MODEL DEVELOPMENT FOR MULTI-FACTOR
BASED FINANCIAL PLANNING
An Integration of Strategic Concepts

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MODELES D'AIDE A LA DECISION EN PRESENCE D'INCERTITUDE ET DE CRITERES MULTIPLES POUR LA PLANIFICATION FINANCIERE

RESUME

Dans ce cahier, nous décrivons une méthodologie pour le développement et la recherche expérimentale de systèmes d'aide à la décision pour la planification financière dans des entreprises. Nous avons développé un modèle hiérarchique de planification financière dans lequel l'analyse multicritère, l'évaluation des options et une représentation multi-facteur pour exposition des activités de l'entreprise à des changements dans des facteurs externes et internes sont...
1. Introduction

In designing support systems for financial management, it is of interest to understand how financial management decisions in business firms are made. This includes interrelating processes such as (mis-)use of information, judgment, control and decision or choice. The firms' decision system deals with decisions to be taken in external markets (capital market, resources markets), but also considers long term strategy. The decision system itself is organized partly by internal (imperfect) markets, partly by means of procedures. An example which we shall investigate further is the process of resource and capital allocation among several business units in the firm. Support systems for this problem should contain sound theoretical concepts. Financial theory may result in useful concepts (such as risk, value, arbitrage, option) to be employed in support systems, but application of these concepts is guided by situational requirements such as information available, computational complexity, organizational procedures and the negotiation character of many decision situations. These aspects are undervalued in finance theory, which is mainly devoted to decisions in efficient (capital) markets. However, the design of theory through the stadia of testing of these concepts in new situations, experience in practice resulting in observations, and formation of concepts is a process that is of direct practical importance, and may result in interesting concepts as well as in principles for procedures and support systems to be used by financial managers. This paper is mainly directed to the step of integration of concepts in a framework for financial planning.

In this paper, a methodology is described to be used in investigation of financial decision processes and in designing and evaluation of computer-aided procedures for support of these decisions. A model of the firm is designed, on basis of abstract concepts (exposure, risk, options, arbitrage), and this model defines the support system to be used by the firm. This support system is combined with a task structure which allows communication between decision units within the firm which are supported by parts of the model. The approach is to be used in a gaming environment with a simulator software system which is currently in development. In presenting the approach, we concentrate on a simple systems model of a firm which consists of three levels: a strategy
level, a level for demand for resources and allocation of resources to business units as well as efficient supply of resources through markets, and as a third level the utilization of resources for investment projects by the collection of business units. The model formulation which will be presented in section 4 formalizes some actual developments in corporate strategy and is directed to financial and resources policy. It applies also a multi-factor approach for optimal exposure of the firms activities to risk, which is expressed as sensitivities of business results for unexpected variations in systematic factors. The function of the model, which also forms the basis for the simulator system, is to define the context of the paper more clearly and to present a starting point for further model development. An interesting direction of research is the formulation of rule-based models for sub-units which are coordinated by a central level. We therefore should weaken assumptions with respect to complete information as common in hierarchical optimization models, and we shall pay attention to the structure of 'loose coupled' models to be employed by lower decision levels. In constructing such models, it can be shown how, at least theoretically, the financial management system may improve.

Emphasis in developing the approach is on dynamic financial decision situations with strategic interaction among decision levels. Emphasis is also on process (the sequence and type of actions) rather than on outcome. Bottlenecks in financial decision making can be understood more clearly and this may provide a basis for more effective decision support. Also, advice from normative theories can be compared with actual decision behavior and possibly supplemented by decision and coordination rules.

The problem area is financial strategy and capital investment in business firms. In this context, financial management decisions are undertaken at multiple decision centres by decision makers having multiple objectives (often corresponding to claimholders' wishes), various and different information sources to be used in decision support systems, in an environment creating new information (events), new decision problems and new project opportunities, and disciplining management decisions through the capital market. Computational complexity gives rise to decision rules. Decisions are planned and implemented in a set
of procedures which allow delegation and coordination among decision levels. In this structure, financial managers select and transfer information (often in the form of constraints for other decision levels), adapt their and others' decision rules, select and implement plans and so on. In doing so, managers use support systems (forecasting and decision models, data, decision rules, manuals). Thus, object of study is a network of man-computer relations. Of concern is the representation and control of agency-situations, to be considered as instances of (potentially) degenerating learning systems.

The paper is organized as follows. In section 2, the approach is explained. Then, in section 3, we introduce some concepts (multi-factor representation, optional decisions, multiple objectives) to be used in financial models. Section 4 we present a simple model formulation. We conclude with a discussion of experiments to be organized with the approach in section 5.

2. Background and Methodology

2.1 A financial planning experiment
observed by independent observers. We will now present some observations on strategic interactions which resulted from the game.

It could be observed that information was communicated by divisions to the central level in a distorted manner in order to create short-term divisional profits. This was especially the case while the central level did not control the results of divisions. Also, this was stimulated by difference in objectives of central level and divisions. There were, at least informal, instruments for the central level to control results of divisions but these instruments were not used satisfactorily. The central level did not create clear norms for divisions, possibly because the importance of doing this was not clear. Thus, the central level had no clear insight in what was happening at the divisional level. This resulted in divisional goals to be seen as more important by divisional units than corporate goals which were left unclear by the central level.

The planning process that evolved was bottom-up (both top down and bottom up was possible in principle). The reason was possibly the information overload of the central level. Plans were accepted easily by the central level.

Divisional players tried to estimate relations for market share development in time on basis of historical results. Plans apparently were created in such a way to be insensitive for unexpected developments in market growth as well as resulting in highest profits.

Alternatives were generated by divisions in a 'satisficing' manner. There was no software available to produce a 'best' plan, but the Lotus system was used to design and adapt plans in a successive manner. In fact a 'best' plan is difficult to define because outcomes of plans are dependent on other units' actions. New information resulted in adaptation of divisional plans. This was also a reason of information overload of the central level.

From this one-shot case study, it becomes clear that the network of decision units in a firm, at least under the conditions as indicated, results in decision processes that easily may lead to inferior results (in terms of market value of the firm or other central objectives).
Therefore there is an interest in designing procedures and support systems that facilitate control by the central level as well as leaving flexibility as well as incentives to lower level decision units. In the remainder of this section we give an outline of a gaming methodology facilitating design and investigation of such support systems.
In order to explain these experimental objectives, some observations and speculations might be useful. (1) A firm operates through sets of decision rules. Decisions may be operating decisions (capital investments, timing, adjustment of decisions to forecasts) or strategic decisions (choice of constraints, and also 'decisions on decisions': choice and adaptation of rules). Firm decisions and firms' state might at least partially be explained by its decision structure: its set of rules. It is then useful to investigate whether decision support systems may enhance decision making in alternative settings. (2) The well-known agency problem within the firm, and between the firms' shareholders and management, has consequences for alternative modes of (financial) planning. From public and business policy studies it is known that adjusting policies to current forecasts is not always an optimal policy because of (among others) anticipation mechanisms. Rather, inflexible rules will have advantages. Even in statical situations rules might be better than static trade-offs (See Myers [1984] in case of capital structure decision, using an anticipation under information asymmetry argument). A case is then under what conditions agency situations become destructive for learning capacity of the system, and how in dynamic environments financial decision support system might aid a financial manager in optimally adapting to new situations. (3) In real-world decision making, managers not only optimize and design, but also make mistakes and detect and recover from failures. Firms not only optimize, but also engage in insurance and stabilization actions, and corrections. These activities require different types of knowledge. A support system should contain facilities to store, use and adapt these different types of knowledge.

In Fig. 1, the abstract firm and its environment (markets, data-generation) is represented as a decision system with communication flows between decision units. All decision units use a support system (models, data, decision rules).

The over-all methodology consists of the following parts: (1) Development of financial models to be used in a support system (See section 4); (2) Development of a simulator representation of the firm and its environment; (3) Development of a process model in which decisions on decision-making are specified; (4) Creation of represen-
ative financial decision situations (examples: negotiation process, risk sharing process, agency situations) within the context of financial policy formation and implementation by the firm; (5) Use of decision support (decision rules, financial models, multi-factor models, data etc) in the gaming situation; (6) Evaluation of composite parts of the approach; (7) Application in practical settings. The next two sections will introduce concepts to be used in the financial models and will present a simple multi-level model formulation.

![Diagram of Financial Decision System Representation](image)

**Fig. 1** Financial decision system representation
3. Multiple Objectives, Multi-Factor Representation and Optional Decisions in Financial Planning

3.1 Multiple Objectives in Financial Planning

In this paper we are not dealing with interactive procedures for multiple objective decision making (See a.o. Spronk [1985]). Rather we will show how a multi-factor approach for modelling uncertainty as well as the optional character of plans can be integrated in a multiobjective formulation. We start with assuming that the central level as well as the business levels contribute separately to attaining objectives represented by vector $g(x^c, x_i^c)$ where $x^c$ denotes the vector of central decision variables and $x_i^c$ denotes the set of vectors of decision variables in business i (for example, decisions on projects $1(i)$).

Besides these common objectives, businesses i have their own objectives which are not precisely known to the central level. The value of the firm, which should be maximized, then is represented by $V(g)$, including impacts of real as well as financial decisions in plans. We will concentrate to a static formulation where investment decisions create a level stream of cash-flows.

3.2 Modeling Uncertainty Through Factor Sensitivities

A multi-factor approach to the modelling of uncertainty in cashflows can be integrated in an interactive financial planning model (For background, see Hallerbach and Spronk [1986], Goedhart, Schaffers and Spronk [1987]). Outcomes of financial plans are generally uncertain, due to unexpected changes in input data (for example, sales, inflation, interest rates, oil price, market developments). Modelling of uncertainties can be accomplished in several ways, in which we shall have to trade-off aspects like completeness, computability, and user-friendliness. Uncertain outcomes of planning alternatives often are modelled as probability distributions defined on the set of possible outcomes. Decision-makers are then required to assess parameters (mean and variance) of these distributions. In addition, decision-makers have to express their preferences (e.g. utility values) with respect to the

*) Parts of this section are adapted and revised from Goedhart, Schaffers and Spronk [1987].
uncertain outcomes. The information thus provided is then used in the formulation of an objective function (e.g. the expected utility of the decision alternatives). However, in situations with changing environments and incomplete information not all aspects of uncertainty can be modelled satisfactorily.

In the reality of corporate planning, uncertainties often are modeled implicitly in terms of sensitivities of cashflows for changes in multiple environmental conditions. Decisions are taken which result in acceptable sensitivities of the firms' plan for various environmental factors. For example, forms of operational hedging can be designed in which business activities are balanced with the firms' consumption of
In using this approach, objectives which describe the financial plan's sensitivities for unexpected factor changes have to be added to the multiobjective formulation. Thus, when we have \( N \) 'normal' objectives and \( K \) factors, a general first-order approximation for the sensitivity objective function is:

\[
\delta N_k(x^c, z) = [\delta g_1 / \delta F_k; F_k = E(F_k)]
\]

which denotes the sensitivity of objective \( g_1 \) (for example, total cashflow) for unexpected changes in factor \( F_k \) and is a function of decision variables (\( E \) denotes the expectation operator).

Implementation of this approach in a financial planning model is rather complicated. Factors influence firms' cashflows at several levels with different sensitivities. With regard to the risk generating factors that affect the company's cash flows, one can make the following classification:

- systematic (s) risk factors \((F^S_j)\), \( j \) denoting the factor index;
- idiosyncratic risk factors which can be subclassified in company (c) specific factors \((F^C_j)\), unit (v) specific factors \((F^V_{jw})\) and a random disturbance \( \epsilon \) \((f, w \) denoting factor indices).

Through application of this classification to the multi-factor model we obtain:

\[
CF_l(i) = E(CF_l(i)) + \sum_j \beta^S_l(i)j (F^S_j - E(F^S_j)) + \sum_f \beta^C_l(i)f (F^C_f - E(F^C_f)) + \sum_w \beta^V_l(i)w (F^V_{jw} - E(F^V_{jw})) + \epsilon
\]

\((CF_l(i))\): cash flow for project \( l(i) \) in business \( i \), \( \beta^S_l(i)k \): sensitivity of cashflow \( l(i) \) for factor \( k \in \{j, f, w\} \) of class \( z \in \{s, c, v\} \); \( \epsilon \): random disturbance; \( E \) denotes the expectations operator.

As sources of the systematic risk represented by \( F^S_k \), Chen, Roll and Ross [1986] suggested unexpected changes in growth of industrial production, in the inflation rate, in the long term real interest rate and in the risk premium in the stock market. These four factors are supposed to influence the returns of all securities. The company- and unit specific factors can be chosen in such a way that they are both
mutually independent and independent of the systematic risk factors, but this does not need to be necessary. A company specific factor could be e.g. the price of natural resources used, a unit specific risk factor could be the autonomous growth of its sales market. The distinction between the three kinds of risk is useful because of the diversification opportunities that arise at the different levels of aggregation of the cash flows.

To the financial market the only important risk is the systematic risk of the company in terms of its cash flows' sensitivities to the systematic factor movements. Thus, only for the sensitivities ($\beta^s_k$) a risk premium on the stock market return is required. For central management, however, the company specific factors may form a substantial source of risk, as it lacks the diversification effects of a large well-chosen portfolio. The unit specific factors in turn are non-systematic.
\( \eta = \frac{\eta_1(x^2(x))}{\sum_i x_i \psi_i}; \quad \psi_i: \text{price of resource } \psi; \quad \eta: \)
decisions on central financial instruments or local investment activities as well as decisions on central resources (for example, the unused amount of resources) can be interpreted and valued as options or option-generating decisions. For example, some of the central or local decisions may involve costly activities such as research and exploration, which may create 'good' investment projects later in time when circumstances are profitable (this involves a timing problem of exercising the option after acquiring the option). Also, the level of central resources can be chosen such that an unused part kept in reserve by the central level facilitates investment in a 'good' project that comes up at the operational decision levels later in time. In addition, projects may have other optional properties (such as the possibility to postpone or to expand or adapt the project) that increase their value and therefore should be valued*).

The optional value of decisions on activities at the central or business level can be included in one of the central objective functions. In general, this optional value is a function of (among others) the amount of investment in central or business project activities $x^C$ and $(x_1)$ (the cost of exercising the option), the value of assets generated with $x^C$ and $(x_1(\mathbf{i}))$, the risk of the activities, and the expiration times of the options. With respect to reservation of central resources $s_j$, which is treated as an 'activity' by the central level, the first problem is to value this amount and to compare this with its opportunity cost. As with the option-generating activities $x^C$ and $(x_1(\mathbf{i}))$, we have an optimal timing (and postponing) problem of activities which come up later in time and which are made possible by the reserve $s_j$, but this problem will not be dealt with here (a general structure is given in 3.3). As explained later in more detail, decision units i specify a value function $O^i(s_\mathbf{i})$ which represents the optional value for unit i of a vector $s_\mathbf{i}$ of additional resources $s_j$, kept in reserve by the central level for unit i. This function may be approximated by unit given a set of candidate future projects with their resources needs. At the central level, the aggregate value function $O(g)$ is included in the multiobjective problem and is to be traded off with other goal functions in vector g.

*) See Mason and Merton [1985] for an overview of valuation methods and further literature on the subject.
The optional value of central slack $g$ which is distributed to business units $i$ ($g_i$) and the central level itself ($g^c$) and decisions on activities is thus introduced as a goal variable:

$$g^c_4(g) = g^c_4(g^c) + \sum g^i_4(g_i)$$

Functions $g^c_4(g^c)$ and $g^i_4(g_i)$ are deduced from option value functions $O^c(g^c)$ and $O_i(g_i)$ ($i = 1, \ldots, I$), which are assumed to be calculated using option pricing theory.

3.4 General Structure for Real Optional Decisions

Brealey and Myers [1984], and Myers [1984] indicate financial planning as 'management of a portfolio of options'. We will show in a qualitative way how, in principle, the option perspective can be applied in organization of investment decisions. There exists a logical structure between 4 categories of real options for each business activity:

- growth-options (for instance, investment in promising activities);
  these options can be created for example by R&D investments and will be important at a strategic level;
- options with respect to timing or postponement decisions (for instance, postponement of an investment in development of a new product);
- options with respect to continuation or stopping decisions;
- options with respect to adaptation decisions, for instance change of products in process industry as a consequence of changing economic conditions.

At each decision level, the decision problem can be divided in:
- acquisition of options (investment decisions)
- exercising the options (postponing, production or adaptation decisions).

A business activity thus can be represented as a combination of types of options, to be managed by decisions on options connected with that activity. Thus, the aggregate problem of investment decision making can be
results from lower levels. The hierarchical structure is indicated in Fig. 2. At level 1, central management allocates strategic resources to divisions on basis of valuation by the divisional level of its optional decisions. The division consists of a number of return generating activities (level 3A) to be executed by projects. These projects use strategic resources. Business activities are using strategic resources as well as projects, thus a problem of optimal project planning exists (level 3B) to be solved by valuation of postponement options. Divisional management solves a trade-off between benefits, generated by project-using activities and costs of project planning. Problems at levels 4 and 5 can be solved given states resulting from higher levels; solutions for these problems are used in solving higher level problems.

The elements of the approach as described give rise to a decomposition of the over-all goal-optimization problem in a set of level problems to be solved by decision units within an information and coordination structure. The levels and the problem formulations are represented in Section 4.

Fig. 2 Hierarchical Structure of optimal decisions

LEVEL 1
- Central Management
- Acquisition of growth options
- Distribution of growth options over divisions

LEVEL 2
- Divisional management
- Allocation of resources over projects with different optional characteristics

LEVEL 3A
- Use of projects for activities; demand for resources

LEVEL 3B
- Project planning
- Timing of projects
- Postponement

LEVEL 4
- Stopping/continuation decisions

LEVEL 5
- Adaptation decisions
4. Multi-Factor Based Financial Planning Model

4.1 Introduction

In this section, we develop a systems model of a firm in terms of its characteristic activities (use of resources, development of resources, coordination of supply and demand of resources) and its environment (resource markets). Prices of resources are sensitive for various systematic factors. The firm is organized in three levels: (1) a strategy level; (2) a resource allocation and supply of resources level; and (3) a business unit level. Upper levels coordinate lower levels by means of coordination parameters. Several possibilities exist here: price coordination (non-feasible method), budget coordination (feasible method). We will use a form of budget coordination, applied to a vector of resources. The firms optimum decisions are the result of coordination of supply and demand of resources. Demands of resources stem from the needs of business units activities. These activities result in returns and cashflows. Supply of resources at a certain level results in costs and risks. Risks are treated as sensitivities of returns for systematic factors. Costs, returns and risks are traded off at the coordination level.

Systems methodology has been developed primarily for large-scale systems (See: Singh and Titli [1978], Himmelblau [1973], Haimes [1982]). The framework we present, integrates methodologies of systems theory (hierarchical optimization) with the multi-factor approach. The objective is to derive a basic set of models suited for description and control of the firms financial and real operations, and to be used in experiments (See section 2, 4). Of course, the framework can and should handle multiple objectives of the firm, and should allow dynamic optimization, but for expository reasons the firms' objectives are represented by its market value and the formulation is static. However, development of resources by means of planning capacity expansion of projects, and planning of activities by units, is possible in the framework. Also, it will be shown that options can be integrated in the framework. We will indicate also possibilities for design of stochastic optimal control models. The framework formalizes some actual developments in corporate strategy (See for instance Naylor [1984]). These developments involve
design of explicit resource strategies for competing businesses. We show how these approaches easily can be integrated by the desire for optimal exposure of the firms activities to multiple risks.

4.2. Notation

In next section, following notation is used:

\( i,j,k \): index for respectively units, resources, systematic factors

\( l^i \): project (activity) available for \( i \) (vector: \( l^i \))

\( b_k \): sensitivity of company return for factor \( k \)

\( \mu_{ik} \): sensitivity of cashflow of business \( i \) for factor \( k \)

\( \alpha_{jk} \): sensitivity of price \( p_j \) for factor \( F_k \)

\( \phi_{jk} \): sensitivity of price \( \pi_j \) for factor \( F_k \)

\( z^j \): vector \( (z^j) \) of restrictions for the totality of resources
All subscripts i for vectors and matrices denote application to business units i; symbols underlined denote vectors. E denotes an expectations operator; ( ) denotes a set.

4.3. Problem formulation

We present a rather simple formulation, based on adjusted present value maximization. Thus, value function \( V(g) \) in Section 3 is operationalized in a specific way. We will abstract from \( g \) and concentrate to objectives such as firm cash flow \( (g_1: \sum_i CF_i) \), optional slack value \( (g_4: \sum_i 0_i) \), and sensitivities of business returns for systematic factors \( (g_{N+K}: b_k) \). In this formulation, operational cash flows \( CF_i(x_i; p) \) from i-th business activities are assumed to consist of products of output levels \( x_i \) and prices \( p \) (revenues minus allocated cost). The value of the firm \( V \) is composed of the unlevered value \( V_U \) and value of financial side-effects \( V_F \). \( V_U(x, p, k^U, K) \) is a function of product output levels \( x \), output prices \( p \), investment \( K(x) \) in the totality of external acquired resources including slack supplied by resource markets \( x_1 \) which is a product function \( \pi^T x_1 \) of resource prices \( \pi \) and resource quantities \( x_1 \); and opportunity cost of capital \( k^U \), representing business risk. Available resources \( \bar{x} \) can be supplied by resource markets \( (\bar{x}_1) \) with prices \( \bar{\pi} \) or by own activities \( (\bar{x}^2) \); \( \bar{x} = \bar{x}_1 + \bar{x}^2 \). The present value of central (financial) decisions \( V_F(d) \) is a function of financial decisions \( d \). In addition, \( V \) consists of optional value of slack \( O(g) \) which is a function of slack vector \( g \) and which presumably can be derived by specifying a return generating process of businesses i and deriving the riskless hedge. Also, \( O(g) = \sum_i 0_i(g_i) \).

The function \( V_U \), representing unlevered net present value of cashflows generated with vector of resources \( x_1 \), in its static form can be written as:

\[
V_U = -K(\bar{x}_1) + (1/k^U) \sum_i [\pi^T x_1]
\]

The cashflows are discounted by \( k^U \) which is, following a arbitrage equilibrium approach, a function of sensitivities \( b_k \) of company return \( R \) for systematic factors \( F_k \), risk-free return \( r_F \) and prices \( \Omega_k \) for these sensitivities which are obtained from the capital market or alternatively can be estimated by the firm:
\[ k^U = r_f + \sum_k b_k \Omega_k \]

Company expected return \( E(R) \) and function \( b_k \) can be written as follows:

\[ E(R) = \left[ \sum_i (\mathbf{\Sigma}^T \mathbf{\pi}_i) \right] / K(\mathbf{\xi}^1, \mathbf{\pi}) = H(\mathbf{\xi}^1, \mathbf{\pi}) \]

\[ b_k = \delta H/\delta F_k = b_k[\mathbf{\xi}, \mathbf{\xi}^1, (\delta p_j/\delta F_k), (\delta \pi_j/\delta F_k)] \]

Functions \( b_k \) can be expressed in sensitivities of \( p_j \)'s and \( \pi_j \)'s for \( F_k \)'s which should be available as data, as well as vectors \( \mathbf{\xi} \) and \( \mathbf{\xi}^1 \). In the decomposition approach explained below, sensitivities \( b_k \) are to be obtained from sensitivities of business cashflows \( \mu_{1k} \) for systematic factors \( F_k \). Sensitivities \( \mu_{1k} \) then can be obtained from \( (\delta p_j/\delta F_k) \), \( (\delta \pi_j/\delta F_k) \), \( \mathbf{\xi}_1 \), \( \mathbf{\xi}^1 \):

\[ \mu_{1k} = \delta CF_1(\mathbf{\xi}_1, \mathbf{\pi}) / \delta F_k = \mu_{1k}[\mathbf{\xi}_1, (\delta p_j/\delta F_k)] \quad ; \text{ and:} \]

\[ b_k = \delta H(CF_1)/\delta F_k = b_k[K(\mathbf{\xi}^1, \mathbf{\pi}), R(CF_1), (\delta CF_1/\delta F_k), (\delta \xi/\delta F_k)] \]

where \( (\delta \xi/\delta F_k) \) is a function of \( \mathbf{\xi}^1 \) and \( (\delta \pi_j/\delta F_k) \).

In defining its policy, the firm may set constraint levels \( \beta_k \) for \( b_k \), or alternatively may set weight levels also denoted by \( \beta_k \) in a process of multi-objective optimization. In the first case, optimization at the central level results in Lagrange multipliers \( \lambda_k \), which are to be interpreted as:

\[ \lambda_k = \delta \mathbf{V}/\delta \beta_k \]

These \( \lambda_k \) can be compared with \( \Omega_k \). In the second case, optimization results in \( b_k \). Then, prices \( \Omega_k \) for sensitivities can be compared with weights \( \beta_k \).

Decisions to be taken in order to optimize the firms' objective function are slack \( \delta \) kept in reserve, resources to employed \( \mathbf{\xi} \), outputs to be produced \( \mathbf{\xi} \). Our formulation implies that project decisions are already implied in decisions on \( \mathbf{\xi} \), but the problem formulation easily can be adapted to take these more specific decisions into account (See Goedhart, Schaffers and Spronk [1987]). Constraints (for example, sources-uses constraints, production possibilities) are denoted by:

\[ G(\delta, K(\mathbf{\xi}, \mathbf{\xi}^1), \mathbf{\xi}, \mathbf{\pi}, \mathbf{\xi}) = 0 \quad ; \mathbf{\xi} \in X \]
Thus, the firm has as its over-all objectives:

1. maximize net present value of cashflows generated:
   \[ \text{MAX } [V_U(x, z, K) + V_F(d)] \]

2. maximize the optional value of resource slack:
   \[ \text{MAX } \sum_i O_i(z_i) \]

3. minimize sensitivities of returns for systematic factors:
   \[ \text{MIN } [b] \]

Organization of the decision process in which this is accomplished follows from a decomposition structure. Business units \( i \) maintain an output level \( x_i \) (a vector consisting of elements \( x_{1i} \)) over all \( i \) in order to support cross-activities (\( A_x \)), production of resources (\( C_x^2 \)) and final output (\( y \) with elements \( y_{1i} \)), such that

\[ x = A_x + C_x^2 + y \]

Resources available (\( \xi = x^1 + x^2 \)) will be divided among resources necessary for \( x \) (\( D_x \)), resources necessary for \( x^1 \) (\( Z_{x^1} \)) and slack \( s \):

\[ \xi = D_x + Z_{x^1} + s \]

Here, \( Z_{x^1} \) is a vector with only one non-zero element at position \( 1 \), denoting the investment \( K(x^1) \) necessary for resource level \( x^1 \).

Decomposition Structure

The Lagrangian to be maximized for the problem is:

\[ L(x, y, x^1, x^2, \lambda, \xi, s; p, z) = V(y, p, x^1, s) - \sum_k \lambda_k(b_k(y, x^1) - \beta_k) + \sum_i O_i(z_i) + \xi^T(x - A_x - C_x^2 - y) + \xi^T(D_x - Z_{x^1} - s) + s^T G(x, y, z, p, z) \]

This formulation lends itself to decomposition as is shown in next sections (See Fig. 3). The decomposition is based on budgets for resources. Thus, the firm follows an explicit resource strategy. The decomposition proceeds by coordination parameters:

- The strategy level (1) uses \( z^1 \), a vector of restrictions for external resources \( x^1 \) and \( s \), a vector of restrictions for slack \( s \). It receives as results from the second level: optimal \( y(z^1, z) \) and \( K(z^1) \), and furthermore the corresponding Lagrange multipliers.
- The resource allocation level (2) uses \( z^2 \) as vectors for restrictions...
for resources to produce by units 1, and \( h_i \) as a vector for resources available for units 1. It receives as optimal decisions from units 1: \( x_i(g^1, h_i) \), \( x_i(g^1, h_i) \) and corresponding lagrange multipliers.

- The resources supply level (2) receives \( g^1 \) and returns optimal \( r^1(g^1) \), \( K(g^1) \) along with lagrange multipliers for resource levels.

**First level: Strategy and Financial Policy.** The first level provides a long-term view in development of product and factor markets, diversification of activities, development of resources. Its objective is to maximize firm value and to secure continuity. It matches demand and supply of resources. Therefore, this level designs a resource strategy, along with financial policy (dividend decision, financial structure, etc). A vector of external resources capacities \( g^1 \) is sent to the demand and supply at the second level in order to maximize over-all value of the firm. The value of the firm is decomposed in an unlevered part \( V^U \), to be optimized by the resource allocation to business units 1, and a financial part \( V^F(d) \), \( d \) denoting strategic financial decisions, to be included at the first level.
Fig. 3 Decomposition structure

**LEVEL (1)**

**Strategy and Financial Policy level**

\[
\begin{align*}
\text{MAX} & \quad \nu(U[y(a^1, g), b(\mu(a^1, g)), K(a^1, z)]) + \nu_F(d) + o(g) \\
& \text{subject to} \quad C[d, K(a^1), y(a^1, g), p, z] = 0
\end{align*}
\]

**LEVEL (2)**

**Resource allocation**

\[
\begin{align*}
\text{MAX} & \quad \sum_i C_F(x_i, p; a^1, g) + \sum_i o_i(a_i) \\
& \sum_i x_i \geq \sum_i a_i 1 + \sum_i a_i^2 + \sum_i x_i \\
& a^1 + \sum_i a_i^2 \geq \sum_i h_i + 2a^1 + \sum_i a_i \\
\implies & \; x(z, a^1), x(z, a^1)
\end{align*}
\]

**LEVEL (3)**

**Business units i**

\[
\begin{align*}
\text{MAX} & \quad C_F(x_i; z^2_i, b_i) \\
x_i = a_i x_i + c_i a_i^2 + x_i \\
D_i x_i \leq b_i \\
\implies & \; x_i(z^2_i, b_i), x_i(z^2_i, b_i)
\end{align*}
\]

**Supply of resources**

\[
\begin{align*}
\text{MIN} & \quad K(z^1) \\
& \; x^1 \leq a^1 \\
\implies & \; x^1(z^1, z^1), K(a^1)
\end{align*}
\]

**Markets for resources j and products**

\[
\begin{align*}
\pi_j = E(\pi_j) + \sum_k \phi_{kj}^* [F_k - E(F_k)] \\
p_j = E(p_j) + \sum_k \phi_{kj}^* [F_k - E(F_k)]
\end{align*}
\]

**Systematic factors F_k and factor sensitivities**

\[
\begin{align*}
\sigma_k = [\delta p_j/\delta F_k \mid F_k = E(F_k)] \\
\phi_k = [\delta \pi_j/\delta F_k \mid F_k = E(F_k)]
\end{align*}
\]
are not independent of future optimal decisions to take. State variables (and input variables) not always can be measured with certainty due to measurement error. Parameters may vary in time and may be stochastic. Therefore, parameters and states should be re-estimated properly. For instance, it will be necessary to adjust factor sensitivity vectors \( \theta \) and \( \varphi \). This might be seen as a filter problem. The problem is made much more complex when also state variables (or non-controllable input variables) cannot be measured properly. We then can apply Kalman-filter theory. However, especially when we have non-linearities, multiplicative uncertainties (products of state variables and/or control variables and stochastic parameters), the computational problem becomes formidable (Kendrick [1981]).

When the problem is deterministic with quadratic objective function and linear state equations, the optimal policy is a linear (in state variables) decision rule. This holds also when uncontrollable inputs are introduced. When measurement error is introduced, the problem is one of estimating states (by Kalman-filter theory) and optimal control. When objective functions are quadratic (in state variables and control variables), for instance in terms of firm value, dividend decision, financial structure etc at times \( t \) over a horizon \( T \), when we have multiplicative uncertainties and when states are measured with measurement errors, algorithms can be designed for passive and active learning (Kendrick [1981]): 'passive learning' denotes re-estimation of parameters and states while 'active learning' also takes into account the existence of future measurements and thus takes into account the information value of decisions.

In our problem it is in principle necessary to (re-)estimate parameters (sensitivities of returns to systematic factors) and to optimize the policy of the firm simultaneously. Factor values can be considered as uncontrollable input variables, of which the impacts (unexpected factor movements) should be controlled (optimal exposure policy). An
deterministic control algorithm might be used to compute a long term strategy trajectory, to be revised each time period. Decision variables are resources constraints and weights for sensitivity levels. At the second level, each time period decision rules are used to adapt to objectives, resulting from the first level. This results in resource allocations to business units. Time lags between decision and results can be included. Along such lines, effectiveness of the decision structure in attaining 'good' and stable results might be assessed.

Fig. 4 Learning Model

LEVEL 1

Objectives Design + Objectives Setting in Time (Trajectory)

LEVEL 2

Control:
Decision Rules
Resource Allocation

Process:
Business Activities

Identification of Factors Fkt

Estimation of Sensitivities bkt

Due to problems of incomplete information and asymmetrical distribution of information over decision levels, and furthermore incentive
contain knowledge with respect to activation of specific submodels, thus broadening the support system to a computer-assisted rule-based system.

5. Experimental Investigation of Financial Planning Behavior

5.1 Structure of a financial planning simulator

Currently, we are developing software on basis of principles explained earlier. As a first step, we have developed a planning
Fig 5  Structure of capital investment process simulator

1. START
   ↓
2. Initialization

LEVEL 1
3. Identification of the situation
   ↓
4. Choice of tasks

LEVEL 2
5. Financial management
6. Setting of objectives and constraints
   ↓
7. Financial management
8. Test of individual business plans
   ↑
9. Financial management
10. Consolidation
11. Business units
12. Financial management
13. Design and test of financial policy
14. Accept

Accept (+) or reject (-)
proposals follow. Another possibility, in analogy of parallel processing, is to actively choose and evaluate at level 1 the sequence of tasks to be executed at level 2.

This task structure follows from the general conception of the strategic and operational management process, modeled as hierarchical coordination of supply and demand of funds, as explained in section 4. The demand side embeds the use of resources in business units; the supply side models the efficient generation of basic resources and price movements on markets. The multi-factor approach for representation of returns in terms of expected returns and a set of sensitivities for systematic factors can be integrated in a very natural way in this conception. Also, the optional character of decisions (for instance, on slack, or types of projects) shows a promising potential for integration (See also Goedhart, Schaffers and Spronk [1987]).

5.2. Experimental Task Structure Settings

In Fig. 6, an overview of experimental task structure settings is given. These settings are meant to coordinate tasks among decision units. Three basic options are shown. In the simulation option, there is no human user. The behavior of the system with respect to several factors can be investigated. These factors are, among others, mechanisms for generation and selection of alternatives, environmental shocks or disturbances, production rules which guide information dependent on...
In the adaptable task structure, two subcases are distinguished. In case A, there is a continuous task selection by one single decision maker, while all other tasks are executed automatically. But also parts of the task at hand can be automated by using decision rules as specified by the decision maker. In case B, this can be done by more than one decision maker.

Fig. 6 Classification of experimental task structure settings

```
start

Selection of modes:
1. simulation of the system
2. man-computer interaction with fixed tasks structure
3. man-computer interaction with adaptable task structure

1. simulation
   Choice of Experimental Parameters
   A Single level, single user
   B Single user, multiple tasks
   C Multiple users, multiple tasks

2. fixed task structure
   A Single level, continuous task selection
   B Multiple users, division of multiple tasks

3. adaptable task structure
   A Single user, continuous task selection + automation of tasks not chosen
   B Multiple users, division of multiple tasks + Continuous task selection + Automation of tasks not chosen
```

An important element of the simulator as proposed here is that it is possible to generate different decision situations. Not only it is a testing environment for theoretical frameworks (for instance the multi-factor approach), it is also possible to use it in generating several kinds of agency-situations. While it is very difficult to attain valid conclusions from experiments in which the objective is to test a theory, or to link decision behavior to decision setting, it is very well possible to
isolate characteristics of decision situations resulting consistently in specific decision performance.

5.3 Experiments in Gaming Situations

Currently we are defining experiments which will be carried out with the gaming system as described* (See also section 2.1). We will give a general indication of the possibilities.

First, it is attempted to represent agency-situations in our framework. This provides a means to investigate the various hypotheses from agency theory and to compare mechanisms that mitigate agency problems.
It would also be fruitful to investigate the many links between mathematical control theory and factor models more systematically. In the context of decision support, the factor model should be adapted continuously. New data will make re-estimation of models necessary. Thus, the control and decision problem is a combination of model identification (where filter methods possibly can be used) and optimization using the estimated model. Also, not only minimization of


