORECASTS, AND DECISIONS	ENTER START AND END DATE	PRINT HARD COPY OF BALANCES AND ACCOUNT ACTIVITY BETWEEN SPECIFIED DATES
SAVe	SAVE CURRENT DECISION AND FORECAST SET FOR COMPARITIVE PURPOSES	PROVIDE A FILENAME	SAVE AS A FILE FOR FUTURE RETRIEVAL
REStore	RESTORE A PREVIOUSLY SAVED FILE	ENTER FILENAME	LOAD ACTIVITY SET INTO THE MODEL
set INTerest rate	PROVIDE A NEW PRIME RATE	ENTER NEW RATE	UPDATE PROJECTED ACCOUNT COSTS AND ACTIVITIES FROM CURRENT DATE FORWARD
INItialize	GENERATE A DECISION SET FROM CURRENT DAY FORWARD	SET CURRENT DATE THROUGH "MODify" OR START AT BEGINNING OF DATABASE	CALCULATE A RECOMMENDED DECISION SET
?	HELP	-----	PROVIDE A MENU OF ALL OF THE ABOVE COMMANDS

EXHIBIT 3 (CONTINUED)

ADDITIONAL COMMANDS: (FUNCTION KEYS)

F1	MOVE ACTIVITY DISPLAY LEFT ONE DAY
F2	MOVE ACTIVITY DISPLAY RIGHT ONE DAY
F3	MOVE ACTIVITY DISPLAY LEFT FIVE DAYS
F4	MOVE ACTIVITY DISPLAY RIGHT FIVE DAYS
F5	MOVE ACTIVITY DISPLAY LEFT TO THE BEGINNING OF THE CURRENT MONTH
F6	MOVE ACTIVITY DISPLAY LEFT TO THE BEGINNING OF THE NEXT MONTH
F10	TOGGLE BETWEEN THE CASH FORECAST SCREEN AND THE ACCOUNT ACTIVITY SCREEN

had been presented at the end of the first phase.

The fundamental question to be asked at this point in the project was whether the package, as it then existed, would support the practising cash manager's task. His response to this question evolved as he examined the capabilites, and asked questions regarding the package's ability to handle various scenarios. The spreadsheet was examined first, and was used to change parameters to test the graphic display's abilities to update until the manager had assured himself that the statistics were truly interactive as data entries changed.

No forecasting algorithms had been developed yet and only actual data were available, but the colours and forecast displays needed to be examined. A forecast month was, therefore, 'mocked up' at the end of the actual data, and after examining and experimenting with the package to become familiar with it, two minor additions were found to be required.

First, the scrolling capabilities of the two graphics displays had been discretized to facilitate either week by week or month by month scrolling. The manager noticed that, if he wished to have a very accurate estimate of a value from the vertical axis, he needed to use a straightpage on the screen. He found this unsatisfactory, and so it was agreed that a daily scrolling capability would be added which would allow any specific date to be moved immediately adjacent to the Y-axis for more detailed examination.

The second unanticipated requirement was a way of communicating the results or for comparing several alternative scenarios. A report-generating function to provide hard copy output was needed so that the manager could compare alternatives and communicate with the accounting and finance departments regarding cash account activities. The required report was of simple tabular form with predefined headings, and required only minor modification of the model.

The final issue for this project phase was clarification of any possible omissions from the model, or anticipation of any data which would be unavailable for algorithm development and incorporation into the model. The model required data for inflows and outflows of the account and balance data, which is a combination of the previous values. Additionally, it was determined that all of the variable cost parameters for the model were a fixed function of the Canadian bank's prime lending rate calculated at the beginning of each calendar month. A capability was therefore required to input the prime lending rate calculated for each month.

Agreement was reached regarding the characteristics of the system and the next phase became clearly defined. Algorithms to provide useful, managerial decision support had to be developed which were both valid and credible.

Chapter 7

Third Project Phase:

The Formal Cash Management Model

Following construction of the VIM shell in phase 2, the next step was to make the model 'smart.' Development of the series of algorithms which would drive the graphics screens was facilitated by the problem structuring that had taken place in phases one and two. The need for multiple algorithms for forecasting and decision making had been identified during development of the interactions and displays. An important step in algorithm development was a review of the cost structure facing the firm.

Cost Identification

The Canadian banking industry is unique, largely as a result of Canadian federal banking regulations. The Canadian industry is comprised of a few national branch banks with multiple branches, each providing such services as online nationwide cheque clearings. This capability allowed the corporation under study to consolidate several territorial cash accounts into a central clearing account at the end of each working day, and hence concentrate upon the management of a single central account.

An important part of the cash management process involves the minimization of bank charges. The corporation being investigated had typical banking practices, as outlined by the bank executive interviewed, and the following cost functions were identified:

1: Overdraft, or Negative Balance Costs:

If the company's account balance was negative, the firm incurred a charge against the account at a prespecified interest rate.

2: Average Compensating Balance (ACB) Charges/Revenues:

As outlined in Chapter 6, the bank offered an ACB in lieu of service charges against the account. This requirement stipulated that a minimum average balance, calculated monthly, had to be kept in the account. For any average amount below the requirement, the bank provided a deemed loan at a rate which was a fixed function of the prime lending rate at the beginning of the calendar month. If the average balance exceeded the required ACB, however, the bank paid the corporation interest for the amount in excess of the ACB requirement at the same rate as the deemed loan. If negative balances were incurred which brought the firm's average monthly balance below the ACB requirement, both overdraft charges and ACB charges were levied against the account.

3: Borrow/Lend Rate From/To the Corporate Parent:

In lieu of a prearranged line of credit and short term deposit rate from its bank, the firm under study had arranged for short term loans and deposits with its American parent. The parent company received a dividend from the firm at the end of each month and any outstanding balance from these activities was cleared at this time. If, for example, the cash manager required cash to cover a temporary shortage, he could arrange to borrow this amount from the parent until the end of the month. If, however, he did not require the money for the entire month, or should he have a cash surplus, he could invest the money in the parent's account at the same interest rate as the loaned amount. This rate was below the overdraft charge, but above the ACB rate. There was, however, a fixed service charge from the bank to transfer these funds, and the cost of a long distance telephone call to make the necessary arrangements. These funds could be transferred immediately, and served as a buffer against foreseen cash shortages.

The variable part of all of the above costs was a function of the corporate prime lending rate at the beginning of each calendar month.

The assumptions for the formal model, then, include the following:

A linear cost with a fixed charge for transfers to and from the American parent.

Instantaneous transfer of funds, assumed to take place at the beginning of each day.

A period length of one day, with a one month decision horizon. This decision horizon is a result of both the ACB calculations and the clearing of the short term position against the American parent's dividend.

Since the opening balance can be modified by the cash manager through a transfer to or from the U.S. parent company, this opening balance is the decision variable for the problem formulation. This formulation seeks to minimize operating costs, subject to the forecast receipts and disbursements on a monthly basis. The interest rate for the overdraft and the lend/borrow ACB rate are assumed constant over the month.

The Model:

Given these costs, the decision process can now be formulated:

Define:

ζ_p the interest rate for an overdraft.

ζ_a the lend/borrow ACB rate.

R the amount of the ACB monthly average requirement (in \$).

K the fixed cost of a transfer to or from the U.S. parent (in \$).

For each day t (t=1,...,T), define:

c_t the daily lend/borrow interest rate for transfers to or from the U.S. parent in period t. Note that c_t is a (T+1-t) period interest rate.

L_t the amount transferred to (positive) or from (negative) the U.S. parent (in \$).

B_t the balance in the cash account at the start of period t (in $),

$X_t = B_t - R$ the balance in excess of the ACB requirement at the beginning of period t (in $),

$T_t(L_t)$ the transfer cost function for period t (in $).

$$T_t(L_t) = \begin{cases} 0 & L_t = 0 \\ K + c_t L_t & L_t \neq 0 \end{cases}$$

$\tilde{\Gamma}_t$ the demand for funds from the account on day t, a continuous random variable with density $f_t(\tilde{\Gamma}_t)$ and cumulative density $F_t(\tilde{\Gamma}_t)$ ($\tilde{\Gamma}_t$ may be negative for a net inflow of funds).

The problem can now be formally stated as a cost minimization problem:

On day τ (τ=1, . . . , T):

$$\underset{X_\tau,\ (\tau=t,\ldots,T)}{\text{Minimize}}\ E\left[\sum_{\tau=t}^{T} C_\tau[X_\tau]\right] \quad (7.1)$$

Where:

$$C_t[X_t] = \zeta_p \int_{X+R}^{\infty} (\tilde{\Gamma}_t - X - R) f_t(\tilde{\Gamma}_t) d\tilde{\Gamma}_t \qquad \text{(overdraft charges)}$$

$$+ \zeta_a \int_{X+R}^{\infty} (\tilde{\Gamma}_t - X_t) f_t(\tilde{\Gamma}_t) d\tilde{\Gamma}_t \qquad \text{(ACB charges)}$$

$$- \zeta_a \int_{-\infty}^{X} (X_t - \tilde{\Gamma}_t) f_t(\tilde{\Gamma}_t) d\tilde{\Gamma}_t \qquad \text{(ACB revenues)}$$

$$+ T_t(L_t) \qquad \text{(Transfer costs)}$$

Subject to:

$$X_t = B_t - R \qquad t = 1, 2, \ldots, T$$

$$B_t = B_{t-1} + L_t - \Gamma_{t-1} \qquad t = 2, 3, \ldots, T$$

The constraints for this formulation exploit two major features of the specific problem under study. First, costs are symmetrical with respect to R, since the cost of borrowing from the parent company are the same as the revenues generated from lending to it, and the ACB charges are at the same rate as the revenues. Second, the ACB requirement can be stated in a daily formulation, since there is no discounting in this model. For this case, an average monthly compensating requirement is equivalent to a daily requirement.

This formulation is novel in the cash management literature. While the objective of minimizing operating costs is standard in the literature, this is distinguished by the symmetry of the cost functions, although it remains similar in general structure to models which were previously rejected as inappropriate by the cash manager. The forecast data enters the formulation as the distribution of the demand for funds from the account ($f_t(\Gamma_t)$) which, assumedly, is non-stationary over time as the corporation earns profits. Other models have assumed this distribution is independent, identically distributed over time.

Theoretical Results:

Consider, first, the single period problem:

$$\underset{X_t}{\text{Minimize}}\ E\left[C_t[X_t]\right] \tag{7.2}$$

Where $C_t[X_t]$ is given by equation (7.1).

Since $C_t[X_t]$ is continuous (in X_t) and differentiable as long as $f_t(\Gamma_t)$ is differentiable, then a necessary condition for X_t^* to be the minimum of (7.2) is that:

$C_t'[X_t^*] = 0$ (where ' denotes differentiation)

with:

$C_t''[X_t^*] > 0$

Differentiating (7.2) with respect to the decision variable, X_t, and dropping t subscripts for notational convenience leads to:

$$C'(X) = -\zeta_p \int_{X+R}^{\infty} f(\tilde{T})d\tilde{T} - \zeta_a \int_{X}^{\infty} f(\tilde{T})d\tilde{T} - \zeta_a \int_{-\infty}^{X} f(\tilde{T})d\tilde{T} + T'(L) \quad (7.3)$$

Note that: $B_t = B_{t-1} + L_t - \tilde{T}_{t-1}$

Implying: $L_t = X_t + R + \tilde{T}_{t-1} - B_{t-1}$

Hence, $T_x'(L) = T'(L)$

Writing $\int_{X}^{\infty} f(\tilde{T})d\tilde{T}$ as $1 - \int_{-\infty}^{X} f(\tilde{T})d\tilde{T} = 1-F(X)$

and $\int_{X+R}^{\infty} f(\tilde{T})d\tilde{T}$ as $1-F(X+R)$

leads to:

$$C'(X) = -\zeta_p + \zeta_p F(X+R) - \zeta_a + T'(L) \quad (7.4)$$

Further:

$C''(X) = \zeta_p F'(X+R) + T''(L)$

but $T''(L) = 0$ for all L

and $F'(X+R) = f(X+R) > 0$ for all X.

Therefore $C''(X) > 0$ for all X

and $C'(X\ ) = 0$ denotes a minimum.

Setting $C'(X\ ) = 0$, from (7.4), leads to

$$F(X^* + R) = \frac{\zeta_p + \zeta_a - T'(L^*)}{\zeta_p} \quad (7.5)$$

As long as $L^* \neq 0$, (7.5) becomes:

$$F(X^* + R) = \frac{\zeta_p + \zeta_a - c}{\zeta_p} \tag{7.6}$$

This result depends on the symmetry of the cost functions in this formulation. Should, for example, the variable transfer costs differ between inflows and outflows from the account, another step would be required. Two expressions would take the place of expression (7.6), and a decision rule would be required to evaluate the optimal decision. In that case, it has been shown (Bell and Hamidi-Noori, 1984) that there are three alternative strategies: (1) a do-nothing strategy, where no transfer was made; (2) a transfer-out strategy, where only funds are transferred out of the account; and (3) a transfer-in strategy, where funds are only transferred into the account. It has also been shown that only pure strategies are candidates for optimal solutions, so this would not increase the complexity of the formulation significantly (Bell and Hamidi-Noori, 1984).

Ignoring the fixed transfer cost, equation (7.6) provides a target value of X^* (and hence L^*) for the minimum cost solution. Existence of such a target requires:

$$0 < \frac{\zeta_p + \zeta_a - c}{\zeta_p} < 1$$

$$\text{or} \quad 0 < \zeta_p + \zeta_a - c \qquad : \zeta_p + \zeta_a > c$$

$$\text{and} \quad \zeta_p + \zeta_a - c < \zeta_p \qquad : \qquad \zeta_a < c$$

$$\text{or} \quad \zeta_a < c < \zeta_p + \zeta_a \tag{7.7}$$

Note that $\zeta_p + \zeta_a$ represents the total cost of a negative balance (i.e. the overdraft charges plus the reduction of the ACB return or an increase in the ACB costs).

This result follows logically from the definition of the cash management problem since c, the lend/borrow rate, must always fall between the ACB rate and the penalty cost of an overdraft for convergent cash management decision making. This rate represents the (longer term) rate realized for being able to predict either a need for funds or a surplus in the cash account. If, for example, $c \leq 0$, the amount borrowed at this rate would be infinite if the account balance could provide any positive return. If c was less than the ACB rate, transfers out of the account would never occur, since alternative investments could not offer a better return than the cash account rate. Conversely, if c was greater than the sum of the ACB rate and the penalty cost of an overdraft, the overdraft alternative would be the cost minimizing decision for borrowing funds to cover a shortage of funds in the cash account.

If condition (7.7) is met, and in the absence of fixed transfer costs, the optimal solution is given by L^* and X^*. The existence of a positive fixed transfer cost complicates analytical determination of an optimal solution although, conceptually, the problem can be formulated as a dynamic programming (DP) problem with the single state variable: B_t, $t=1,\ldots,T$. Expected costs levied against the account can be minimized by recursively examining all possible states that result from an optimal policy which compares a "transfer" strategy to a "do-nothing" strategy each day. Solution of this problem, however, is slow and complex (See Bell and Hamidi-Noori, 1984). Since determination of an exact optimal solution in real time to the T period problem was deemed impractical, it was decided to use the single period problem result to develop a heuristic solution procedure for the multiperiod problem.

The single period solution (7.6) provides an optimal plan for cash management transfers in the absence of fixed transfer costs. Without these fixed cost components an optimal target level for the opening balance would be derived and the optimal set of decisions would be to adjust the opening balance to this level every workday morning. This result provides the basis for both upper and lower bounds of a heuristic to incorporate the fixed cost component.

The lower bound on total expected operating costs for a model with non-zero fixed costs would be the expected value of the optimal set of decisions outlined above. An upper bound on total expected operating costs would be the lower bound plus the transfer cost multiplied by the number of working days in any given month. That is:

$$E[\sum_{\tau=t}^{T} C_{\tau}(X_{\tau}^{*})] \leq E[\sum_{\tau=t}^{T} C_{\tau}(X_{\tau})] \leq (T-t-1)K + E[\sum_{\tau=t}^{T} C_{\tau}(X_{\tau}^{*})]$$

for $t=1,2,\ldots,T$

Since the fixed transfer cost for this firm was small, the upper and lower bounds were quite close together. Within this range, an heuristic could be tested which could readily provide a series of decisions to be programmed into the VIM.

An Heuristic to Incorporate the Fixed Cost Component

Utilizing the symmetry within the problem structure (since both the transfer costs and the cost of borrowing or lending were symmetrical), a simple combinatorial heuristic could be employed without directional bias. Additionally, since the horizon was quite short, no discounting was provided for. This followed from the activities of the cash manager who sought to minimize monthly charges against the cash account without considering the time value of money within a month, and allowed development of a memoryless one day look-ahead heuristic.

An unanticipated cash shortage where the overdraft financing would have to be employed was much more expensive than either an arranged loan or an unanticipated surplus. At this extreme, the costs levied against the account, then, were not symmetrical. If the cost of a shortage was the same as the return from a surplus, the manager would be able to transfer all of the funds from the account into the parent company's interest earning account with no penalty and the problem would be trivial. The basis of the heuristic decision rule was therefore to only seek to hold funds in the account until there was sufficient differences in the yields of the two accounts to offset the fixed costs of a transfer.

The decision rule developed was as follows:

Each period Υ, $\Upsilon \in [t,\ldots,T]$:

Solve the one period problem for periods $t, t+1, \ldots, T$ (giving $L_t^*, L_{t+1}^*, \ldots, L_T^*$) assuming:

$$B_\tau = B_{\tau-1} - E[\Gamma_{\tau-1}] + L_{\tau-1}, \quad \tau = t, \ldots, T$$

Examine L^*_τ for each $\Upsilon \in [t, \ldots, T]$

If $L^*_\tau > 0$ (transfer out)

and $L^*_\tau (c_\tau - \zeta_a) \geq K$

Combine L^*_τ and $L^*_{\tau+1}$

Such that: $L^*_{\tau+1}$ becomes $L^*_\tau + L^*_{\tau+1}$

and: L^*_τ becomes 0.

Similarly,

If $L^*_\tau < 0$ (transfer in),

and $-L^*_\tau (c_\tau - \zeta_a) \geq K$

Combine L^*_τ and $L^*_{\tau-1}$

Such that: $L^*_{\tau-1}$ becomes $L^*_\tau + L^*_{\tau-1}$

and: L^*_τ becomes 0.

The above model and heuristic to incorporate fixed costs were evaluated by comparison to upper and lower bounds after the distribution for the demand for funds from the account was determined. Determining this distribution necessitated the development of the forecasting component of the model.

Evaluation of the Cash Flows

A frequent assumption in the literature is that of independent, identically distributed cash flows into or out of the cash account (Girgis, 1968; Daellenbach and Archer, 1969; etc.) This was a model weakness perceived by the cash managers interviewed at the outset of this research, and this assumption was rejected by the cash manager with whom the project was undertaken. These managers all suggested that a credible and valid forecasting component that allowed for non-stationary demand was imperative for any useful cash management model.

Seven months of cash account balances, including both inflows and outflows of cash but excluding deposits or withdrawals by the manager, were examined. The objective of this examination was to attempt to determine the distribution of demand for funds in the account. In order to be able to forecast this demand, either the overall demand for cash would have to be estimated, or the inflow and outflow components estimated separately.

The first test was to determine if there was any change over time in any of the above parameters. Analysis of Variance (ANOVA) was used to test whether a significant difference in the means could be detected between months. The ANOVA for days proved insignificant at a significance level of 0.05 for receipts or disbursements. The results of this test are summarized in Table 7.1.

Table 7.1
ANOVA Results Between Months
Daily Receipt and Disbursement Data
For 7 Months

	F-Ratio	Significance
Receipts	2.14515	0.05195
Disbursements	0.18989	0.97924

The null hypothesis that the mean values by month did not differ, then, could not be rejected.

A scatter plot of the cash balance data for separate months, however, suggested that patterns existed within the months. At this point, the manager was consulted to determine if there were underlying accounting practices which could be exploited in the forecasting techniques. The company was in a stable environment, experiencing neither growth nor decline, and was not subject to seasonal variations in cash flow over time. The manager suggested that both billings and payments to creditors were performed according to a monthly routine. There was, however, some random variation as a result of postal delivery variations and variations in cheque clearing times. It was suggested that the account operated to a large extent on a four-period cycle, which could loosely be interpreted as the weeks within a month. A customer, for example, would typically have a cheque run at about the same time each month, so the receipt of these funds could reasonably be anticipated within a weekly period. The account data was then tested to determine if mean account activities could be estimated for four separate periods within each month. These groups were broken out for the seven months, using as the first seven calendar day period, the second, the third, and the remaining days of the month.

The ANOVA tests (Table 7.2) resulted in the rejection of the hypothesis that the mean receipt levels did not differ across groups, but the hypothesis that mean disbursement levels and, hence, demand levels did not differ could not be rejected at a significance level of 0.05. Subsequent ANOVA tests for days within the four groups did not lead to rejection of the hypothesis that receipts differed within these groups. These results are summarized in Table 7.3.

Table 7.2
ANOVA Results Between Groups
Daily Receipt and Disbursement Data
For 7 Months

	F-Ratio	Significance
Receipts by Groups	6.21600	0.00050
Disbursements by Groups	0.61400	0.60680
Demand by Groups	1.63600	0.18360

Table 7.3
ANOVA Results Between Days Within Groups
Daily Receipt and Disbursement Data
For 7 Months

	F-Ratio	Significance
GROUP 1:		
Receipts	1.52900	0.20810
Disbursements	0.74900	0.61600
Demand	0.55600	0.76080
GROUP 2:		
Receipts	0.39700	0.87450
Disbursements	2.54500	0.04290
Demand	2.39000	0.05440
GROUP 3:		
Receipts	1.74200	0.15100
Disbursements	1.64400	0.17500
Demand	0.98500	0.45550
GROUP 4:		
Receipts	0.79200	0.62570
Disbursements	1.17800	0.33920
Demand	0.65000	0.74710

Based on these results, a forecasting technique was selected which treated the four groups separately. There was no indication of trend or seasonality within the forecasts for each group, and therefore simple exponential smoothing models were used to estimate, and subsequently update, the means and standard deviations for each of the four groups. Four separate estimates of receipts and disbursements were prepared by this approach. The next step was to present these forecasts and explain the technique employed to the manager, in order to determine if the approach was considered acceptable. This determination of face validity by the cash manager was considered critical for the implementability of the model.

Computation of the sums of squares of the error terms for different values of the smoothing coefficient showed a minimum at 0.1. This final formulation can be expressed as:

Expected Mean Demand for group i (i=1,4) and day t,

$\hat{D}_{t,i}$:

$$\hat{D}_{t,i} = \alpha D_{t-1,i} + (1-\alpha)\hat{D}_{t-1,i} \qquad (7.8)$$

Expected Demand Variance for group i and day t,

$(\hat{S}_{t,i})^2$:

$$(\hat{S}_{t,i})^2 = \beta (D_{t,i} - X_{t,i})^2 + (1-\beta)(\hat{S}_{t-1,i})^2 \qquad (7.9)$$

Where: $D_{t,i}$ represents the demand for funds on day t, group i.

α and β are smoothing constants ($\alpha = \beta = 0.1$).

(For a full description of exponential smoothing techniques see Montgomery and Johnson, 1976).

Equations (7.8) and (7.9), evaluated through equation (7.7), ignoring fixed costs, resulted in a target opening balance for each of the four periods. The incorporation of the fixed costs through the heuristic resulted in a set of suggested account activity decisions for the modeled time horizon.

These decisions were then evaluated against the upper and lower bounds, providing a benchmark to determine the impact of the fixed costs and the decision rules. The decisions that this formulation provided were recommendations based upon the forecast cash flow data and the cost estimates. This result was only the first step in the evaluation of the model, for it was expected that the cash manager would change these decisions to accommodate the externalities of the problem environment. These activities were to be tested and evaluated in the final phase of model development - implementation and evaluation.

Chapter 8

The Integrated Model: Implementation and Evaluation

The cash manager began his planning process with accounting cash flow forecasts. Projected cash balances had to be calculated, and decisions were made to inject or withdraw cash to modify the projected balances. The costs of borrowing required funds and of investment opportunities were evaluated by hand, and total account costs for the period were determined. This process had to be repeated each time new information was received. The proposed cash management model, which was complete at this point, had to be evaluated in terms of its ability to support, improve, and facilitate the cash management function starting from this planning process.

The final presentation of the integrated model required introduction of only those aspects of the model which had been developed since the demonstration of the interaction component. The evaluation of the completed package, however, was the critical element of this project phase. Each separate element of the model had been examined in terms of its function, but the integration of these functions determined the model's usefulness to the cash manager.

Prior to final model presentation, each component of the model had been developed, tested, and discussed with the manager for whom it was to provide decision support. This final phase of the development process, then, was not a distinct implementation step. The decision maker was familiar with what was to be presented and sought to validate the model as a complete package rather than as pieces designed to meet specified design criteria. The new characteristics of the model to be evaluated included such aspects as response time on changing an account activity, the effectiveness of interactions with the model in an actual problem situation, and the usefulness of the model in supporting the cash management function.

For this final presentation, seven months of actual data were retained in the model and two months of forecast data were calculated. The manager was asked to evaluate the package, and to consider the appropriateness of using the decision set that the model had recommended as a starting point for decision planning.

At the final presentation, the manager's first activities were to again familiarize himself with the model's functions. Included in this test was his observation of the model's new ability to update the displays when he modified the cash activities in the account. The final screens provided by the model are illustrated in Exhibits 3 and 4.

After verifying that the model could perform the functions that had been previously discussed, the manager turned from verification to a process of validation and evaluation. First, the forecasts were examined without the model's decisions imposed upon them. The manager was familiar with the approach employed to derive these forecasts, and determined that they offered a reasonable expectation of account activities for the next two months. The account data was then loaded with the model's decision recommendations. The graphic displays were used to help explain in detail the algorithms used to make these decisions. The fixed cost hurdles for the heuristic had been estimated from actual costs including a long distance telephone call for each transfer and appropriate bank charges. The manager noticed that the model made transfers for amounts smaller than those he would normally make, so the appropriateness of this fixed cost calculation was discussed. The implicit value of the manager's time and the inconvenience of frequently contacting head office for smaller than usual transfers made the cost estimate, he suggested, inappropriate. To determine the costs levied against the account, however, these costs were accurate.

EXHIBIT 4

THE FINAL MODEL'S SCREEN

(SHOWING ACCOUNT BALANCES GRAPHIC WINDOW)

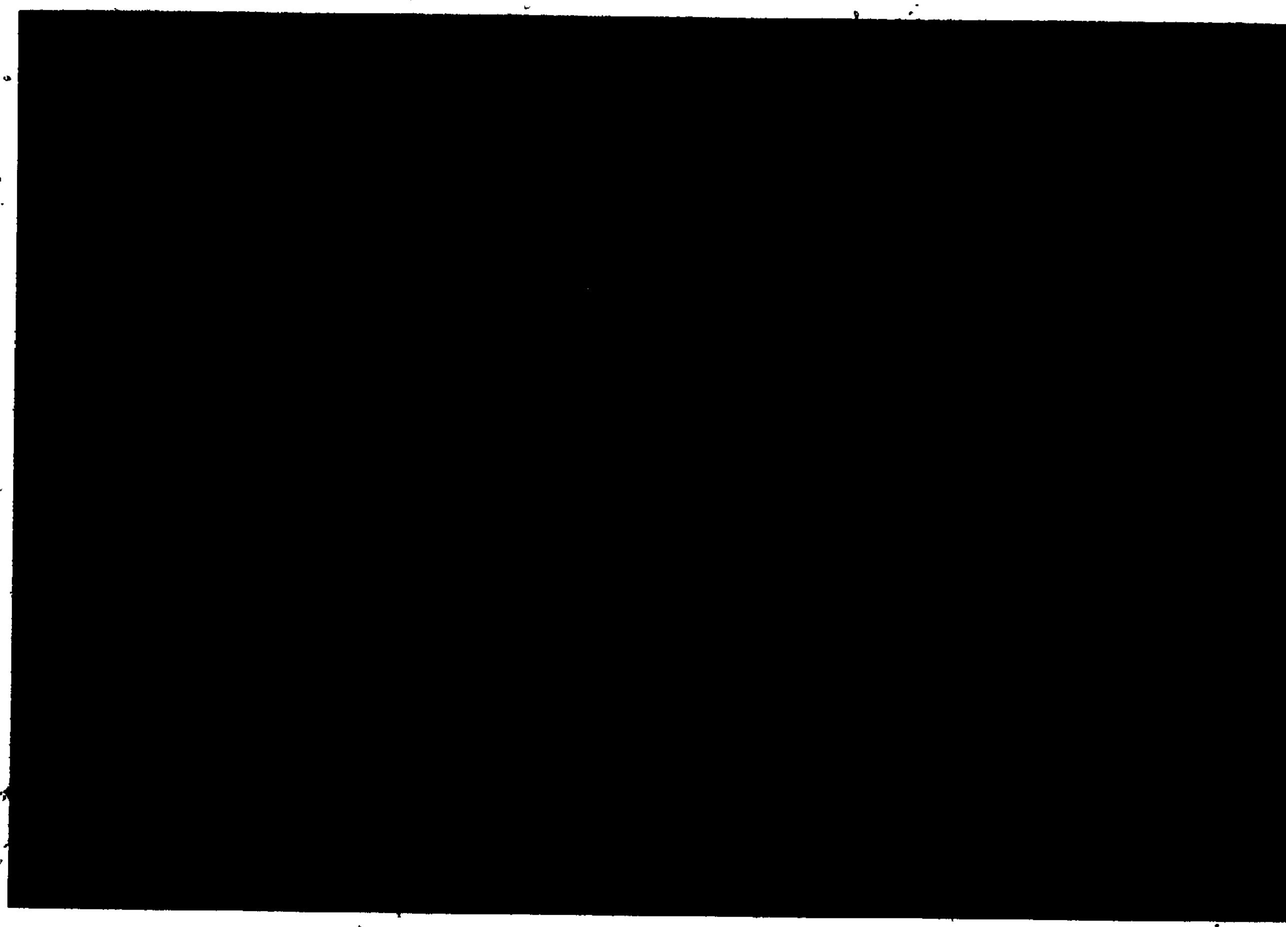
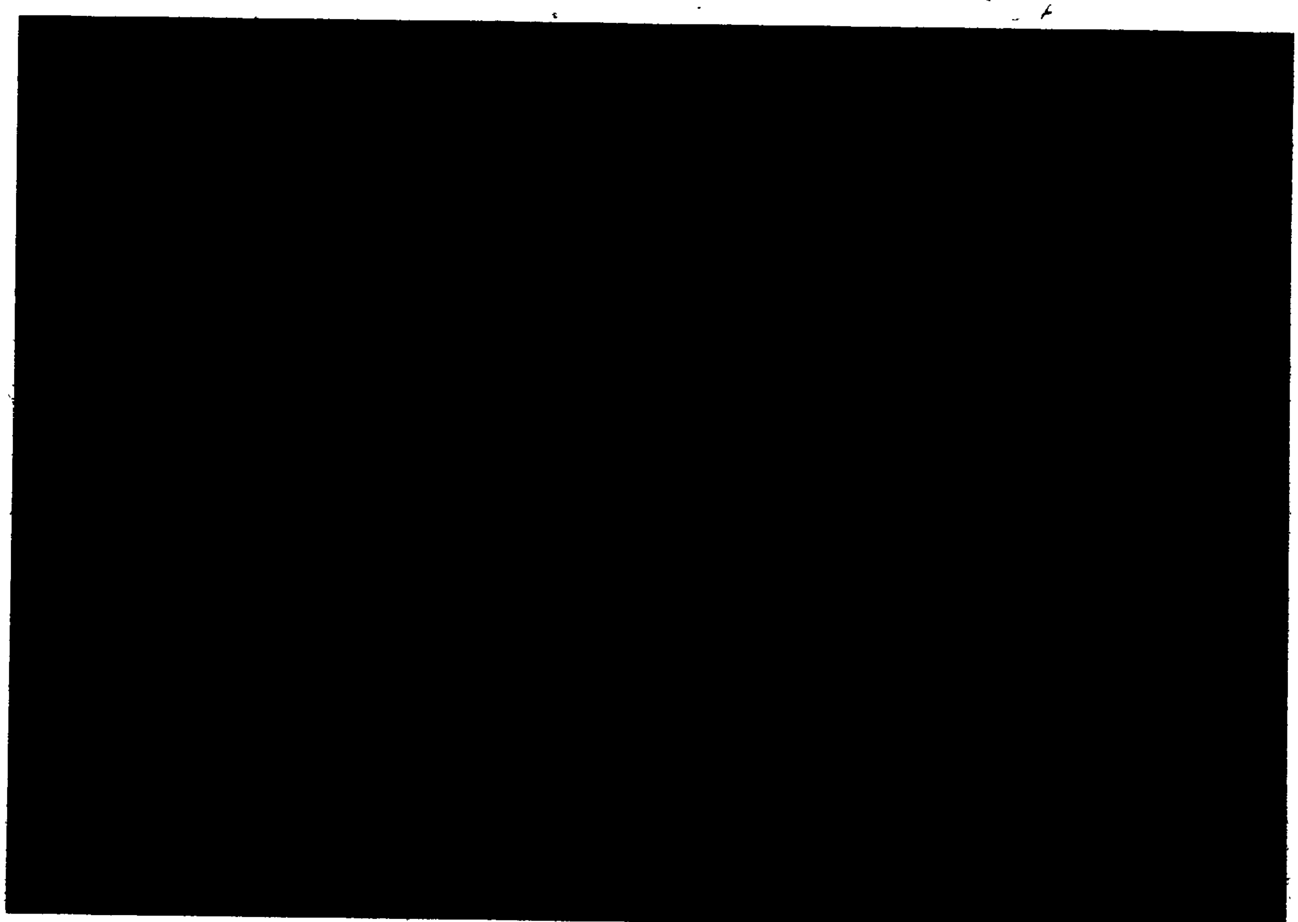


EXHIBIT 5

THE FINAL MODEL'S SCREEN

(SHOWING CASH INFLOWS AND OUTFLOWS GRAPHIC WINDOW)



To resolve this problem and provide what the manager felt was a more reasonable starting point, the hurdle rate considered by the heuristic outlined in Chapter 7 was changed, while the cost calculation remained at its original amount. The fixed cost of a transfer was approximately $5 in Canadian funds, but the manager suggested that: "I would only transfer funds into or out of the account if it could save me $100 or more..." As a result, the final cost in the heuristic was raised to $100.

The result of this change to the fixed cost hurdle for the heuristic reduced the number of transfers over the seven month evaluation period from an average of 16.43 per month to 2.43, which more closely approximated past activities. After installing this new parameter into the model, the manager could see the effect on the projected account costs, and determine if these costs merited the change in the model's policies. He determined that the cost change was insignificant, and the new parameters were adopted into the model. Additionally, as had been expected, the decisions over the immediate term (a one to two week horizon), with which the manager was intimately familiar, were modified somewhat to accommodate various options and activities that were not considered by the model, such as anticipated reductions in raw material costs leading to a larger than usual purchase of these materials.

The model, through its displays of projected account costs, quantified the cost of a decision policy change. This quantification was a major element of the model's unique information provision to the manager. If, for example, a decision maker were risk averse and sought a series of decisions to accommodate these risk preferences, the cost of deviating from an expected value solution was prominently displayed to him. Also, a change in expected costs to deal with the external elements of the problem environment were quantified through this mechanism. The combination of these external characteristics of the decision environment made up the expected difference between the model's unaltered decision set and the series of decisions arrived at after the cash manager's interactions.

The activity of modifying the decision set to derive an acceptable series of decisions took less than half an hour, in contrast to the manual process that took approximately one morning per week, and the manager was prepared to utilize these decisions for the short term planning process. With this package, the manager would be able to modify these decisions on a daily basis as new account information became available, and to automatically print these results in a modified decision report. The package was efficient in that it could automatically provide such features as report preparation, but the major objective was an increase in the effectiveness of the decisions arrived at. Efforts were therefore made to evaluate the decisions arising through use of the model versus the manual decisions.

Evaluation of the Model Against Manual Policies

To test the model's ability to provide effective cash management decisions, two operational tests were carried out. In the first test, a forecast for the seven months for which data had been obtained was made and total account costs calculated as if the model's recommended decisions had been implemented without modification (i.e. a seven month static projection). This tested the model's ability to project over a longer time period than the manager had been considering, and provided an estimate of costs for longer term planning support. (In practice, however, decisions are modified daily as new information is received.)

The second test started the model from the first test's forecast and planning position with updating. The model would receive daily actual account activities and iteratively update the decision set from the next day forward given this new information. This test simulated the actual cash management decision procedures, and provided an effectiveness measure for the model.

The results of these tests are summarized in Table 8.1, and the outcome of each individual day's activities are provided in Appendix 1.

Table 8.1
Account Costs:
Actual Cost Data
Against the Two Test Policies

MONTH	ACTUAL ACCOUNT COSTS	TEST 1 ACCOUNT COSTS	TEST 2 ACCOUNT COSTS
January	$-6232.76	$-6856.93	$-2182.97
February	-2686.34	-3036.86	-1508.10
March	2008.52	664.20	-1727.88
April	2709.42	1838.23	-1628.61
May	-1856.28	1519.48	-1669.87
June	-2509.97	- 310.66	-1671.33
July	1122.02	875.57	-1492.91
Totals	$-7445.39	$-5306.97	$-11881.67

As a measure of the heuristic, an optimal solution was determined assuming zero fixed costs for Test 1. This solution was determined by adjusting the opening balance to its optimal level each day. For this evaluation, both upper and lower bounds (calculated as an upper bound where transfers would be made every day with fixed costs being incurred, and the zero-fixed-cost lower bound) were determined. These bounds were revenues of $5151.90 and $5891.90 respectively, to be compared with the model's solution revenues of $5306.97. The model's solution represents a deviation from the optimum solution assuming zero fixed costs of $584.93 over a seven month period, or an average of $83.56 per month. This solution was 103.0 percent of the lower bound and, as a relative measure, is 20.96 percent of the distance above the lower bound toward the upper bound.

Bell and Hamidi-Noori (1984) solved a similar problem using a discretized approximation that had been solved using Dynamic Programming. This approach could have lead to a cost improvement over the heuristic results, but programming and computation time would have increased significantly. The potential cost improvement of such an optimization routine is difficult to determine since the cost differences would include both fixed transfer costs based on the optimal number of transfers and variable costs levied against the account at, possibly, balances which differed from those determined in the model. The heuristic solution, however, managed to absorb fixed costs of $82.14 per month on average, which were not considered in the lower bound solution, but remained within $83.56 per month on average of this solution. As a measure of the heuristic's effectiveness, the increased variable account costs, then, represent only an average of $1.42 per month over the lower bound (from the optimal solution with zero fixed costs).

The final test of the package was an evaluation of its usefulness to the cash manager. The focus of this research was on the effectiveness of the proposed model building approach for VI modeling to support a complex decision environment. Cost/benefit analysis of the hardware and software was not an issue to be explored in this thesis so software and hardware was selected to allow maximum programming flexibility to develop the model. To provide a more reasonable framework for the manager to evaluate the package, he was informed that the final model could be rewritten in a high level programming language rather than using the VI modeling software employed. Additionally, it could be loaded onto a less expensive microcomputer such as an IBM Corporation's Personal Computer XT or Personal Computer AT. The cash manager agreed that the model would be of enough benefit to merit his acquisition of the graphics monitor, card, and software for such a microcomputer installation, and that under these circumstances he would use the model. Further, he kept the forecasts generated from the model for the four months remaining in the year to aid in his manual planning process.

The Model's Support of the Cash Management Function

The cash management problem, as it appears in the literature, involves the optimization of some objective function, such as the minimization of operating costs levied against the cash account or the maximization of return on investment on a short-term portfolio withdrawn from the account. The model employed in this application sought initially to follow this objective, but it had been found (Bell and Newson, 1982) that the cash management function includes complexities that had not been incorporated into existing models (or into the formal model outlined in Chapter 7). The formal model, however, provided an initial series of account activity decisions for the cash manager to work from, and allowed incorporation of the softer system aspects of the problem through user-friendly interaction and communication elements. If, for example, funds must remain in the account for a known cash-on-delivery order the model sought to invest these funds, but can be overriden by managerial intervention. Once the manager has modified a day's decisions using this package, it would not reverse that modification, but sought to optimize the decision horizon from the next day forward.

In addition, the change in expected costs of deviating from a model-recommended solution was immediately displayed through the account statistics display window. Should, for example, the cash manager choose to reduce risk levels for a particular period or periods by moving cash into the account for a particular time period, the model would highlight the new expected costs charged against the account and thereby illustrate the cost of this reduced risk position.

Additional constraints could have been included in the model to accommodate the externalities of the cash management problem, but there is a tradeoff between model complexity and its marginal utility. If a facility were built into the model to interactively add constraints as they were identified, programming complexity would have increased considerably and response time for a microcomputer application could have become unacceptable. Additionally, these constraints tended to be structured to the extent that the cash manager could easily deal with them without integrating them into the model. The required support was the ability to change the model's decisions to accommodate the actions required by these externalities.

Computing resources were a major consideration throughout this model building approach. Microcomputer technology was employed exclusively, and response time was an important factor for interactions between the computer and the decision maker. The completed model had a batch operation to initially develop the forecasts, and could then be used interactively. The first test outlined in Chapter 7, the seven month test with daily updating, for example, required more than one hour to compute with a Sage IV microcomputer equipped with 1 megabyte (Mb) of random access memory (RAM) and a 12 Mb hard disk. This test required 161 individual iterations of the interaction employed by the cash manager to change a decision set. The cash manager, however, works on a one-month horizon in his day-to-day decision making which could be run by this package each time in a few seconds.

Had the decisions selected by the model in the second test been implemented over the seven month horizon, operating costs would have been reduced from the manual decision outcomes by $4436.28, but this is a somewhat artificial saving. As was outlined in Chapter 2, there are many externalities in the cash management problem which this model, by design, ignored in arriving at its recommended decision set. The manager pointed out several situations in the scenario outlined by this decision set which would have been unacceptable in practice. It was agreed, however, that the information provided to the manager by the model would speed up decision making and lead to an intermediate solution between that portrayed by the model and that arrived at by the manager using his manual procedures -- that is: operating costs, as incurred with the use of the model, would decrease.

Chapter 9

Summary and Conclusions

This thesis emerged from the confluence of two research streams. Visual interactive (VI) modeling has been a major new research area within Operational Research (OR) since 1976 (Hurrion, 1976). The distinction and unique advantages of this problem-solving process over other OR approaches has, however, remained somewhat obscure. Computer graphics in general have proved a difficult research area to develop specific contributions and generalizations (Ives, 1982), but have remained a major research area for OR (Bowen et al, 1979; Fiddy et al, 1981; Hurrion, 1978, 1980, 1981; Parker and Bell, 1983; Withers and Hurrion, 1982) and DSS (Beagley, 1984; Canning, 1982; Cooper, 1984; Editorial Staff, Canadian Data Systems, 1981; Ives, 1982; Keen, 1981; Kelley, 1980; McEwan, 1981; McLenning, 1983; Watson and Driver, 1983). Major successes have been realized utilizing VI modeling (Lyons, 1983; Kaufman and Hanani, 1981; Hollocks, 1981; Hurrion, 1978; Hurrion, 1980), but each application was a "one-off" project which made little attempt to generalize a development or problem solving approach. This apparent vacancy in the literature provided an opportunity to synthesize the successes of past endeavors into a generalizable problem solving approach. Discussions with

VI modeling practitioners cited a strength of VI modeling as the ability to aid in the analysis of complex and difficult to define problems (Kaufman and Hanani, 1981; Hurrion, 1976; Fiddy et al, 1981; Lyons, 1983). This thesis describes a modeling exercise utilizing a predefined, novel problem solving approach building upon these experiences.

The second research stream, cash management, has proved a complex and difficult modeling area for OR researchers, and even more complex to implement. Very few reported implementations exist in the literature (Bell and Newson, 1982; Daellenbach, 1975), and the cash managers and banking experts interviewed reported few algorithmic approaches to the problem in practice.

After consideration of the cash management problem and the major issues within it, a VI modeling approach was proposed. Interviews were made with several practitioners who expressed interest in the proposed approach and suggested that they would be willing to implement a decision support technique if one could be found to support a realistic definition of the cash management problem. It was with this objective that this thesis was then proposed. A practising cash manager was found with a sufficiently complex problem to offer a realistic problem to address and who had sufficient interest in the process to offer his time and supply confidential data.

The visual interactive problem solving (VIPS) approach, as outlined by Bell (1984) is time consuming, but promised to develop an implementable model which could realistically support the decision process under study. The first step of this thesis was to develop a formal problem solving approach which exploited the unique nature of VI modeling. This approach, as outlined in Chapter 2, requires the development of mocked-up graphical solutions through interactive problem definition between manager and analyst as the first step, and thereby seeks to structure the steps which remain. This is a deviation from a more classical OR problem solving approach, such as that outlined by Wagner (1969), where problem definition and model building are the first two distinct steps. Checkland (1981) outlines a "Soft Systems Approach," where the definition of the problem it itself part of the process. The approach outlined in this thesis follows Checkland's philosophy closely, but differs in that its first goal is to delineate and, hence, structure the problem and subsequently develop models to support the decision maker. Interactions with the decision maker after this first step are for validation and fine-tuning of a problem which has been agreed upon by both problem owner and analyst. After this first step, the problem to be addressed is more clearly defined than the approach outlined by Checkland. This procedure, then, is similar to a prototyping approach where a subset of the final model is tested prior to full model development (Naumann and Jenkins, 1982; Dennis and Burns, 1984).

The resulting model differed somewhat from the ex ante expectations of the modeler, and expanded upon models in the literature. The algorithms employed were novel from those in the literature, although the defined objective function was similar. A major contribution of the package, however, was its ability to derive an implementable solution through interaction with the cash manager. The model differs from inventory approaches through its consideration of the problem as a process rather than as a stock problem, and from other models through its incorporation of complexities encountered by the practising cash manager, such as the issue of fixed costs. The major difference of the VIM from other cash management models was its interactive component with the cash manager. A cost saving could be determined from the results derived and presented in Chapter 8, but the reality of the cash management problem could not facilitate implementation of these decisions without modification to consider the externalities and contingencies encountered on a dynamic basis. A model, then, which offers utility to the practising cash manager must be dynamic and flexible. This flexibility has been attained through an interactive model, and the rapid communication required of the process through dynamic graphs which are linked to that model.

Generalizability

There are three distinct aspects to the generalizability of this research. They involve the methodology applied to other modeling endeavors, other firm's cash management applications, and the hardware and software employed.

The main focus of this thesis was the proposal and implementation of a generalizable VIPS approach. The approach was developed in isolation from the cash management modeling task, and could serve as a starting point for a modeler intending to utilize VI modeling. The approach outlined in this thesis integrates the identification of basic information requirements into the overall process, and incorporates a modular approach. The problem is divided into outputs, interactions, algorithms, and data collection routines, and then developed in a predefined, "solutions-first," structure. This development approach requires the use of graphical outputs from the model to communicate exactly what the model will be expected to do. Through this interaction, the formal modeling process remains the task of the analyst, but the underlying processes and assumptions are agreed upon by both analyst and decision maker prior to model development. This process is not, however, restricted to cash management applications.

The model resulting from this problem analysis had several unique characteristics, such as the forecasting routines employed and the form of the cost functions. Additionally, it included the idea of management of an ACB requirement, which few applications in the literature have addressed. In order to generalize this model to another firm's specific cash management problem certain phases of the model building approach would have to be repeated. The final graphics displays would provide input for the first phase, and the algorithms modified to accommodate new screen features or the data from the new firm. This would not prove an onerous task, but each company could be expected to have unique banking and credit arrangements. New forecasting routines could be developed to estimate the moments of the daily cash flows, and the symmetry of cost functions could be replaced with a three-policy Dynamic Programming formulation such as that derived by Hamidi-Noori and Bell (1984).

This application was developed using OPTIK 1, a state-of-the-art software package developed by Insight International, Ltd. in the United Kingdom. This package offers the flexibility to develop an integrated VIM in a modular format, so that elements can be readily changed as the model is being constructed. Current applications require that an ISC Intecolor 8052 (Intelligent Systems Corp., U.S.A.) graphics terminal be used and a SAGE IV or equivalent microcomputer (STRIDE Corporation, U.S.A.) at a combined cost of approximately $20,000, excluding software costs. OPTIK has recently been announced for an IBM Personal Computer AT, which eliminates the need for the separate graphics terminal, and reduces these costs by approximately $10,000. To implement this model, however, more cost-beneficial microcomputer equipment could be employed without a generalized VI modeling software package. This software package proved an excellent prototyping tool to allow the modeler to rapidly develop graphic displays and models in a modular format. Once the prototype has been deemed valuable for the decision maker, the derived package can relatively easily be rewritten for a less expensive, but more complex to program, microcomputer without the generalized software package. The graphics displays, for example, can be written using FORTRAN or BASIC subroutine calls, and the models linked to these subroutines through the selected high level language.

The next phase of an ongoing research program will be the development of an IBM PC, or comparable, application written in a high level programming language. The completed package from this subsequent project will then have applicability for smaller firms for cash management.

Future Research Issues

This thesis focused on the development and testing of a novel methodology for building VIMs. The test site for this research was a medium-sized Canadian manufacturing and wholesaling corporation. Opportunities for future research from this thesis are in three major areas: the problem which was addressed, the model building methodology, and the technology employed.

The Cash Management Problem

Many formulations of some form of a cash management problem are offered in the literature, but the problem encountered at the research site differed in several aspects. The cost structures had a form which allowed a novel formulation due, to a large extent, to the symmetry of some of the variable costs in the problem. Further research will involve consideration of the differences between this formulation and others which have been examined, and of alternative models to deal with this particular formulation. Additionally, other companies will offer cost structures which differ from the one outlined in this thesis, and the nature of these differences will be examined to evaluate the appropriateness of the form of model derived in this work against others in the literature.

Visual Interactive Modeling

The methodology developed in this thesis shows promise for the future development of VIMs. It required the involvement of the decision maker early on in the problem solving process, and offered an alternative to current model building paradigms such as those outlined by Buzacott (1982). This approach requires that the problem-owner participate in every phase of the problem definition - modeling - validating - implementing process, and used computer graphics as a communication vehicle for these interactions. VI modeling has been developed largely through OR academics and practitioners, but the objective of providing decision support for a complex problem environment has been an objective of both OR and DSS. The integration of techniques developed through the DSS research area offers significant support for OR problems (Parker, 1983) and promise for future VI modeling projects.

Current. VI modeling practice focuses on the building of iconic graphic models. A major new development area in this field is the application of VIMs in complex problem situations which can be graphically represented logically rather then physically. Notable areas include other financial analysis, such as portfolio management extending from the work of Gerrity (1971), or corporate "what if..." modeling such as the impact of potential takeover bids. With continually improving technology and theory in related areas, such as database and model base management systems, the notion of a generalized interactive graphic corporate model is becoming realizable. This kind of facility would allow top level executives to interactively pose possible scenarios to a graphics-based modeling system, and experiment with high-level decision alternatives.

Additionally, corporate simulations are used in many North American business schools. The promise of adding a VI modeling capability to such a simulation suggests two major research questions. First, further evaluation of the effectiveness of VIMs could be undertaken in an experimental mode, where teams with identical problems could be provided with different decision support systems. Lucas (1980) and Lucas and Nielson (1981), for example, developed an experiment to evaluate batch, interactive, and graphic information presentation. Utilizing the problem solving methodology outlined in this thesis, an interactive graphic mode could be included in this type of analysis to attempt to overcome the research difficulties outlined by Ives (1982). Ives outlined computer graphics as a data summarization vehicle, but new opportunities are available to utilize and evaluate computer graphics as a powerful modeling tool.

The second research question involves the development of more non-iconic VIMs using this model building methodology. This research would serve to expand the area of VI modeling and to aid in the formalization of an approach to deal with the problems of evaluation.

Technology

Most of the VI modeling technology available today requires expensive, special purpose hardware and software. New product offerings, such as Commodore Business Machine's new Amiga microcomputer, offer high resolution graphics and routines integrated into their operating systems for the price of a personal computer. These systems, which offer more computing power and primary storage capacity than many minicomputers, present an opportunity to develop cost effective VIMs in new problem areas. In addition to hardware developments, software products such as Symphony (Lotus Development Corporation) allow the development of some interactive graphic models without additional special purpose graphics software.

Major areas for future research and development utilizing this approach, then, are: the evaluation of the differences between the algorithms developed utilizing this approach as opposed to a more traditional OR modeling endeavor, the utility of the graphics to provide better, more confident, and/or faster decisions on the part of the manager involved, and the ability to develop less expensive VIMs. These areas will require significant effort and time to develop, but computer graphics remain prevalent in business and the area remains a fruitful one for Operational Researchers.

Development and evaluation of models employing computer graphics remains an extremely complex issue. Improving methodologies to develop and use graphics, improving software, improving technology, and continually declining costs per unit of computing power are major factors which alter the basis from which to make evaluations. The industry, it appears, will continue to develop, and new opportunities will continue to exist to implement and evaluate cost-effective VI modeling applications for managerial decision support.

APPENDIX 1

SEVEN MONTH RESULTS:

1: ACTUAL ACCOUNT COSTS

2: TEST 1 RESULTS:
SEVEN MONTH PROJECTION

3: TEST 2 RESULTS
DAY-BY-DAY PROJECTIONS

1: ACTUAL CHARGES (+) AND REVENUES (-)

LEVIED AGAINST THE ACCOUNT

JANUARY ACTUAL RESULTS:

DAY	ACTUAL OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACTUAL ACCOUNT COSTS
3	220157.22	0.00	0.00	-211.12
4	802690.00	0.00	0.00	-277.94
5	1047265.88	0.00	0.00	-354.67
6	1328076.50	0.00	0.00	-380.47
9	1422519.00	0.00	0.00	-384.09
10	1435785.25	0.00	0.00	-290.15
11	1091961.75	0.00	0.00	-277.44
12	1045436.25	0.00	0.00	-217.40
13	825702.25	0.00	0.00	-231.42
16	877014.25	0.00	0.00	-319.78
17	1200397.00	0.00	0.00	-259.40
18	979406.88	0.00	0.00	-261.05
19	985448.38	0.00	0.00	-423.85
20	1581276.25	0.00	0.00	-447.99
23	1669650.25	0.00	0.00	-474.61
24	1767081.00	0.00	0.00	-269.01
25	1014587.50	0.00	0.00	-246.80
26	933294.75	0.00	0.00	-195.45
27	745341.75	0.00	0.00	-227.79
30	863707.00	0.00	510009.31	-231.06
31	875670.13	0.00	0.00	-251.25

TOTAL ACTUAL COSTS= -6232.76

FEBRUARY ACTUAL RESULTS:

DAY	ACTUAL OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACTUAL ACCOUNT COSTS
1	949573.75	0.00	0.00	-240.76
2	911185.25	0.00	0.00	-215.80
3	819812.50	0.00	0.00	-267.85
6	1010340.88	0.00	0.00	-293.84
7	1105458.50	0.00	0.00	-296.54
8	1115326.25	0.00	0.00	-287.94
9	1083872.25	0.00	0.00	-157.33
10	605823.13	0.00	0.00	-179.18
13	685813.00	0.00	0.00	-200.76
14	764785.13	0.00	0.00	-108.34
15	426520.31	0.00	0.00	-100.96
16	399516.56	0.00	0.00	-75.17
17	305116.50	0.00	0.00	-142.79
20	552613.25	0.00	0.00	-260.13
21	982077.13	0.00	0.00	-25.23
22	122346.25	0.00	0.00	-65.51
23	269749.50	0.00	0.00	161.87
24	-247225.38	0.00	2042.19	111.47
27	-166150.16	0.00	0.00	87.14
28	-127008.36	0.00	0.00	-68.77
29	281690.94	0.00	0.00	-59.92

TOTAL ACTUAL COSTS= -2686.34

MARCH ACTUAL RESULTS:

DAY	ACTUAL OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACTUAL ACCOUNT COSTS
1	249315.59	0.00	200000.00	192.77
2	-296937.50	0.00	0.00	109.81
5	-163479.34	0.00	5601.86	-50.44
6	214597.50	0.00	3.50	-28.91
7	135824.84	0.00	0.00	-14.59
8	83408.47	0.00	0.00	192.77
9	-296933.75	0.00	0.00	120.35
12	-180432.28	0.00	0.00	15.31
13	-11439.02	0.00	0.00	166.86
14	-255258.47	0.00	0.00	144.84
15	-219826.69	0.00	0.00	200.91
16	-310036.69	0.00	0.00	-0.50
19	31835.37	0.00	0.00	-75.33
20	305726.00	0.00	0.00	176.17
21	-270241.38	0.00	0.00	-26.64
22	127509.16	0.00	0.00	236.12
23	-366686.50	254920.00	0.00	7.61
26	2143.81	0.00	0.00	-28.33
27	133689.91	0.00	0.00	200.92
28	-310053.81	0.00	0.00	206.36
29	-318805.63	0.00	0.00	257.40
30	-400919.38	318925.00	0.80	5.07

TOTAL ACTUAL COSTS= 2008.52

APRIL ACTUAL RESULTS:

DAY	ACTUAL OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACTUAL ACCOUNT COSTS
2	11458.58	0.00	0.00	-146.66
3	566767.75	0.00	0.00	-166.41
4	639047.00	0.00	0.00	-170.62
5	654464.88	0.00	0.00	-6.18
6	52626.01	0.00	0.00	-13.32
9	78742.22	0.00	0.00	-57.48
10	240380.34	0.00	0.00	381.23
11	-600129.88	0.00	0.00	346.35
12	-544015.38	0.00	0.00	521.47
13	-825747.00	0.00	0.00	339.76
16	-533419.25	0.00	0.00	160.89
17	-245643.59	0.00	0.00	280.69
18	-438377.06	0.00	0.00	230.96
19	-358386.31	0.00	0.00	246.35
23	-383141.19	0.00	0.00	211.67
24	-327344.00	0.00	0.00	105.58
25	-156675.63	0.00	0.00	92.96
26	-136366.59	0.00	0.00	217.11
27	-336091.00	386.25	0.00	151.33
30	-230265.41	0.00	0.00	-16.25

TOTAL ACTUAL COSTS= 2709.42

MAY ACTUAL RESULTS:

DAY	ACTUAL OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACTUAL ACCOUNT COSTS
1	89463.36	0.00	0.00	-80.58
2	324926.94	0.00	0.00	-173.83
3	666234.13	0.00	0.00	-1.67
4	36109.81	645400.00	0.00	-234.24
7	887304.25	0.00	0.00	-288.65
8	1086449.00	0.00	3003.00	-125.62
9	489751.75	0.00	0.00	-105.11
10	414702.63	0.00	0.00	-26.21
11	125935.97	0.00	0.00	-70.00
14	286201.38	0.00	0.00	-95.58
15	379812.44	0.00	0.00	153.47
16	-233720.69	0.00	0.00	-32.94
17	150571.88	0.00	0.00	-111.02
18	436323.50	0.00	0.00	-152.34
22	587567.13	0.00	300000.00	-118.01
23	461932.50	0.00	0.00	-38.44
24	170680.47	0.00	0.00	4.17
25	14748.20	2524.13	0.00	-35.76
28	160897.16	0.00	0.00	-84.55
29	339459.44	0.00	0.00	-105.93
30	417706.75	0.00	0.00	-123.78
31	483030.94	0.00	0.00	-9.66

TOTAL ACTUAL COSTS= -1856.28

JUNE ACTUAL RESULTS:

DAY	ACTUAL OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACTUAL ACCOUNT COSTS
1	65346.44	0.00	0.00	-44.88
4	194267.97	0.00	0.00	-68.72
5	281523.00	0.00	500.00	-120.62
6	471458.88	0.00	0.00	-60.96
7	253105.88	3.00	0.00	-49.31
8	210483.72	0.00	0.00	-67.22
11	276036.38	0.00	0.00	-97.48
12	386791.38	454860.00	0.00	-6.82
13	54947.36	0.00	0.00	-6.54
14	53947.36	0.00	0.00	24.82
15	-26749.01	0.00	0.00	-84.19
18	338145.69	0.00	0.00	-171.91
19	659201.13	0.00	0.00	-184.82
20	706456.13	305547.00	0.00	-296.22
21	1114182.50	0.00	0.00	-334.63
22	1254756.00	0.00	27.23	-427.80
25	1595741.00	0.00	0.00	-442.44
26	1649335.75	0.00	800000.00	46.55
27	-61698.62	157236.00	-0.00	-6.03
28	52068.93	0.00	0.00	-29.96
29	139664.72	358.73	0.00	-80.76

TOTAL ACTUAL COSTS= -2509.97

JULY ACTUAL RESULTS:

DAY	ACTUAL OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACTUAL ACCOUNT COSTS
3	325587.06	0.00	0.00	-164.86
4	633397.38	0.00	0.00	-215.06
5	817102.13	0.00	0.00	-30.02
6	139879.25	0.00	0.00	-59.55
9	247963.75	0.00	0.00	-110.09
10	432932.00	0.00	0.00	82.25
11	119136.06	0.00	0.00	2.67
12	20219.99	0.00	0.00	24.97
13	-26982.01	0.00	0.00	-36.91
16	165106.94	0.00	0.00	-151.97
17	586220.88	0.00	0.00	376.05
18	-591800.88	0.00	0.00	330.67
19	-518791.94	0.00	0.00	429.99
20	-678570.25	140000.00	0.00	283.57
23	-443011.13	36380.00	0.00	73.07
24	-104361.88	0.00	0.00	478.08
25	-755940.25	0.00	0.00	472.75
26	-747366.75	0.00	0.00	-125.31
27	488644.44	0.00	0.00	-179.42
30	686664.88	0.00	0.00	-179.42
31	686664.88	0.00	0.00	-179.42

TOTAL ACTUAL COSTS= 1122.02

2: SEVEN MONTH PROJECTION RESULTS

JANUARY TEST 1 RESULTS:

DAY	EXPECTED OPENING BALANCE	DEPOSITS	WITHDRAWALS	EXPECTED ACCOUNT COSTS
3	220157.22	76035.77	0.00	-33.39
4	878725.88	0.00	582532.88	-228.36
5	540768.75	0.00	244575.88	-310.22
6	577003.63	0.00	280810.63	-404.21
9	390635.50	0.00	0.00	-416.23
10	403901.75	0.00	0.00	-420.54
11	60078.30	345332.50	0.00	-300.44
12	358885.13	0.00	0.00	-290.17
13	139151.16	219734.03	0.00	-211.62
16	410197.25	0.00	0.00	-247.54
17	733579.88	0.00	335941.44	-350.79
18	176648.47	220990.13	0.00	-276.83
19	403680.00	0.00	0.00	-283.85
20	999508.00	0.00	601869.50	-478.27
23	486012.50	0.00	105456.25	-529.61
24	477987.06	0.00	97430.75	-562.22
25	-371937.31	833786.38	0.00	-309.80
26	380556.25	0.00	0.00	-288.15
27	192603.34	187953.00	0.00	-220.25
30	498921.50	0.00	118365.25	-259.86
31	902528.75	0.00	521972.50	-434.57

TOTAL EXPECTED TEST 1 COSTS = -6856.93
COMPARED TO A LOWER BOUND OF: -6933.23
AND AN UPPER BOUND OF: -6828.23

FEBRUARY TEST 1 RESULTS:

DAY	EXPECTED OPENING BALANCE	DEPOSITS	WITHDRAWALS	EXPECTED ACCOUNT COSTS
1	949573.75	0.00	614992.25	-277.33
2	296193.00	0.00	0.00	-269.68
3	204820.28	91372.75	0.00	-234.09
6	486721.44	0.00	190528.38	-297.86
7	391310.63	0.00	95117.63	-329.70
8	306060.75	84278.50	0.00	-308.42
9	358885.25	0.00	0.00	-303.03
10	-119163.80	478049.19	0.00	-138.03
13	438875.19	0.00	0.00	-168.95
14	517847.38	0.00	158962.00	-191.23
15	20620.55	404021.88	0.00	-91.70
16	397638.63	0.00	0.00	-87.74
17	303238.56	94400.05	0.00	-51.14
20	645135.38	0.00	247496.75	-133.98
21	827102.50	0.00	429463.88	-277.72
22	-462092.31	842648.63	0.00	-11.73
23	527959.63	0.00	147403.25	-61.07
24	-136418.50	516974.88	0.00	111.97
27	463673.75	0.00	83117.50	84.15
28	419698.06	0.00	0.00	66.18
29	828397.38	0.00	447841.00	-65.75

TOTAL EXPECTED TEST 1 COSTS =	-3036.86
COMPARED TO A LOWER BOUND OF:	-3118.26
AND AN UPPER BOUND OF:	-3013.26

MARCH TEST 1 RESULTS:

DAY	EXPECTED OPENING BALANCE	DEPOSITS	WITHDRAWALS	EXPECTED ACCOUNT COSTS
1	249315.59	46877.41	0.00	-43.15
2	-50060.09	346253.00	0.00	72.74
5	429651.13	0.00	133458.16	28.07
6	679871.63	0.00	304909.50	-99.55
7	296192.94	0.00	0.00	-78.98
8	243776.56	115108.69	0.00	-31.99
9	-21456.90	380342.13	0.00	95.31
12	475386.63	0.00	116501.44	56.32
13	527878.38	0.00	168993.19	-0.25
14	115065.84	247140.88	0.00	81.36
15	397638.50	0.00	0.00	50.74
16	307428.50	90210.05	0.00	85.93
19	739510.50	0.00	341872.00	-28.49
20	671529.13	0.00	273890.69	-120.16
21	-178328.88	575967.25	0.00	72.61
22	795388.88	0.00	414832.69	-82.27
23	-113639.42	494195.63	0.00	83.13
26	494466.44	0.00	113910.30	45.01
27	512102.25	0.00	131546.13	0.98
28	-63187.57	452495.50	0.00	149.51
29	380556.19	0.00	0.00	147.43
30	298442.44	82113.75	0.00	179.91

TOTAL EXPECTED TEST 1 COSTS = 664.20
COMPARED TO A LOWER BOUND OF: 568.40
AND AN UPPER BOUND OF: 678.40

APRIL TEST 1 RESULTS:

DAY	EXPECTED OPENING BALANCE	DEPOSITS	WITHDRAWALS	EXPECTED ACCOUNT COSTS
2	11458.58	284734.38	0.00	36.46
3	851502.13	0.00	555309.13	-149.40
4	368472.25	0.00	0.00	-177.92
5	383890.19	0.00	87697.13	-178.75
6	-305645.88	638414.75	0.00	22.86
9	358885.06	0.00	0.00	33.39
10	520523.19	0.00	161638.06	-15.71
11	-481625.06	840510.13	0.00	265.60
12	414999.56	0.00	0.00	242.25
13	133267.94	225617.13	0.00	341.12
16	651212.75	0.00	253574.38	229.51
17	685414.00	0.00	287775.75	133.20
18	204904.88	192733.50	0.00	197.70
19	477629.13	0.00	0.00	166.56
23	452874.25	0.00	0.00	152.90
24	508671.44	0.00	128115.25	138.78
25	551224.50	0.00	170668.38	81.66
26	400865.19	0.00	0.00	69.90
27	201140.78	179415.38	0.00	141.71
30	485995.50	0.00	105439.38	106.42

TOTAL EXPECTED TEST 1 COSTS = 1838.23
COMPARED TO A LOWER BOUND OF: 1765.84
AND AN UPPER BOUND OF: 1865.84

MAY TEST 1 RESULTS:

DAY	EXPECTED OPENING BALANCE	DEPOSITS	WITHDRAWALS	EXPECTED ACCOUNT COSTS
1	89463.36	206729.63	0.00	10.35
2	531656.50	0.00	235463.53	-68.46
3	637500.25	0.00	341307.19	-182.69
4	-333931.31	630124.25	0.00	28.21
7	501987.38	0.00	205794.47	-40.67
8	495337.69	0.00	136452.41	-82.88
9	-234808.97	668743.25	0.00	116.59
10	358885.13	0.00	0.00	135.95
11	70118.47	288766.75	0.00	237.60
14	519150.63	0.00	160265.50	183.96
15	452496.19	0.00	0.00	134.17
16	-161036.94	558675.38	0.00	344.21
17	781931.00	0.00	384292.50	215.59
18	683390.13	0.00	285751.75	119.95
22	548882.00	0.00	168325.78	47.57
23	554921.50	0.00	174365.31	-10.79
24	89304.19	291252.00	0.00	86.69
25	224623.91	155932.25	0.00	138.88
28	524181.00	0.00	143624.88	90.81
29	559118.38	0.00	178562.19	31.05
30	458803.50	0.00	0.00	0.38
31	524127.69	0.00	143571.47	-17.01

TOTAL EXPECTED TEST 1 COSTS = 1519.48
COMPARED TO A LOWER BOUND OF: 1422.90
AND AN UPPER BOUND OF: 1532.90

JUNE TEST 1 RESULTS:

DAY	EXPECTED OPENING BALANCE	DEPOSITS	WITHDRAWALS	EXPECTED ACCOUNT COSTS
1	65346.44	230846.53	0.00	18.42
4	425114.50	0.00	128921.52	-24.73
5	383448.00	0.00	87255.02	-53.93
6	486628.88	0.00	190435.88	-117.67
7	77840.00	218353.00	0.00	-44.59
8	253567.84	105317.47	0.00	-5.87
11	424437.94	0.00	0.00	-32.23
12	535193.00	0.00	176307.66	-64.88
13	-427818.75	787704.00	0.00	198.43
14	358885.25	0.00	0.00	193.76
15	278188.88	119449.63	0.00	212.01
18	762533.25	0.00	364894.75	89.88
19	718693.88	0.00	321055.38	-17.58
20	444893.63	0.00	0.00	-38.17
21	547073.00	0.00	149434.44	-67.60
22	538211.88	0.00	157655.69	-136.40
25	721568.63	0.00	341012.38	-250.54
26	434151.00	0.00	0.00	-273.23
27	-476883.50	900908.13	0.00	36.61
28	380556.19	0.00	0.00	45.99
29	468152.00	0.00	87595.80	21.67

TOTAL EXPECTED TEST 1 COSTS = -310.66
COMPARED TO A LOWER BOUND OF: -391.88
AND AN UPPER BOUND OF: -286.88

JULY TEST 1 RESULTS:

DAY	EXPECTED OPENING BALANCE	DEPOSITS	WITHDRAWALS	EXPECTED ACCOUNT COSTS
3	325587.06	0.00	0.00	-73.56
4	633397.38	0.00	337204.38	-171.70
5	479897.75	0.00	183704.75	-233.19
6	-381029.94	677222.88	0.00	-6.52
9	404277.50	0.00	0.00	-22.97
10	589245.75	0.00	230360.44	-80.16
11	-193182.75	552068.00	0.00	104.62
12	498241.25	0.00	92154.05	58.28
13	358885.19	0.00	0.00	68.77
16	550974.13	0.00	153335.63	-4.28
17	818752.50	0.00	421113.94	-145.23
18	-780383.13	1178021.75	0.00	249.05
19	470647.50	0.00	0.00	220.15
20	310869.19	86769.25	0.00	278.10
23	493197.56	0.00	112641.25	224.35
24	682825.50	0.00	302269.25	123.18
25	-271022.06	651578.25	0.00	341.27
26	389129.69	0.00	0.00	333.40
27	1625140.75	0.00	1244584.75	-75.29
30	578576.50	0.00	198020.50	-141.57
31	468828.25	0.00	88272.05	-171.12

TOTAL EXPECTED TEST 1 COSTS = 875.57
COMPARED TO A LOWER BOUND OF: 794.33
AND AN UPPER BOUND OF: 899.33

3: DAY-BY-DAY PROJECTION RESULTS

JANUARY TEST 2 RESULTS:

DAY	OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACCOUNT COSTS
3	220157.22	76035.77	0.00	-231.89
4	878725.88	0.00	582532.88	-139.55
5	540768.75	0.00	244575.75	-149.45
6	577003.75	0.00	280810.75	-98.53
9	390635.50	0.00	0.00	-102.16
10	403901.75	0.00	0.00	-8.22
11	60078.31	345332.63	0.00	-89.86
12	358885.25	0.00	0.00	-29.82
13	139151.28	219734.00	0.00	-103.88
16	410197.38	0.00	0.00	-192.23
17	733580.00	0.00	335941.38	-40.07
18	176648.66	220989.97	0.00	-102.10
19	403680.00	0.00	0.00	-264.89
20	999508.00	0.00	601869.38	-124.59
23	486012.63	0.00	105456.25	-122.40
24	477987.19	0.00	97430.80	239.39
25	-371937.25	833786.38	0.00	-95.78
26	380556.38	0.00	0.00	-44.43
27	192603.41	187952.97	0.00	-128.12
30	498921.50	0.00	118365.13	-238.40
31	902528.88	0.00	521972.50	-115.97

TOTAL TEST 2 COSTS= -2182.97

FEBRUARY TEST 2 RESULTS:

DAY	OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACCOUNT COSTS
1	454460.00	0.00	119878.55	-72.73
2	296193.00	0.00	0.00	-47.77
3	204820.28	91372.72	0.00	-124.79
6	486721.38	0.00	190528.38	-98.72
7	391310.56	0.00	95117.55	-75.43
8	306060.75	84278.50	0.00	-89.86
9	358885.31	0.00	0.00	82.27
10	-119163.77	478049.00	0.00	-111.71
13	438875.13	0.00	0.00	-133.29
14	517847.25	0.00	158961.94	2.56
15	20620.51	404021.88	0.00	-100.45
16	397638.56	0.00	0.00	-74.66
17	303238.56	94400.05	0.00	-168.07
20	645135.38	0.00	247496.75	-217.79
21	827102.50	0.00	429463.88	295.43
22	-462092.31	842648.63	0.00	-136.05
23	527959.50	0.00	147403.13	92.99
24	-136418.41	516974.75	0.00	-118.49
27	463673.75	0.00	83117.38	-106.47
28	419698.13	0.00	0.00	-218.14
29	828397.50	0.00	447841.13	-86.93

TOTAL TEST 2 COSTS= -1508.10

MARCH TEST 2 RESULTS:

DAY	OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACCOUNT COSTS
1	348180.94	0.00	0.00	7.67
2	1927.89	294265.00	0.00	-109.19
5	429651.06	0.00	133458.03	-177.56
6	679871.75	0.00	304909.50	-72.73
7	296193.06	0.00	0.00	-58.41
8	243776.69	115108.63	0.00	21.53
9	-21456.83	380342.13	0.00	-121.69
12	475386.69	0.00	116501.38	-136.03
13	527878.50	0.00	168993.19	-23.24
14	115065.97	247140.88	0.00	-100.45
15	397638.63	0.00	0.00	-75.80
16	307428.63	90210.00	0.00	-193.86
19	739510.63	0.00	341872.00	-175.28
20	671529.25	0.00	273890.63	119.04
21	-178328.69	575967.25	0.00	-209.12
22	795389.00	0.00	414832.63	78.83
23	-113639.17	494195.50	0.00	-126.90
26	494466.56	0.00	113910.19	-131.72
27	512102.50	0.00	131546.13	47.47
28	-63187.34	452495.50	0.00	-95.78
29	380556.38	0.00	0.00	-73.34
30	298442.63	82113.75	0.00	-121.31

TOTAL TEST 2 COSTS= -1727.88

APRIL TEST 2 RESULTS:

DAY	OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACCOUNT COSTS
2	474010.06	0.00	177817.03	-224.45
3	851502.25	0.00	555309.25	-92.48
4	368472.25	0.00	0.00	-96.69
5	383890.19	0.00	87697.19	198.18
6	-305646.00	638415.00	0.00	-89.86
9	358885.25	0.00	0.00	-134.02
10	520523.38	0.00	161638.03	307.57
11	-481624.88	840510.13	0.00	-105.19
12	414999.75	0.00	0.00	-28.22
13	133268.13	225617.19	0.00	-169.73
16	651213.00	0.00	253574.38	-179.07
17	685414.25	0.00	287775.63	-47.79
18	204905.25	192733.38	0.00	-122.30
19	477629.38	0.00	0.00	-115.54
23	452874.50	0.00	0.00	-130.78
24	508671.69	0.00	128115.30	-142.41
25	551224.63	0.00	170668.25	-101.33
26	400865.50	0.00	0.00	-46.76
27	201141.09	179415.25	0.00	-124.59
30	485995.69	0.00	105439.30	-183.14

TOTAL TEST 2 COSTS= -1628.61

MAY TEST 2 RESULTS:

DAY	OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACCOUNT COSTS
1	700285.13	0.00	404092.13	-137.06
2	531656.63	0.00	235463.63	-165.98
3	637500.25	0.00	341307.25	215.76
4	-333931.38	630124.38	0.00	-128.96
7	501987.44	0.00	205794.44	-127.14
8	495327.75	0.00	136452.44	154.15
9	-234808.91	668743.38	0.00	-89.86
10	358885.31	0.00	0.00	-10.96
11	70118.66	288766.63	0.00	-133.65
14	519150.69	0.00	160265.38	-115.44
15	452496.38	0.00	0.00	108.29
16	-161036.75	558675.38	0.00	-205.45
17	781931.13	0.00	384292.50	-178.52
18	683390.25	0.00	285751.63	-141.77
22	548882.25	0.00	168325.88	-143.42
23	554921.75	0.00	174365.38	-16.20
24	89304.39	291251.94	0.00	-53.18
25	224624.06	155932.28	0.00	-135.02
28	524181.19	0.00	143624.78	-144.57
29	559118.63	0.00	178562.25	-117.16
30	458803.75	0.00	0.00	-135.01
31	524127.88	0.00	143571.50	31.27

TOTAL TEST 2 COSTS= -1669.87

JUNE TEST 2 RESULTS:

DAY	OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACCOUNT COSTS
1	-37128.07	333321.00	0.00	-107.95
4	425114.50	0.00	128921.50	-96.57
5	383448.00	0.00	87255.00	-124.76
6	486628.94	0.00	190436.94	-13.07
7	77840.00	218353.00	0.00	-61.08
8	253567.81	105317.50	0.00	-107.77
11	424437.94	0.00	0.00	-138.03
12	535193.00	0.00	176307.69	274.12
13	-427818.75	787704.00	0.00	-89.86
14	358885.25	0.00	0.00	-67.81
15	278188.88	119449.75	0.00	-200.15
18	762533.38	0.00	364894.75	-188.17
19	718694.00	0.00	321055.38	-113.36
20	444893.75	0.00	0.00	-141.28
21	547073.00	0.00	149434.38	-138.86
22	538212.13	0.00	157655.75	-188.95
25	721568.75	0.00	341012.38	-110.42
26	434151.13	0.00	0.00	304.62
27	-476883.38	900908.13	0.00	-95.78
28	380556.31	0.00	0.00	-119.71
29	468152.06	0.00	87595.69	-146.48

TOTAL TEST 2 COSTS= -1671.33

JULY TEST 2 RESULTS:

DAY	OPENING BALANCE	DEPOSITS	WITHDRAWALS	ACCOUNT COSTS
3	566120.00	0.00	269927.00	-156.83
4	604003.38	0.00	307810.38	-122.92
5	479897.75	0.00	183704.75	245.04
6	-381029.94	677222.88	0.00	-102.26
9	404277.44	0.00	0.00	-152.80
10	589245.75	0.00	230360.44	128.28
11	-193182.78	552068.00	0.00	-127.93
12	498241.25	0.00	92153.94	-89.86
13	358885.31	0.00	0.00	-142.34
16	550974.25	0.00	153335.63	-215.51
17	818752.63	0.00	421114.00	493.27
18	-780383.13	1178021.75	0.00	-120.40
19	470647.50	0.00	0.00	-76.74
20	310869.19	86769.44	0.00	-126.56
23	493197.81	0.00	112641.44	-178.37
24	682825.50	0.00	302269.13	176.66
25	-271021.94	651578.25	0.00	-98.12
26	389129.81	0.00	0.00	-435.83
27	1625141.00	0.00	1244584.75	-149.88
30	578576.75	0.00	198020.38	-119.90
31	468828.50	0.00	88272.13	-119.90

TOTAL TEST 2 COSTS= -1492.91

References

Ackoff, R.L. (1978)
The Art of Problem Solving, Wiley, New York.

Ackoff, R.L. and F.E. Emery (1972)
On Purposeful Systems, Aldine-Atherton, Chicago.

Agin, G.J. (1980)
"Computer Vision Systems for Industrial Inspection and Assembly," Computer, Vol.13, No.5, May 1980, pp 11-19.

Ahituv, N. and S. Neumann (1982)
Principles of Information Systems for Management, Wm. C. Brown, Dubuque, Iowa.

Alavi, M. (1982)
"An Assessment of the Concept of Decision Support Systems as Viewed By Senior-Level Executives," MIS Quarterly, December 1982, pp 1-9.

Alter, S.L. (1975)
"A Study of Computer Aided Decision Making in Organizations," Unpublished Ph.D. Thesis, Sloan School of Management, Massachusetts Institute of Technology.

Alter, S.L. (1976)
"How Effective Managers Use Decision Support Systems," Harvard Business Review, November-December 1976, pp 97-104.

Alter, S.L. (1977)
"A Taxonomy of Decision Support Systems," Sloan Management Review, Fall 1977, pp 39-56.

Alter, S.L. (1980)
Decision Support Systems: Current Practice and Continuing Challenges, Addison-Wesley, Reading Massachusetts.

Ambrosetti, R. and T.A. Ciriana (1983)
"A Graphic Approach to Linear Programming Sensitivity". TIMS/ORSA Joint National Meeting, Chicago, April 25-27, 1983, IBM Program Product Development Center, Rome, Italy.

Andriole, S.J. (1983)
Handbook of Problem Solving, Petrocelli Books, Inc., New York.

Anundson, R. and D. Squire (1983)
"Interactive Graphics Help Us Visualize Data, Communicate Results," Industrial Research and Development, Vol. 25, No. 9, September 1983, pp 114-118.

Archer, S.H. (1966)
"A Model for the Determination of Firm Cash Balances," The Journal of Financial and Quantitative Analysis, Vol 1, March 1966, pp 1-14.

Babin, A., M. Florian, L. James-Lefebvre, and H. Speiss (1982)
"EMME/2: An Interactive Graphic Method for Road and Transit Planning," Publication #204, Centre de Recherche sur les Transports, Universite de Montreal, Quebec.

Bariff, M.L. and E.J. Lusk (1977)
"Cognitive and Personality Tests for the Design of Management Information Systems," Management Science, Vol. 23, No. 8, April 1977, pp 820-829.

Baumol, W.J. (1952)
"The Transactions Demand for Cash: An Inventory Theoretic Approach," The Quarterly Journal of Economics, Vol. 66, November 1952, pp 545-556.

Beagley, K. (1984)
"Micrographics Ins and Outs," Infosystems, Vol. 31, No. 4, April 1984, pp 90-91.

Beehler, P. J. (1983)
Contemporary Cash Management: Principles, Practices, Perspectives, Second Edition, John Wiley and Sons, New York.

Beehler, P.J. (1978)
Contemporary Cash Management, John Wiley and Sons, New York.

Bell, P.C. (1983)
"Visual Interactive Modeling as an Operations Research Technique," Working Paper # 83-44, Research and Publications Division, School of Business Administration, the University of Western Ontario.

Bell, P.C. and A. Hamidi-Noori (1984)
"Foreign Currency Inventory Management in a Branch Bank," Journal of the Operational Research Society, Vol. 35, No. 6, pp 513-525.

Bell, P.C. and D.C. Parker (1985)
"Developing a Visual Interactive Model for Corporate Cash Management," Accepted for Publication, Journal of the Operational Research Society, September, 1985.

Bell, P.C. and D.C. Parker (1984)
"Visual Interactive Modeling: A New Dimension for Managerial Decision Support," in S. Rivard (Ed.) Proceedings 1984, INFORMATION SYSTEMS, Administrative Sciences Association of Canada, Guelph, Ontario.

Bell, P.C., D.C. Parker, and P. Kirkpatrick (1984)
"Visual Interactive Problem Solving - A New Look at Management Problems," Business Quarterly, Spring 1984.

Bell, P.C. and E.F.P. Newson (1982)
"How Major Canadian Corporations Manage Cash," Business Quarterly, Vol. 47, No. 2, August 1982, pp 49-52.

Benbasat, I. (1977)
"Cognitive Style Considerations in DSS Design," Minipapers, Data Base, Vol. 8, No. 3, pp 37-38.

Benbasat, I and Schroeder, R. (1977)
"An Experimental Investigation of Some MIS Design Variables," MIS Quarterly, Vol. 1, No. 1.

Benbasat, I. and R.N. Taylor (1978)
"The Impact of Cognitive Style on Information Systems Design," MIS Quarterly, Vol. 2, No. 2, June 1978.

Bennett, J.L. (1983)
Building Decision Support Systems, Addison-Wesley, Reading.

Beranek, W. (1963)
Analysis for Financial Decisions, Richard D. Irwin, Inc., Homewood, Illinois.

Bhatnager, S.C. (1983)
"Locating Social Service Centres Using Interactive Graphics", Omega, Vol. 11, No. 2, pp. 201-205.

Birtwistle, G., B. Wyvill, D. Levinson, and R. Neal (1984)
"Visualising a Simulation Using Animated Pictures," 1984 Multiconference Presentation, Society for Computer Simulation.

Blake, G.B. (1978)
"Graphic shorthand as an aid to managers," Harvard Business Review," March-April 1978, pp 6-12.

Blanning, R.W. (1979)
"The Functions of a Decision Support System," Information and Management, Vol.2, pp 87-93.

Bonczek, R.H., C.W. Holsapple, and A.B. Whinston (1979)
"Computer-Based Support of Organizational Decision Making," Decision Sciences, Vol.10, pp 268-291.

Bonczek, R.H, C.W. Holsapple, and A.B. Whinston (1980)
"Future Directions for Developing Decision Support Systems," Decision Sciences, V.11, pp 616-631.

Bowen, H.C., R.J. Fenton, M.A.M. Rogers, R.D.Hurrion, and R.J.R. Secker (1978)
"Interactive Computing as an Aid to Decision Makers," in R.B. Haley (Ed.), OR '78, North Holland Publishing Company, pp 829-842.

Brightman, H.J. (1980)
Problem Solving: A Logical and Creative Approach, Business Publishing Division, College of Business Administration, Georgia State University, Atlanta.

Brysson, David W. (Ed.) (1978)
Hypergraphics: Visualizing Complex Relationships in Art, Science and Technology, AAAS Selected Symposium, Westview Press, Boulder, Colorado.

Bryer, R.A. (1979)
"The Status of the Systems Approach," Omega, Vol. 7, No. 3, pp 219-231.

Buzacott, J. (1982)
"Images of Reality: The Relation Between the Real World and the Model World in OR," Infor, Vol. 20, No. 3, August, 1982, pp 264-272.

Calman, R.F. (1968)
Linear Programming and Cash Management: CASH ALPHA, The M.I.T. Press, Cambridge.

Carlson, E.D. (1979)
"An Approach for Designing Decision Support Systems," Data Base, Winter 1979, pp 3-15.

Checkland, P.B. (1981)
Systems Thinking, Systems Practice, Wiley, New York.

Checkland, P.B. (1983)
"O.R. and the Systems Movement: Mappings and Conflicts," Journal of the Operational Research Society, Vol. 34, No. 8, August 1983, pp 661-675.

Chernoff, H. (1973)
"Using Faces to Represent Points in K-Dimensional Space Graphically." Journal of the American Statistical Association, Vol. 68, pp 361-368.

Chervany, N.L. and G.W. Dickson (1974)
"An Experimental Evaluation of Information Overload in an Production Environment," Management Science, Vol.20, No.10, June 1974, pp 1335-1344.

Constantinides, G.M. (1976)
"Stochastic Cash Management with Fixed and Proportional Transaction Costs," Management Science, Vol. 22, No. 12, August 1976, pp 1320-1331.

Constantinides, G.M. and S.F. Richard (1978)
"Existence of Optimal Simple Policies for Discounted-Cost Inventory and Cash Management in Continuous Time," Operations Research, Vol. 26, No. 4, July-August 1978, pp 620-636.

Couturier, R.M. (1973)
"Liquidity Management: A Heuristic Decision Making Model," Unpublished Ph.D. Thesis, School of Business Administration, The University of Western Ontario, London, Canada.

Crookes, J.G. and B. Valentine (1982)
"Simulation in Micro-Computers," Journal of the Operational Research Society, Vol. 33, No. 9, pp 855-858.

Daellenbach, H.G. (1971)
"A Stochastic Cash Balance Model with Two Sources of Short-Term Funds," International Economic Review, Vol. 12, No. 2, June 1971, pp 250-256.

Daellenbach, H.G. (1975)
"How Widely Are Cash Management Optimization Models Used," Interfaces, Vol. 5, No. 2, February 1975, pp 69-73.

Daellenbach, H.G. and S.H. Archer (1969)
"The Optimal Bank Liquidity: A Multi-Period Stochastic Model," Journal of Financial and Quantitative Analysis, Vol. IX, No. 4, December 1969, pp 329-343.

Dawson, W., S.M. Lakshminarayan, A.A. Landry, and J.B. McLeod (1981)
"Keeping Ahead of a $2 Billion Canal," Interfaces, Vol. 11, No. 6, December 1981, pp 70-83.

Dawson, W., S. Lakshminarayan, A.A. Landry, and J.B. McLeod (1982)
"The Acceptance of a Simulation Model for Planning Decisions at the St. Lawrence Seaway Authority," Infor, Vol.20, No.1, February 1982, pp 16-27.

Dennis, A.R. and R.N. Burns (1984)
"Phased Design: A Flexible Approach to Application System Development," Working Paper 84-19, October 1984, School of Business, Queen's University, Kingston.

Dickson, G.W., J.A. Senn, and N.L. Chervany (1974)
"Research in Management Information Systems: The Minnesota Experiments," Management Science, Vol.20, No.10, June 1974, pp 913-923.

Doktor, R., R.L. Schultz, and D.P. Slevin (Eds.) (1979)
The Implementation of Management Science, North Holland.

Donovan, J.J., M.M. Jones, and T.W. Alsop (1969)
"A Graphical Facility for an Interactive Simulation System," In: Proceedings IFIP Congress 68, North-Holland, Amsterdam.

Earl, M.J. (1978)
"Prototype Systems for Accounting, Information and Control," Accounting, Organizations and Society, Vol. 3, No. 2, March 1978, pp 161-170.

Editorial Staff (1984)
"Micros can Manage Cash Flow, Investments," Data Management, Vol. 22, No. 4, April 1984, pp 22,37.

Edstrom, O. (1973)
Man-Computer Decision Making, BAS, Goteborg.

Ellison, D., I. Herschdorfer, and J.T. Wilson (1982)
"Interactive Simulation on a Microcomputer," Simulation, May 1982, pp 161-175.

Elton, E.J. and M.J. Gruber (1974)
"On the Cash Balance Problem," Operational Research Quarterly, Vol. 25, No. 4, October 1974, pp 553-572.

Elton, E.J. and M.J. Gruber (1975)
Finance as a Dynamic Process, Prentice-Hall, Englewood Cliffs, New Jersey.

Eppen, G.D. and E.F. Fama (1968)
"Solution for Cash Balance and Simple Dynamic Portfolio Problems," Journal of Business of the University of Chicago, Vol. 41, No. 1, January 1968, pp 94-112.

Fetter, W.A. (1964) Computer Graphics in Communication, McGraw-Hill Book Company, New York.

Fiddy, E., J.G. Bright and R.D. Hurrion (1981)
"See-why: interactive simulation on the screen", Proceedings of the Institute of Mechanical Engineers, C293781, pp. 167-172.

Field, E.A. (1983)
"The Decision Support System (DSS): Is It a Trojan Horse for O.R.?" OR Newsletter, Vol.12, No.8, April 1983.

Fisher, M., A. Greenfield and K. Thompson (1983)
"Real World Experience with an Interactive Graphic Colour Interface for Vehicle Routing Models", presentation ORSA/TIMS Joint National Meeting, Orlando.

Fisher, M.L., Greenfield, A.J., Jaikumar, R., and Lester, J.T. III (1982)
"A Computerized Vehicle Routing Application," Interfaces, Vol. 12, No. 4, July-August 1982, pp 42-52.

Fisher, D.J. (1972)
Cash Management in the Moderate-Sized Company, Conference Board Report No. 559, Ottawa.

Frost, P.A. (1970)
"Banking Services, Minimum Cash Balances, and the Firm's Demand for Money," Journal of Finance, Vol. 25, No. 5, December 1970, pp 1029-1039.

Garbini, J.L., M.R. Lembersky, U.H. Chi and M.T. Hehnen (1983)
"Merchandiser Design using Simulation with Graphical Animation", Weyerhaeuser Research and Development, WTC 2E2, Tacoma, Washington.

George, F.H. (1980)
Problem Solving, Duckworth, London.

Gerrity, T.P. (1971)
"Design of Man-Machine Decision Systems: An Application to Portfolio Management," Sloan Management Review, Vol. 12, No. 2, Winter 1971, pp 59-75.

3 OF/DE 3

MICROCOPY RESOLUTION TEST CHART
NBS 1010a
ANSI and ISO TEST CHART No 2

1.0 2.8 2.5 3.2 2.2 3.6 4.0 2.0 1.1 1.8 1.25 1.4 1.6

Gilman, L. and A.J. Rose (1976)
APL: An Interactive Approach, Second Edition, Wiley, New York.

Ginzberg, M.J. (1981)
"Key Recurrent Issues in the MIS Implementation Process," MIS Quarterly, June 1981, pp 47-59.

Girgis, N.M. (1968)
"Optimal Cash Balance Levels," Management Science, Vol. 15, No. 3, November 1968.

Goode, B. (1977)
"Measurements of Professional Team Performance - Football, Baseball and Basketball". ORSA/TIMS Joint National Meeting, Atlanta, Georgia, November 7-9, 1977.

Gray, P. J. Aronofsky, N.W. Berry, O. Helmer, G.A. Kane, and T.E. Perkins (1981)
"The SMU Decision Room Project," Working Paper 81-201, Southern Methodist University.

Green, R.E. and R.D. Parslow (Eds.) (1970)
Computer Graphics in Management: Case Studies of Industrial Applications, Gower Press, London, England.

Gupta, S.K. and J.M. Cozzolino (1975)
Fundamentals of Operations Research for Management, Holden-Day, Inc., San Francisco.

Hackathorn, R.D. (1977)
"Modeling Unstructured Decision Making," Minipapers, Data Base, Vol. 8, No. 3, pp 41-42.

Hackathorn, R.D. and P.G.W. Keen (1981)
"Organizational Strategies for Personal Computing in Decision Support Systems," MIS Quarterly, September 1981, pp 21-27.

Hamidi-Noori, A. (1981)
"Management of Foreign Currencies with Applications to a Branch Banking System: An Inventory Modeling Approach with Upper Control Limit and Emergency Provisions," Unpublished Ph.D. Thesis, School of Business Administration, The University of Western Ontario, London, Canada, April 1981.

Hardikar, S. (1983)
"Using Graphics to Communicate," Data Processing, Vol. 25, No. 6, July/August 1983, pp 34-35.

Hartley, W.C.F. (1976)
Cash: Planning, Forecasting and Control, Business Books, Ltd., London.

Hastings, C. (1970)
Approximations for Digital Computers, Princeton University Press, Princeton, N.J.

Hausman, W.H. (1969)
"Sequential Decision Problems: A Model to Exploit Existing Forecasters," Management Science, Vol 16, No. 2, October 1969, pp B93-B111.

Hausman, W.H. and A. Sanches-Bell (1975)
"The Stochastic Cash Balance Problem with Average Compensation-Balance Requirements," Management Science, Vol. 21, No. 8, April 1975, pp 849-857.

Hill, R.W., Jr. (1970)
Cash Management Techniques, American Management Association, Inc.

Hollocks, B. (1981)
"Personal Computers and Operational Research -Experience in British Steel," Journal of the Operational Research Society, Vol. 32, No. 4, pp 269-275.

Hollocks, B. (1983)
"Simulation and the Micro," Journal of the Operational Research Society, Vol. 34, No. 4, pp 331-343.

Homonoff, R. and D.W. Mullins, Jr. (1975)
Cash Management, D.C. Heath and Co., Lexington.

Huber, G.P. (1981)
"The Nature of Organizational Decision Making and the Design of Decision Support Systems," MIS Quarterly, June 1981, pp 1-10.

Hurrion, R.D. (1976)
"The design, use and required facilities of an interactive visual computer simulation language to explore production planning problems", Ph. D. Thesis, University of London.

Hurrion, R.D. (1978)
"An Investigation of Visual Interactive Simulation Methods Using the Job-Shop Scheduling Problem," Journal of the Operational Research Society, Vol. 29, No. 11, pp 1085-1093.

Hurrion R.D. (1980)
"An Implementation of Visual Interactive Simulation Using a Microcomputer," Omega, Vol. 8, No. 2, pp 237-238.

Hurrion, R.D. (1980)
"An Interactive Visual Simulation System for Industrial Management," European Journal of Operations Research, Vol.5, pp 86-93.

Hurrion, R.D. (1981)
"Visual Interactive Simulation Using a Microcomputer," Computers and Operations Research, Vol.8, No.4, pp 267-273.

Hurrion, R.D. (1984)
"Visual Interactive Simulation: Its Role in the Decision Support Environment," 1984 TIMS/ORSA Conference Presentation Paper.

Hurrion, R.D. and R.J.R. Secker (1978)
"Visual Interactive Simulation: An Aid To Decision Making," Omega, Vol.6, No.5, pp 419-426.

Huysmans, J.H.B.M. (1970)
The Implementation of Operations Research, ORSA Publication # 19, Wiley-Interscience, New York.

Ives, B. (1982)
"Graphical User Interfaces for Business Information Systems," MIS Quarterly, Special Issue, 1982.

Ives, B., S. Hamilton, and G.B. Davis (1980)
"A Framework for Research in Computer Based Management Information Systems," Management Science, Vol. 26, No. 9, September 1980, pp 910-934.

Janson, R.L. (1980)
"Graphic Indicators of Operations," Harvard Business Review, November-December 1980, pp 164-170.

Johnson, H. and M. Johnson (1983)
"Graphics in Accounting," Data Processing, Vol. 25, No. 6, July/August 1983, pp 32-33.

Johnson, L.E. and D.P. Loucks (1980)
"Interactive Multiobjective Planning Using Computer Graphics," Computers and Operations Research, Vol.7, pp 89-97.

Johnson, R.A., F.E. Kast, and J.E. Rosenzweig (1973)
The Theory and Management of Systems, Third Edition, McGraw-Hill Book Company, New York.

Kaufman, A. and M.Z. Hanani (1981)
"Converting a Batch Simulation Program to an Interactive Program with Graphics," Simulation, Vol. 36, No.4, April 1981, pp 125-131.

Keen, P.G.W. (1975)
"Computer-Based Decision Aids: The Evaluation Problem," Sloan Management Review, Spring 1975, pp 17-29.

Keen, P.G.W. (1976)
"Interactive Computer Systems for Managers: A Modest Proposal," Sloan Management Review, Fall 1976.

Keen, P.G.W. (1980)
"Decision Support Systems: Translating Analytic Techniques into Useful Tools," Sloan Management Review, Spring 1980, pp 33-44.

Keen, P.G.W. (1981)
"Value Analysis, Justifying Decision Support Systems," MIS Quarterly, March 1981, pp 1-15.

Keen, P.G.W. and M.S. Scott Morton (1978)
Decision Support Systems: An Organizational Perspective, Addison-Wesley, Reading Massachusetts.

Keen, P.G.W. and G.R. Wagner (1979)
"DSS: An Executive Mind-Support System," Datamation, November 1979, pp 117-122.

Kelley, N.D. (1980)
"Business Turns to Graphics," Infosystems, November 1980, pp 51-60.

Kidder, L.H. (1981)
Selltiz Wrightsman and Cook's Research Methods in Social Relations, Fourth Edition, Holt, Rinehart and Winston, New York.

King, L.T. (1981)
Problem Solving in a Project Environment, Wiley, New York.

Knight, W.D. (1972)
"Working Capital Management - Satisficing versus Optimization," Financial Management, Vol. 1, No. 1, Spring 1972, pp 33-40.

Kolata, G. (1982)
"Computer Graphics Comes to Statistics," <u>Science</u>, Vol.217, 3 September 1982, pp 919-920.

Krarup, J. and D. de Warra (1982)
"Chromatic Optimisation: Limitations, Objectives, Uses, References," <u>European Journal of Operational Research</u>, Vol. 11, pp 1-19.

Landry, M., J. Malouin and M. Oral (1983)
"Model Validation in Operations Research", <u>European Journal of Operational Research</u>, Vol. 14, No. 3, pp. 207-220.

Lapalme, G. (1983)
"Amellioration Interactive de Routes a l'aide d'un outill Graphique en Couleur". The first Quebec computer symposium, Montreal, Quebec, February 24,1983: Centre de recherche sur les transports; Universite de Montreal.

Lay, P.M. and G.F. Ellis (1982)
"Graphics Design for Management," <u>Journal of Systems Management</u>, August 1982, pp 37-42.

Lee, J. and E. Singer (1983)
"ALICE : Advanced Lab for Interactive Computing at Exxon". TIMS/ORSA Joint National Meeting, Chicago, April 25-27,1983.

Lembersky, M.R. and U.H. Chi (1983)
"Decision Simulators Speed Implementation and Improve Operations", Weyerhaeuser Research and Development, WTC 2F2, Tacoma, Washington.

Little, J.D.C. (1979)
"Decision Support Systems for Marketing Managers," <u>Journal of Marketing</u>, V.43, Summer 1979, pp 9-26.

Lucas, H.C.,Jr. (1981)
"An Experimental Investigation of the Use of Computer-Based Graphics in Decision Making," <u>Management Science</u>, Vol.27, No.7, July 1981, pp 757-768.

Lucas, H.C., Jr. and N.R. Nielson (1980)
"The Impact of the Mode of Information Presentation on Learning and Performance," <u>Management Science</u>, Vol. 26, No. 10, October 1980, pp 982-993.

Lusk, E.J. and M. Kesnick (1979)
"The Effect of Cognitive Style and Report Format on Task Performance: The MIS Design Consequences," <u>Management Science</u>, Vol.25, No.8, August 1979, pp 787-798.

Luzadder, W.J. (1968)
Basic Graphics for Design, Analysis, Communications, and the Computer, Second Edition, Prentice-Hall Inc., Englewood Cliffs.

Lyons, D.N.G. (1983)
"And When the Belts Stop, The Faces Go Red: Color Graphics in Coal Transport," O.R. Society Conference Presentation, University of Warwick, Coventry, U.K., September 1983.

Makridakis, S. and S.C. Wheelwright (1978)
Forecasting: Methods and Applications, John Wiley and Sons, New York.

Markowitz, H.M. (1959)
Portfolio Selection: Efficient Diversification of Investments, Yale University Press, New Haven.

Mason, R.O. and I.I. Mitroff (1973)
"A Program for Research on Management Information Systems," Management Science, Vol. 19, No. 5, January 1973, pp 475-487.

Maxwell, W. and C. Jones (1983)
"Scheduling Using Interactive Computer Graphics," LIMS/ORSA Joint National Meeting, Chicago, April 25-27, 1983, Cornell University, Ithica, NY.

McCosh, A.M. and M.S. Scott Morton (1978)
Management Decision Support Systems, Macmillan, London.

McEwan, C.E. (1981)
"Computer graphics: Getting more from a management information system," Data Management, Vol. 19, No. 7, July 1981, pp 30-32.

McLean E.R. and T.F. Riesling (1980)
"Installing A Decision Support System: Implications for Research," Information Systems Working Paper #7-80, Graduate School of Management, UCLA, June 1980.

McLenning, M. (1983)
"Business Graphics set for Rapid Growth," Data Processing, Vol. 25, No. 6, July/August 1983, pp 29-31.

Miller, D.M. (1984)
"Operations Research Offers Valuable Tools for Increasing Productivity, Profits," Industrial Engineering, Vol. 16, No. 4, April 1984, pp 38-42.

Miller, I.M. (1969)
"Computer Graphics for Decision Making," Harvard Business Review, Vol. 47, No. 6, November-December 1969, pp 121-132.

Miller, M.H. and D. Orr (1966)
"A Model of the Demand For Money By Firms," Quarterly Journal of Economics, Vol. 80, August 1966, pp 413-435.

Miller, M.M. and D. Orr (1969)
"The Demand for Money by Firms: Extensions of Analytic Results," The Journal of Finance, Vol. 23, No. 5, December 1969, pp 735-759.

Miller, R.R. (1982)
"Simulation and Graphics on a Microcomputer," Simulation, Vol.38, No.6, June 1982, pp 215-220.

Montgomery, D.C. and L.A. Johnson (1976)
Forecasting and Time Series Analysis, McGraw-Hill, New York.

Morton, M.S. Scott (1971)
Management Decision Systems, Division of Research, Harvard, Boston.

Moreira da Silva, C., R.D. Hurrion, W.H. Swann, and P.J. Tosney (1981)
"A Decision Support System for the Planning and Control of Complex and Interrelated Manufacturing Units," IFORS '81 Conference Presentation Paper.

Musgrave, J.F. (1978)
"Experiments in Computer-Aided Graphic Expression," IBM Systems Journal, Vol.17, No.3, pp 241-259.

Myers, W. (1981)
"Computer Graphics: The Need for Graphics Design: Part One," Computer, Vol.14, No.6, June 1981, pp 86-92.

Myers, W. (1981)
"Computer Graphics: The Need for Graphics Design: Part Two," Computer, Vol.14, No.7, July 1981, pp 82-88.

Naddor, E. (1966)
Inventory Systems, John Wiley and Sons, New York.

Naisbitt, J. (1984)
Megatrends, Warner, New York.

Naumann, J.D. and A.M. Jenkins (1982)
"Prototyping: The New Paradigm for Systems Development," _MIS Quarterly_, September 1982, pp 29-44.

Naylor, T.H. (1982)
"Decision Support Systems or Whatever Happened to MIS?" _Interfaces_, V.12, No.4, August 1982, pp 92-94.

Neave, E.H. (1970)
"The Stochastic Cash Balance Problem with Fixed Costs for Increases and Decreases," _Management Science_, Vol. 16, No. 7, March 1970, pp 472-490.

Newman, W.M. and R.F. Sproull (1979)
Principles of Interactive Computer Graphics, Second Edition, McGraw-Hill Book Company, New York.

Niehoff, W.H. and A.L. Jones (1980)
"An APL Approach to Presentation Graphics," _IBM Systems Journal_, Vol.19, No.3, pp 367-381.

Orgler, Y.E. (1970)
Cash Management: Methods and Models, Wadsworth, Belmont, California.

Orr, D. (1970)
Cash Management and the Demand for Money, Praeger Publishers, New York.

Orr, K.T. (1977)
Structured Systems Development, Yourdon, Inc., New York.

Palme, J. (1977)
"Moving Pictures Show Simulation to User," _Simulation_, Vol. 29, No. 6, December 1977, pp 204-209.

Parker, D.C. (1983)
"Graphic Options for Operational Research Modelers," Paper presented at the 1983 Winnipeg Conference, Canadian Operational Research Society, May 24, 1983.

Parker, D.C. (1983)
"The Evolution of Management Decision Support Systems," in J. McKeen (Ed.), _Proceedings 1983_, Vol. 4, Part 4, INFORMATION SYSTEMS, Administrative Sciences Association of Canada, Vancouver, B.C.

Parker, D.C. (1983)
"Using the 'Brewing' Decision Tree Program," Supplementary Note # 9-83-E004, School of Business Administration, The University of Western Ontario, London, Canada.

Parker, D.C. and P.C. Bell (1983)
"Computer Graphics -- A New Tool in Operational Research," Working Paper # 83-38, Research and Publications Division, School of Business Administration, The University of Western Ontario.

Parker, D.C. and P.C. Bell (1985)
"Developing a Visual Interactive Model for Corporate Cash Management," Journal of The Operational Research Society, Vol. 36, No. 9, September, 1985.

Parslow, R.D., R.W. Prowse, and R.E. Green (1969)
Computer Graphics: Techniques and Applications, Plenum Press Ltd., New York.

Patel, Nitin R. (1979)
"Locating Rural Social Service Centers in India," Management Science, Vol. 25, No. 1, January 1979, pp 22-30.

Peterson, R. and Silver, E.A. (1979)
Decision Systems for Inventory Management and Production Planning, Wiley, New York.

Pferd, W. and F.X. Prendergast (1979)
"Interactive Graphics Teleconferencing," Computer, Vol.12, No.11, November 1979, pp 62-72.

Pidd, M. (1979)
"Systems approaches and operational research," European Journal of Operational Research, Vol. 3, No. 1, pp 13-19.

Porteus, E.L. (1972)
"Equivalent Formulations of the Stochastic Cash Balance Problem," Management Science, Vol 19, No. 3, November 1972, pp 250-253.

Porteus, E.L. and E.H. Neave (1972)
"The Stochastic Cash Balance Problem With Charges Levied Against the Balance," Management Science, Vol. 18, No. 11, July 1972, pp 600-602.

Rardin, R.R. (1983)
"Interactive Resource Constrained Project Planning and Control With Color Graphics". TIMS/ORSA Joint National Meeting, Chicago, April 25-27,1983, Purdue University, West Lafayette, IN.

Remus, W. (1984)
"An Empirical Investigation of the Impact of Graphical and Tabular Data Presentations on Decision Making," Management Science, Vol. 30, No. 5, May 1984, pp 537-542.

Robichek, A.A. (Ed.) (1969)
Financial Research and Management Decisions, John Wiley and Sons, New York.

Robichek, A.A., D. Teichroew, and J.M. Jones (1965)
"Optimal Short-Term Financing Decision," Management Science, Vol. 12, No. 1, September 1965, pp 1-36.

Sanderson, M. (1979)
Successful Problem Management, Wiley, New York.

Schabacker, J.C. (1960)
Cash Planning in Small Manufacturing Companies, Small Business Administration, Washington.

Schroeder, R.G. and I. Benbasat (1975)
"An Experimental Evaluation of the Relationship of Uncertainty in the Environment to Information Used by Decision Makers," Decision Sciences, Vol.6, July 1975, pp 556-567.

Shannon, R.E. (1975)
Systems Simulation: The Art and Science, Prentice-Hall, Inc., Englewood Cliffs.

Shepard, S.W. (1983)
"DISPATCH: Downsized Interactive System For Planning Assignments to Trucks Using Combinatorial Heuristics", Exxon Corporation CCS Department, P.O. Box 153, Florham Park, New Jersey.

Simon, H.A. (1960)
The New Science of Management Decision, Harper and Row, New York.

Simpson, M.G. (1978)
"Those who Can't?" Journal of the Operational Research Society, Vol. 29, No. 6, pp 517-522B.

Smart, C., Vertnsky, I, Vertinsky, P. (1984)
"Aiding Decision Making in Uncertain Environments: Problems and Prescriptions," INFOR, Vol. 22, No. 2, May 1984, pp 141-154.

Sohnle, R.C., J. Tartar, and J.R. Sampson (1973)
"Requirements for Interactive Simulation Systems," Simulation, Vol. 24, pp 145-152.

Sprague, R.H., Jr. (1980)
"A Framework for the Development of Decision Support Systems," MIS Quarterly, December 1980, pp 1-26.

Sprague, R.H., Jr. and H.J. Watson (1979)
"Bit by Bit: Toward Decision Support Systems," California Management Review, Vol.22, No.1, Fall 1979, pp 60-68.

Sprague, R.H., Jr. and E.D. Carlson (1982)
Building Effective Decision Support Systems, Prentice-Hall, Inc., Englewood Cliffs.

Stone, B.K. (1972)
"The Use of Forecasts and Smoothing in Control-Limit Models for Cash Management," Financial Management, Vol. 1, No. 1, Spring 1972, pp 72-84.

Sulonen, R.K. (1972)
"Online Simulation with Computer Graphics," In: ONLINE 72 Conference Proceedings, Brunel University, pp 535-549.

Sweeney, E.T. (1983)
"Microcomputer Graphics," Journal of the Operational Research Society, Vol. 34, No. 4, pp 309-316.

Tomlinson, R. (1981)
"Some dangerous misconceptions concerning operational research and applied systems analysis," European Journal of Operational Research, Vol. 7, No. 2, pp 203-212.

Ulvilla, J.W. and R.V. Brown (1982)
"Decision Analysis Comes of Age," Harvard Business Review, September-October 1982, pp 130-141.

Usher, E. (1983)
"Interfaces in Real-Time Systems," Data Processing, Vol. 25, No. 6, July/August 1983, pp 36-37.

Vial, J. (1972)
"A Continuous Time Model for the Cash Balance Problem," in Mathematical Methods in Investment and Finance, North-Holland, 1972.

Vierck, R.K. (1981)
"Decision Support Systems: An MIS Manager's Perspective," MIS Quarterly, December 1981, pp 35-48.

Wagner, G.R. (1980)
"Optimizing Decision Support Systems," Datamation, May 1980, pp 209-214.

Wagner, H.M. (1969)
Principles of Operations Research, Prentice-Hall, Inc., Englewood Cliffs.

Wagner, H.M. (1975)
Principles of Management Science, Second Edition, Prentice-Hall, Inc., Englewood Cliffs.

Wang, Peter C. C. (Ed.) (1978)
Graphical Representations of Multivariate Data, Academic Press, New York.

Watson, C.J. and R.W. Driver (1983)
"The Influence of Computer Graphics on the Recall of Information," MIS Quarterly, Vol. 7, No. 1, March 1983, pp 45-53.

Weller, D.L., E.D. Carlson, G.M. Giddings, F.P. Palermo, R. Williams, and S.N. Ziles (1980)
"Software Architecture for Graphical Interaction," IBM Systems Journal, Vol.19, No.3, pp 314-330.

Wetherbe, J.C. and D.P. Rademacher (1982)
"Computer Graphics," Journal of Systems Management, December 1982, pp 6-9.

Wheelwright, S.C. and S. Makridakis (1980)
Forecasting Methods for Management, Third Edition, John Wiley and Sons, New York.

Withers, S.J. and R.D. Hurrion (1982)
"The Interactive Development of Visual Simulation Models," Journal of the Operational Research Society, Vol. 33, No. 11, pp 973-975.

Young, D. and R.L. Rardin (1983)
"GITPASE: An Interactive Planning Aid For Project Scheduling with Time-Resource Tradeoffs," Joint ORSA/TIMS Conference Presentation, Chicago, April 1983.

Zmud, R.W. (1978)
"An Empirical Investigation of the Dimensionality of the Concept of Information," Decision Sciences, Vol. 9, No. 2, October 1978, pp 187-195.

Zmud, R.W. (1979)
"Individual Differences and MIS Success: A Review of the Empirical Literature," Management Science, Vol. 25, No. 10, October 1979, pp 966-979.

END

14 04 87

FIN