KM 9 (1983)
pag 123-151

Fund Management for R&D under Uncertainty

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ABSTRACT

An integrated data base and budget allocation system is presented for the management for R&D funds. Concerning the R&D-projects it is assumed that: (i) progress can be checked on a limited number of sequentially ordered stages, (ii) the outcomes of the stages may be subjected to uncertainty concerning termination, (iii) execution of the stages can be speeded up by allocating (additional) subsidies, (iv) a stage can be subsidized only if its preceding stage is terminated succesfully, (v) utilities or benefits of the projects are valuated by one- or multi-dimensional cardinal data, and (vi) the utility data of all projects are mutually compatible. In this context, the system might be applied successfully for subsidy management over many projects with different budgetary needs.

Keywords: Fund management, budget allocation, R&D management, project management.

CONTENTS

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0. Introduction.

At the end of 1980, the Commission of the European Communities, Directorate-General for Science, Research and Development (XII/D/5) initiated a research project devoted to the problem, how to allocate budgets for the development of new energy technologies. Under the supervision of Dr. E. Römberg and Dr. E. van der Voort, three research teams (KFA, Jülich Germany; CORE, Belgium; Twente University of Technology, the Netherlands) formulated a global set-up of the project, and a global set-up for a pilot implementation. With respect to the data and data-handling of R&D-projects and the development of practical budget allocation techniques, three aspects were distinguished:

- Technological Data; in the form of temporal structures, technological relations, uncertainties in progress and feasibility, cost/benefits, and stimulating effects of additional budgets (German team).
- Long run models on demand/supply of energy forms, in order to trace the economic returns of energy technologies, fuel supply aspects, and social utilities (Belgian team).
- Data structuring and budget allocation procedures, in order to provide a practical support for budget allocation decisions and progress evaluation (Dutch team).

The first analysis on data structuring and budget allocation procedures was undertaken by the author in cooperation with Dirickx and Brouwer. One of the first findings was that the topic has received only little attention in the literature. A second finding was that, because of the complexity of the technological relations in R&D for energy technology and the complexity of cost/benefit analysis, an enormous reduction of this information was inevitable. As a matter of fact, instead of starting from the technological relations, it was necessary to relate the database and the allocation procedure directly to the management viewpoint. Thus, it was decided to formulate the problem in terms of a sequential stochastic decision problem where each R&D-project is represented by a simple sequential structure and where the optimization technique is based on (what we have called) trade-off values of the fund-budgets.

In a summarized form, the present paper reports about the further development and elaboration of this approach, its consequences with respect to the implementation, the interactive computer system for data handling, and some cases. The computer codes are developed in cooperation with Droste, Hueting and Knol. The complete report, containing all technical details and the computer codes, will be published separately.

In order to disconnect the problem from its specific context and to stress its essentials, the budget allocation activities are described in general terms. First, there is the project management, being any organization which is an applicant or potential applicant of R&D-budget. On the other side we have the fund management, being one single (collective) organization controlling the R&D-funds. The R&D-projects under consideration are supposed to possess the following features:

(1) progress of the R&D-project can be checked on a limited number of sequentially ordered stages;
(2) the outcomes of the stages are subjected to uncertainty concerning termination;
(3) stages can be speeded up by allocating subsidy;
(4) the utilities or benefits of the R&D-projects are valuated by (eventually multi-dimensional) cardinal data.

Finally we have the material decisions taken by the fund management in the form of rejecting, postponement, allocation or continuation of budgets. In this manner a general Fund Information System is presented which might be applied successfully for subsidy management for projects with different budgetary needs, but such that the benefits are mutually compatible.

The first section presents a general sketch of the fund management problem under uncertainty, and a overview of the fund information system which is in fact the topic of this report. Next, in the sections 2 to 7, the fund information system is introduced and discussed at the users level.

1. Decisional aspects of Fund management for R&D under uncertainty.

First it should be noted that the project management on one side, and the fund management on the other certainly are different parties. Striking differences can be observed concerning their interests, responsabilities, organizational form, and their information base. Because of this, but also in order to introduce a more or less objective basis for the comparison of different projects, it is necessary to standardize the interface between project management and fund management. In this context, the interface is understood as the integrated whole consisting of a standarized description of a project, a subsidy allocation procedure, and a progress evaluation procedure related to the nature and the goals of the fund.

The description of a project must provide sufficient data to evaluate its progress over a suitable time span. This means that the project has to be subdivided into a number of sequentially ordered stages with a planned duration. With the end of each stage a specification is given, providing sufficient criteria for the project management and the fund management to agree about one of the following outcomes:

(1) the stage is terminated successfully, implying allocation of subsidy for the succeeding stage (if any);
(2) completion of the stage is delayed, but there are sufficient prospects to justify allocation of additional budget (if required) in a planned manner;
(3) the outcome of the stage is such that the entire project must be stopped; i.e. no further budgets will be allocated.

A standarized description of these data, to be discussed in section 2, will be called the progress evaluation schedule. It is important to notice that a progress evaluation schedule may effectuate a substantial contraction of data. Particularly large scale R&D-projects usually are constituted of many interrelated subprojects, giving rise to complex technological networks and related management techniques. Such project descriptions are pointed to technological relations, detailed progress reporting, internal bookkeeping purposes, and so on. Without filtering and contraction the cumulation of these data concerning different R&D projects would lead to an enormous information overload to the fund management.

Now, an important question is: who has to filter and concentrate the project information into the standard form of a progress evaluation schedule? For at least two reasons the principal responsibility for this task has to be assigned to the project management. First, because of the fact that only the project management is able to judge the merit and the reliability of its own project data. A second reason is that, even under supervision of the fund management the main initiative to finance and to execute the R&D-project remains with the project management. Progress schedules are discussed in section 2.

Apart from the progress evaluation schedule, also data are required in order to appraise the benefits of a project in the case of successful completion, or possible also in the case of failure. These utility data may cover different aspects like economic returns, technological, social and ecological aspects, and so on. In addition, the valuation might be subjected to a time-preference ordering. Following the usual practice, these mostly subjective data have to be quantified, in order to arrive at objective standards within which the weights of the constituting aspects may be varied. The first responsibility for collecting these data must be assigned to the fund management. First, because the valuation has to be compatible with the goals of the fund. Secondly, because in the valuation procedure different projects must be compaired mutually. Of course, within a general procedure for utility valuation, it can be asked from the project management to give specific data concerning the benefits of the projects. Utility aspects ar the topic of section 3.

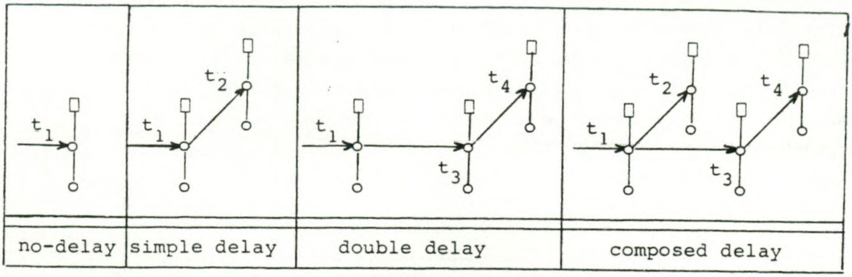
The fund management problem is understood as a budget allocation problem under limited financial resources, where the basic fund budgets for each period is known in advance. This implies that the expected financial consequences of any subsidy policy for the running and the candidate projects has to satisfy the budget restriction over the present and all future periods. An important consequence of this approach is, that the utility figures of the projects not need to be absolute; i.e. it suffices to compare mutually the utility indicators of the projects.

In the case that a fund is divided into subfunds for different (internally more homogeneous) categories, only projects within aspects of fund management are discussed in section 4.

As a consequence of the uncertainties in R&D and the complexity of the utility valuation aspects, it is extremely important that the budget allocation procedure is sequential and adaptive. Therefor a shifting dynamic procedure is proposed, with a fixed cycle time of one budgetary period. Amply before the end of each period, the progress realizations of the running projects will be evaluated (if necessary), and inserted in the dynamic decision procedure, together with the new candidate projects. Next, within the contractual commitments of the fund and the budgetary limitations, a (possible) best or optimal subsidy program is selected for the first future period, but such that consistency of future developments under "optimal" subsidy policies is preserved. The Fund Information System is designed in order to support this management adequately. It contains all bookkeeping and budget allocation tools for an interactive experimentation, where all kinds of data can be varied, and where the consequences in the form of subsidy proposals are displayed in a few minutes. In fact the procedure might be considered as a comperative cost/benefit analysis under uncertainty. It is in the interest of the project management that their application is based on realistic information about the project. Of course, modest subsidy requirements, highly valuated utilities, high probability of success on short term, etc. will increase the chances of subsidy being granted. However, on the other hand, over optimistic data will increase the actual probability that progress evaluation results into "failure" and consequently into removement of the entire project from the subsidy roll. In this manner the conditional nature of the subsidy flow, as induced by the dynamic structure of progress evaluation, guarantees some degree of "cheat-proofness". In principle it is possible to strengthen the effect by requiring (partially) repayment of subsidies in case of failure. It is important to recognize that such a complex matter as fund management under uncertainty requires a very transperant procedure where the reduction of data, the comparison of project, and the contractual commitments are well structured.

2. Project data.

As argued before, progress evaluation requires that the project must be subdivided into a limited number of sequentially ordered stages. In order to keep the data manageable, a simple unified scheme for the description of each stage is required. Thus, concerning the time-scale, we restrict ourself to a sequence of periods with equal duration. All time-data will be expressed in an integer number of periods. For the description of each stage, the project management has the choice out of four standard schemes:



Successful completion of the stage is symbolized by , whereas failure is symbolized by . The "no-delay" option shows only one single evaluation moment, being planned at a number (integer!) of t_1 periods after the start of this stage. In this scheme delay is not expected and consequently after t_1 periods one has to decide, whether the stage is completed as a success or as a failure. Remark: the terms "success" and "failure" are taken fully neutral; one also may think in terms like "yellow" and "blue". The "simple delay" case shows a planned expectation of a delay over an additional time span t_2. So, after the first term of t_1 periods, the stage turns out to be successful delayed, or to be a failure. After the additional fixed time span t_2, in case of delay, and (possibly) an additional budget, the stage terminates either as a success or a failure. The simple delay option is relevant if, if any way at least a state of "near-completion" will be realized.

Next, in the "double delay" option a delay over possibly two time spans t_3, t_4, can be expected, and consequently two additional budgets may be allocated. Finally, the "composed delay" option encloses both the simple delay and the double delay options. Indeed, the other may be considered as special cases, just by putting one or more probabilities of delay equal to zero. Therefore, we restrict further discussions to the "composed delay" option.

In order to keep the allocation problem as simple as possible, the ratio between the probabilities on success and failure are the same for all termination points, i.e. independent with respect to delay. To the "no-delay" case, only one budget can be allocated. For the schemes with delay expectations, different (say maximal three) budget schemes can be proposed. Each budget scheme specifies budgets for both the non-delayed execution state and the delayed states. The budget schemes only affect the probabilities of delay (high budget scheme, low probabilities of delay); the probability ratio of success and failure remains unchanged.

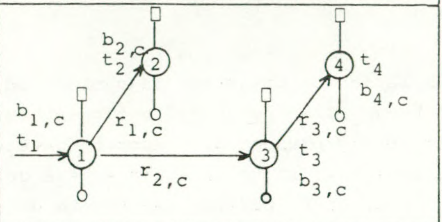
Data structure with $c = 1,2,3$ as index for the budget scheme

p probabilities on success

q probabilities on failure

r probabilities on delay

t execution times



In order to get an impression of the flexibility of the progress evaluation schedules, consider the following example with two budget schemes, where the absolute probabilities on termination after $\tau = 1,2,3,\ldots$ periods after the start of the stage, are deduced from the conditional probabilities of delay as represented by r.

Probabilities on termination, given $t_1,t_2,t_4 = 1$, $t_3 = 2$												
budget scheme				prob.delay				abs.prob. on termination				
b_1	b_2	b_3	b_4	r_1	r_2	r_3	p:q	$\tau = 1$	$\tau = 2$	$\tau = 3$	$\tau = 4$	$\tau > 4$
10	5	10	5	.1	.9	.5	8:2	.0	.1	.45	.45	.0
20	10	0	0	.5	.0	.0	8:2	.5	.5	. 0	. 0	.0

The subsidy contract also can regulate the repayment of subsidy, after termination of a stage or the entire project. Of course the repayment might be arranged in any suitable manner and in any suitable proportion. However, in order to keep the nature of the budget allocation procedure sequentially, only arrangements can be taken in consideration where the (partially) repayment of the subsidy over a stage (if any) is independent with respect to the subsidy schemes and the progress realization of the succeeding stages. Practically it looks reasonable to specify for each separate stage the repayment (if any) such that:

(1) the repayment consists of the sum of a fixed amount and a fixed proportion of the actual total subsidy over that stage; these quantities may differ for successful termination and failure;
(2) the repayment will be effectuated in a limited number of periods after termination of the stage, in such a manner that in each of these periods the same portion will be returned;
(3) repayments never exceed or anticipate on (at present cumulative values) subsidies. More specific, the total repayment of the subsidy over a stage is arranged in the following manner.

Repayment over a stage, given actual total subsidy: b			
success	$\beta(g+b)$	coefficient for success	β
failure	$\gamma(g+b)$	coefficient for failure	γ
Fixed amount of repayment g.			

An important starting point in our subsidy allocation procedure is that after successful termination of a stage, allocation of subsidy for the succeeding stage (if any) is guaranteed; eventually at the minimum level being proposed.

3. Utility valuation

In order to evaluate the benefits and drawbacks of the separate projects, it is necessary that the fund management has a general knowledge on utility aspects and the relations to the ultimate goal of the fund. In the case of fund management for R&D in the energy sector, naturally three fields may be distinguished:

- Economic aspects: long term projections on demand/supply of energy, cost proportions on investments, maintenance, (fuel) inputs, etc., and also economic market penetration aspects.
- Technological aspects: nature of the technology (production, co-production, transition, or saving), flexibility, reliability, geographic restrictions, etc.
- Social aspects: ecological and environmental burdening, security, social market penetration aspects.

Eventually these aspects may lead to a subdivision of the fund into a number of subfunds, corresponding to different time-scales, magnitudes of the budgets being involved, economical, technological or social nature of the candidate projects. In the database concerning the fund (to be discussed in section 7), these subfunds are called categories. Having fixed (if necessary) a workable partition of the fund and the corresponding total subsidy budgets, it is important to recognize that the utility valuation of the candidate projects belonging to the same subfunds only mutually must be compared and quantified. Thus the general utility valuation data can function in at least three manners:

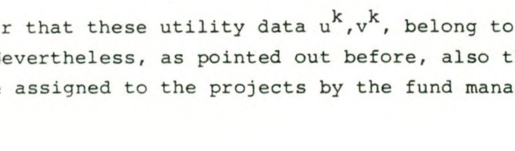
- clarifying and specifying the goals of the fund and eventually fixating the total budget of the fund.
- Partitioning the fund into more or less homogeneous subfunds and determining their financial volumes.
- Supporting the comparison of candidate projects in each of the subfunds.

Following the usual practice, the comparison of projects in a (sub)fund must be effectuated with the help of a fixed limited number - say m - of quantified utility components, in such a manner that positivity of a component indicates a positive utility, negativity indicates a drawback, whereas zero refers to neutrality.

We stress the point that each of the utility components is expressed in a <u>cardinal</u> scale (i.e. consistent with respect to addition and scalar multiplication). Of course it is assumed that the utility scales are <u>increasing</u> (i.e. higher utility corresponds with higher utility number).
Summarizing: one of the first tasks of the fund management is to install a workable partition of the total financial resources (if necessary), and to fix for each subfund the number of utility components and scales (i.e. calculation units).

Having assigned a project to a subfund, its utility components must be determined in conformity with the utility specifications. Of course to that end specific information may be asked from the project management. With a number of m utility components, the utility values associated with successful termination of the project will be expressed in the form of an m-tuple $u: = (u_1, u_2, \ldots, u_m)$. It is also thinkable that failure of the project carries utility values; in that case one has as additional utility m-tuple $v: = (v_1, v_2, \ldots, v_m)$. In stead of associating utility values only with the termination of the entire project, the separate stages also may carry utility values being effectuated at their termination. Thus denoting the m-tuples associated with the termination of stage k by
$u^k: = (u_1^k, u_2^k, \ldots, u_m^k)$ in case of "success", and $v^k: = (v_1^k, v_2^k, \ldots, v_m^k)$ in case of "failure", the utility valuation data of a project consisting of n stages lead to the following data scheme:

<u>utility data</u>
<u>of a project</u>



It will be clear that these utility data u^k, v^k, belong to the specific project data. Nevertheless, as pointed out before, also these utility figures must be assigned to the projects by the fund managements.

Apart from the specific utility data of the separate projects, we also have utility valuation data applying to all projects (belonging to the same subfund) in the form of time preference factors and utility weight factors. As usual in dynamic decision models, the assumption that future utility realizations are valuated lower than present realization is represented by a decreasing sequence of <u>time preference factors</u> $\delta(1),\delta(2),\ldots,\delta(t),\ldots$. Namely, in such a manner that the present value of a utility m-tuple u (or v) being realized at the end of a future period t, is expressed by the m-tuple $\delta(t).u$ (or $\delta(t).v$ respectively). More specific, suppose concerning a project with n stages and with utility as showed by the diagram above, that the stages are terminated successfully after $t_1,t_2,\ldots,t_n$ periods respectively. Then the corresponding utility m-tuples at their present values are given by the expression: $\delta(t_1).u^1 + \delta(t_2).u^2 +\ldots+ \delta(t_n)u^n$. In case the project is terminated after failure of stage k ($1<k\leq n$) the present value of the utility components amounts to: $\delta(t_1)u^1 +\ldots+ \delta(t_{k-1})u^{k-1} + \delta(t_k)v^k$. As is seen, the utility realization of a project at its present value is subjected to uncertainty in two manners: first via the probabilities on success and failure of each of the stages, and secondly via the time-preference factors and the probabilities on delays. As pointed out in section 2, the latter may depend on the subsidy levels being allocated. For that reason the <u>total expected utility values</u> over the forthcoming part of a project will be constituted as the sum over the utilities of the forthcoming stages, weighted with the corresponding absolute probabilities on success and failure and time preference factors; more detailed this concept is introduced in the appendix. Observe that with this definition the total expected utility values depend on the subsidies being allocated: higher subsidies imply lower probabilities on delays and consequently higher total expected utility values. As usual in dynamic decision models, the sequence of time preference factors $\delta(1),\delta(2),\ldots,\delta(t),\ldots$, will be chosen exponentially, implying that with a <u>time discount factor</u> δ between zero and one, the time preference factors are defined by $\delta(1):=\delta$, $\delta(2):=\delta\uparrow 2,\ldots,\delta(t):=\delta\uparrow t,\ldots$ (where $\delta\uparrow t$ stands for δ to the power t).

4. Budgetary aspects of the fund.

For a moment we return to the standard description of projects, in the form of sequentially ordered stages and stages subjected to a chance on failure and delay being arranged in comformity with the data structure of section 2. The budgets in the form of subsidies being allocated and repayments, are subjected to uncertainty in three manners: first by probabilities on prematurely termination because of failure, secondly by chances on delay, and thirdly via the policy regulating future subsidy allocation. As will be discussed in section 6, an "optimal" policy will be established as a decision schedule, relating subsidy allocations to future progress realizations (i.e. successes, delays, or failure). In this manner it is possible to compute for each project, given its execution state and a subsidy policy, the expected subsidies to be allocated at the start of each period. The date being required for this, is introduced in section 2. The corresponding expected repayments (if any) can be deduced in a similar manner. In more detail the subsidy and repayment expectations are discussed in the appendix *). Now, given the execution states of all projects of a (sub)fund, for each selection of subsidy policies (i.e. the whole consisting of one policy of each project) the corresponding total expected subsidies and repayments can be calculated as the sum of these expectation over the projects being involved. Below the total of expected subsidies and repayments (possibly zero!) corresponding to a certain selection of subsidy policies, will be denoted by numbers $x(1)$, $x(2),\ldots,x(\theta),\ldots$ and $z(1)$, $z(2),\ldots,z(\theta),\ldots$, where $x(\theta)$ and $z(\theta)$ express the total expected subsidies and repayments resp. to be effectuated at the start of period θ. Postulating that $\theta = 1$ refers to the first future period, it is important to observe that in fact, $x(1)$ is the non-stochastic result of the subsidy choices at the start of the first period, whereas $z(1)$ stands for the non-stochastic repayments resulting from the subsidy choices and the progress realizations from the past.

*) forthcoming.

Concerning the basic financial resources of the (sub)fund (not including the repayments of subsidies), it is assumed that the (sub)fund budgets for the present, denoted $f(1)$, and for the future $f(2), f(3), \ldots, f(\theta), \ldots, f(h)$ are all known; $f(\theta)$ refers to the budget resource to be allocated at the start of period θ. The planning horizon h is taken large enough in order to cover all relevant future periods with the assumptions. An over-simplified version of the budget restriction can be written: $x(\theta) \leq f(\theta) + z(\theta)$, $\theta = 1,2,\ldots$; in words "for each period the expected total subsidy is not allowed to exceed the fund budget plus the expected total repayments in that period". We shall modify this dynamic budget restriction to a more realistic form by adding successively some natural features.

First, since the running time of projects is limited and since there are no applicants for the long term, the budget allocation procedure might favour long running projects. Therefore it might be necessary to reserve periodically a fixed increasing proportion of the fund for future candidate projects. Thus denoting the proportions being available for the present projects by a drecreasing sequence of numbers $\phi(1), \phi(2), \ldots$, with respect to the fund resources, and by $\psi(1), \psi(2), \ldots$ for the repayments (possibly $\phi(\theta) = \psi(\theta)$, $\theta = 1,2,\ldots$), the resulting effective budget expectations are:

$\phi(1)f(1) + \psi(1)z(1)$, $\phi(2)f(2) + \psi(2)z(2)$, etc.

The coefficients $\phi(\theta)$, $\psi(\theta)$ must be fixed by the fund management; it looks reasonable to choose an exponentially decreasing course. Of course a second extension is that fund surplusses from the preceding periods may be transferred to following periods, under a given financial interest rate, represented by a coefficient π. Then, denoting these (expected) surplusses by $y(0), y(1), \ldots y(\theta), \ldots$, each $y(\theta)$ being available at the end of period θ, we have the dynamic relation: $y(\theta) = \phi(\theta)f(\theta) + \psi(\theta)z(\theta) + (1+\pi)y(\theta-1) - x(\theta)$, $\theta = 1,2,\ldots$, with $y(0)$ being the given surplus of the past. The corresponding budget restrictions are of course:

$x(\theta) \leq \phi(\theta)f(\theta) + \psi(\theta)z(\theta) + (1+\pi)y(\theta-1)$, $\theta = 1,2,\ldots$.

It is important to observe the effect of the time discount factor δ (being introduced in the dynamic utility valuation, section 3) versus the financial discount factor $(1+\pi)$. In case the product $(1+\pi)\delta$ is larger than one, value accumulation by budget saving goes faster than the decline of utility values under postponement. Consequently, the optimal policy would show a tendency of delaying subsidy allocation instead of spending the budgets for stimulating purposes as quickly as possible. Since, on the contrary the fund is aimed to be an incentive for R&D, it is natural to assume that the product $(1+\pi)\delta$ is smaller than one.

A third modification of the budget restriction is motivated by the fact that, although the expected total subsidies and repayments are planned to satisfy the budget restrictions (in terms stochastic expectation) the actual progress realizations may lead to deficits. The chance on such deficits can be diminished by introducing a (what we call) <u>covering factor</u> with respect to the basic fund budgets. Denoting this covering factor by α $(0<\alpha\leq 1)$ the corresponding budget restrictions take the form:
$x(\Theta) \leq \alpha\phi(\Theta)f(\Theta) + \psi(\Theta)r(\Theta) + (1+\pi)y(\Theta-1)$, $\Theta = 1,2,\ldots$, whereas the dynamic relation between expected surplusses remains the same. Observe that with a covering factor $\alpha>1$, the expected surplusses can be negative and thus turning over into expected deficits.

An equivalent form of the budget restrictions, where the transfer of surplusses is taken into account implicitly, can be deduced by accumulating the single period budget restrictions at their present values. Then in terms of the total expected subsidies and repayments, these cumulative budget restrictions can be written:

Cumulative budget restrictions for running periods $\Theta = 1,2,\ldots$	
$\Sigma_{\tau=1}^{\Theta}\ (1+\pi)^{\uparrow-\tau}\ (x(\tau) - \psi(\tau)z(\tau)) \leq \overline{f}(\Theta)$	
$\overline{f}(\Theta)$	reduced cumulative fund resources, defined by: $y(0) + (1+\pi)^{\uparrow-\Theta}\alpha\phi(\Theta)f(\Theta) + \Sigma_{\tau=1}^{\Theta-1}\ (1+\pi)^{\uparrow-\tau}\phi(\tau)f(\tau)$
π	financial interest rate
$x(\tau)$	expected total subsidy at the start of period τ
$z(\tau)$	expected total repayment at the start of period τ
$\psi(\tau)$	reservation factors with respect to repayments
$y(0)$	budget surplus of the past
α	covering factor $0 < \alpha \leq 1$
$\phi(\tau)$	reservation factors with respect to fund resources
$f(\tau)$	basic fund budget at the start of period τ

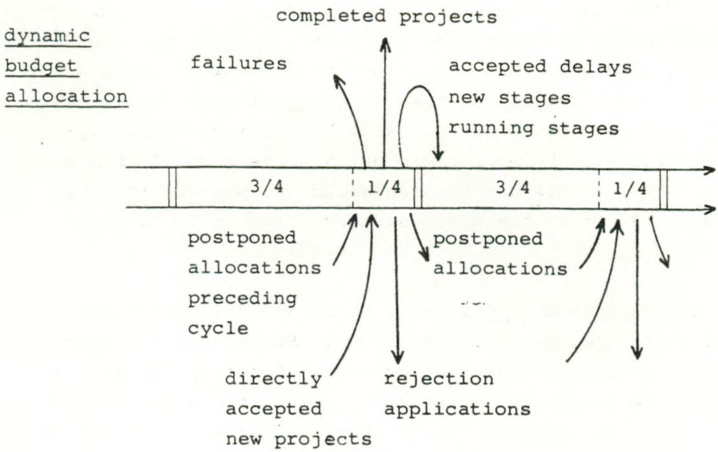
Note: $(1+\pi)^{t-\tau}$ stands for $(1+\pi)$ power $(-\tau)$. As argued before, the fund parameters π, $\phi(.)$, $\psi(.)$, α must be fixed by the fund management. The effects of the reservation factors $\phi(.)$, $\psi(.)$, and of the covering factor α can be ruled out, simply by putting all of these equal to one.

The cumulative formulation of the budget restrictions opens the possibility to reduce the number of periods where it is tested. For instance, with respect to fund management over 20 periods, one may restrict testing to the periods $\Theta = 1,2,3,4,5,10,15,20$. Satisfying the cumulative budget restriction for these periods implies that possible deficits between periods 5-10, 10-15 and 15-20, are eliminated at period 10, 15 and 20 respectively. So accuracy is lost only for the periods being skipped.

One of the first problems in the budget allocation procedure is the identification of a feasible selection of policies; i.e. a selection of policies such that the resulting subsidies satisfy the management commitments and such that the corresponding expected subsidies and repayments satisfy the cumulative budget restrictions. A natural starting point is to identify a minimal subsidy scheme, being a fixed selection of subsidies for each stage of each project such that the corresponding total expected financial means (i.e. subsidies minus repayments) for each period are minimal in comparison with the financial expectations of any selection of policies. Under two postulates on the project date, such a minimal subsidy scheme exists and can be identified easily. The first is the (what we have called) subsidy postulate, implying that for each stage of each project the repayments (at present values) are not larger than the subsidies (at present values) being allocated. Under the subsidy postulate, the minimal subsidy scheme will reject subsidy allocation to new candidate projects and will postpone subsidy allocation in case the commitments to the project management excludes rejection, but includes postponement. The second selection criterion is based on the (what we will call) ordering postulate implying that with each progress stage of each project, either one single subsidy scheme is associated or a minimal subsidy scheme in the sense that the subsidies minus repayment (being counted cumulative at present values) are minimal with respect to other subsidy options, whereas in addition the probabilities on delay are maximal. Of course, under the ordering postulate the minimal overall subsidy scheme just consists (apart from rejection) of minimal subsidy schemes for the separate projects.

5. The dynamic budget allocation procedure

Particulararily because of the uncertainties in R&D progress and the complexity of its utility valuation, it is extremely important that the budget allocation procedure is sequential and adaptive. Therefore we propose a dynamic procedure with a fixed cycle of one period. Thus, progress will be evaluated amply before the end of each period; say, when 3/4 of the period is passed. In addition, at that moment the candidate projects for the new budget allocation cycle must be known, so that the procedure can be started up and the resulting decisions can be implemented effectively at the moment of period-changing. The allocation procedure is summarized by the following scheme:



The corresponding decisions concerning continuation of running projects and allocation budgets to new projects are listed in the table below.

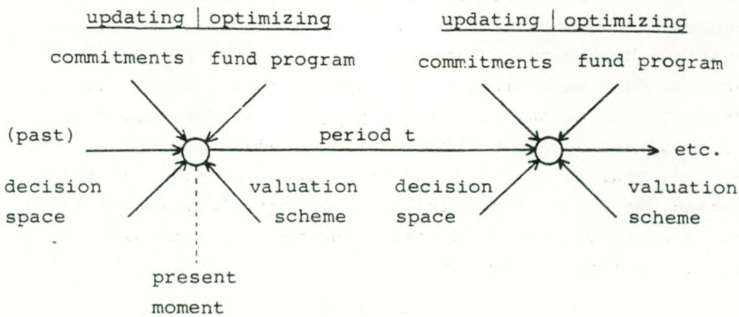
	running projects			candidate projects			
	succes	delay	fail.	a	b	c	d
stop subsidyzing	X		X				
continue subsidyzing		X					
select subsidy scheme	X			X	X		X
reservation				X		X	
rejection				X	X	X	

Concerning the <u>running projects</u> only on stages arriving at a progress evaluation point, certain decisions on a budget or on budget schemes will be made. Firstly: if a stage turns out to be successfully completed, the project will be removed from the subsidy roll if it was the last stage of the project; otherwise one of the subsidy options of the next stage will be selected resulting into a subsidy scheme without postponement. Secondly: in the case of <u>delay</u> the subsidy scheme, being fixed at the start of the stage, will be continued. Thirdly: in the case of a <u>failure</u> the entire project will be removed from the subsidy roll. Of course this does not rule out the possibility that the project again may enter the procedure, but then as a new candidate project.

With respect to <u>candidate projects</u>, four types are distinguished. Concering (a) one of the following decisions will be made: (1) budget allocation in the form of a selection of one of the proposed subsidy schemes, so that the subsidy is allocated without postponement, (2) budget allocation will be postponed one period; the actual selection of the subsidy scheme also is postponed one period (thus this decision may be taken as a global reservation), (3) rejection, i.e. neither budget allocation nor reservation; this does not exclude the possibility to enter the process later as a new candidate project. Concerning a candidate of type (b), the only possibility is directly assigning subsidy or rejection. Type (c) represents the option of subsidy reservation. These are projects presented to the fund, in order to acquire subsidy starting one period later; the decision of fund management will be either rejection (not excluding the possibility to enter the procedure one period later as a new candidate project) or reservation (thus getting the state of candidate project d). Finally, type (d) represents postponed candidates, i.e. projects for which a reservation has been made one period ago, and next, for the present moment only the subsidy scheme must be selected. We stress the point that the categories (a), (b), and (c) are meant as options for the project management in order to present their projects in the most adequate form. In the budget allocation procedure the following items are crucial:

- The commitments of the fund in the form of reservations and subsidy schemes as fixed earlier and updated with present projects applications and realizations.
- The budget decision space, being the whole of possible policies for the present and for the future as sketched above.
- The fund program consisting of the present and future fund budgets, (eventually) its partition in subfunds and the specification of typical (sub) fund parameters.
- The utility valuation for each project consisting of a limited number of cardinal quantities representing utilities and drawbacks.

At the end of each period these data is updated. Next a (possible) best subsidy policy is selected, resulting into a subsidy program for the present period, such that consistency with future expectations is preserved. This leads to the diagram:



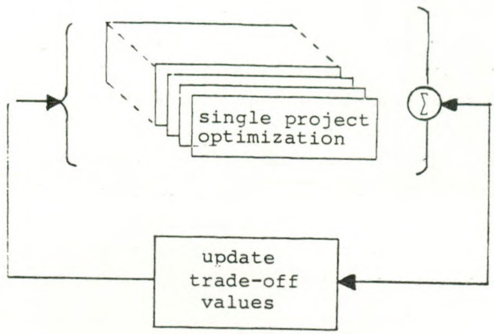
As stated before, the budget allocation system has been designed as a repetitions shifting period procedure, where at each time the present situation is obtained by updating the past situation with the recent progress realizations and by adding candidate projects. Thus at the start of each period, the decision space of the fund management over the future periods is based on all possible subsidy schemes for all running and all candidate projects, provided they are consistent with the commitments of the fund. A policy which satisfies these commitment will be called consistent. As being discussed already in section 3, the quality of a policy is measured in terms of the total expected utility value, being defined as the sum over the expected utility values of the separate projects under that policy; the latter constituted by an aggregation over time with the help of a time-discount factor δ, and by an aggregation over the utility component with weight-factors $w: = (w_1, w_2, \dots, w_m)$. Thus consistent policies will be selected (if any) satisfying the cumulative budget restrictions and such that(within these feasible policies) the total expected utility value is maximal.

The result of an optimality analysis, in the form of optimal policies relative marginal returns of the fund budgets, and sensitivity relations with respect to the model parameters, are important expedients for selecting the final subsidy contracts which must be concluded for the first forthcoming period. The optimality analysis can be used in a flexible manner. For instance, suppose that among the candidate projects a number of them concern a similar technological development. It will be clear that the total utility of these projects together can be characterized rather by the mean of the utility values than by the sum. Therefore, in the overall allocation procedure the fund management might combine these almost identical projects into one or two artificial projects. In case subsidy is allocated, this subsidy can be treated as a subfund for the projects in question. Thus in a second step the actual subsidy can be allocated, indeed. We stress the point that an optimality analysis does not provide an automatism: the final judgement remains with the expertise of the fund management.

6. Optimality aspects.

The core of the optimality analysis consists of an interaction process of two procedures, resulting into (equilibrium) trade-off values for fund budgets and into approximate optimal policy selection. These will be discussed in more detail, with the help of the following diagram.

overall optimization



In this process, each budget restriction (being formulated, cumulative at present values) might be taken as a subsidy market acting at the start at that period, in such a manner that its "trade-off value" functions as a "price" for the subsidies being "traded" (the accounting unit of these "prices" is the "unit" of utility). Now given a sequence of such trade-off values, one for each budget restriction, the "nett value" of a project under certain policy consists of its corresponding expected utility number minus the aggregation over its expected subsidy demand, plus the aggregation over its expected repayments. Thus, given a sequence of trade-off values, the procedure single project optimization selects for each separate project a policy which maximizes its "nett value". Observe that this process allows a decomposed optimization of the separate projects. As a matter of fact, the sum over the maximal "nett values" functions as an approximation of the total expected utility value over the projects under a maximizing selection of policies, satisfying the cumulative budget restriction. Approximative trade-values (if not the best) can be improved with the help of the procedure update trade-off values, where the corresponding expected deficits and ealier approximations (if any) are processed on the basis of a linear programming procedure. Thus, budget trade-off values with the best utility approximation, are determined as follows:

- Identify a minimal subsidy policy. If the budget restrictions are not satisfied with strict inequalities, then no better policy exists; consequently the procedure has to stopped. Otherwise:
- Determine (as a first trial) the optimal single project policies at zero trade-off values. If all expected deficits on the cumulative budget restrictions, are nonnegative (i.e. no deficits), then the zero trade-off values produce the best utility approximation (implying that none of the budget requirements is restrictive); the optimal single project policies constitute an optimal selection of policies, with respect to the (sub) fund as a whole. If there are deficits:
- Start the interaction process of updating trade-off values and single project optimization. In a limited number of interaction steps, the process will terminate with best approximating trade-off values. The corresponding optimal single project policies with the best first period fit constitute an approximative selection of optimal policies with respect to the (sub) fund as a whole.

A few remarks have to be made on the data being involved in a subsidy allocation case (briefly: "case"). First of all, each of the projects of the (sub) fund must be specified in the standardized form being introduced in section 2 and section 3. In addition, concerning the running projects, the present progress states must be known. A second data set concerns the (sub) fund. These data (to be called: fund parameter data) consists of: the time-discount factor, the utility-weight factors, the financial interest rate, the budget covering factor, the budget reservation coefficients, the basic budgets of the (sub) fund, and finally the financial surplus of the past.

7. The Fund Information System (FIS)

This section presents a global description of the data and the data handling system for supporting the budget allocation procedure. Sequentially four aspects will discussed: the subdivision of the data, the functions of the data handling system, the information flows in the budget allocation system, and the key commands. We start with discussion the data structures, which subdivided into the following entities:

Data on categories: motivated by differences on R&D-topics, scale of budgets, scale of running-times etc.. These data complexes contain requirements (imposed by the fund management) on the description of candidate projects.
Project data: an entity "project" contains the description of a project (category, progress, budgets, repayments, utility) satisfying the requirements of the category where it belongs to. Project data will be deduced form information given by the project management.
Fund parameter sets: an entity "fund parameter set" contains the description of a (sub-) fund, like the category where it belongs to, data on the (sub-) fund budgets, utility weight-data. A fund parameter set typically has to be defined by the fund management.
Case data: an entity "case" contains a complete description of subsidizing within a (sub-) fund. It contains a name of a category, a name of one or two fund parameter sets, a collection of project names being assigned to the (sub-) fund, data indicating the state of progress, and data specifying the present selection of subsidies.
Note (1): fund parameter sets, projects, and the case itself must belong to the same category. Note (2): in case two fund parameter sets are specified, the actual parameters are composed as a mix of the form c*param(I)+(1-c)*param(II), with mix-coefficient $0 \leqq c \leqq 1$. Note (3): the updating for a periodical progress realization will be effectuated only by adaptation data on "present state", whereas the updating on next period subsidy contracts is effectuated on the "next period data".

A more detailed overview in these data entities is presented on the following page.

Category

- name
- requirements on utility valuation data,
- conditions on progress evaluation,
- monetary valuta unit, unit of calculation,
- conditions on subsidy budgets and repayments.

Fund parameters

- name
- name of the category where the fund belongs to,
- time-prefence factor δ and utility-weights w,
- financial interest-rate π and covering-factor α,
- reservation factors on fund budgets and repayments $\phi(\cdot)$, $\psi(\cdot)$,
- basic budgets of the fund $f(\cdot)$.

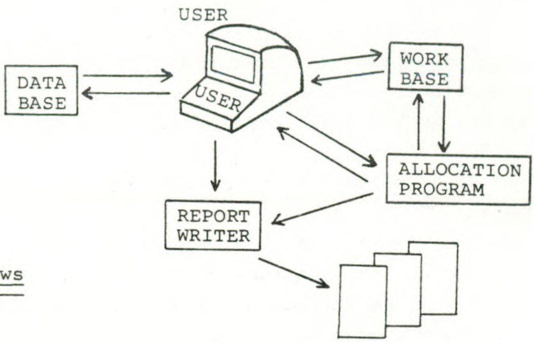
Project data

- name and standard information on project management,
- name of the category where the project belongs to,
- starting time options,
- monetary valuta unit, units of calculation,
- number of progress evaluation stages and their names,
- for each stage: progress evaluation data related to subsidy schemes, specification of repayment and utility valuation data.

Case data

- name
- name of the category where the case belongs to,
- name fund parameter-set I, and (eventually) II, mix coefficient,
- names of associated projects,
- budget cheque points,
- current state of each project: progress state, cumulated previous and present subsidies and repayments at present value,
- current state of the fund: budget surplus from the past,
- next period data for each project: first subsidy scheme, cumulated future expected subsidies and repayments at present value, probability of success or failure, conditional expected termination time and variance given success and given failure.
- next period data of the fund: next budget surplus, total expected subsidies and repayments cumulative at present valuq budget trade-off values.

Each data entity, but also a database as a whole, carries a unique name, with the help of its name, an entity (being a description of one single category, fund parameter set, project, or a case) can be identified and processed. The actual processing is divided into four separate functions: the workbase, the database, the allocation program, and the report writing.



Data flows

- The collection and selection of data and the construction of data entities are supported by the workbase.
- The storage of data entities from the workbase and the modification of stored data takes place in the database. The database is endowed with a system for data protection.
- The budget allocation program offers facilities for identifying selections of minimal subsidies, budget trade-off values and optimal selection of subsidies. It is also possible to execute single project optimization (under given budget trade-off values), and to investigate sensitivities with respect to two sets of fund parameters. The required data are collected under the "case" being indicated and being stored in the workbase. The starting point of all allocation operations is the "current state" from the, "case data".
- With the help of the report writer the resulting data from the other functions can be displayed in a controlled manner.

The allocation program contains several functions. The procedure for determining budget trade-off values of an allocation case and identifying a corresponding optimal selection of subsidy schemes, is activated by the command OPTIMIZE. Then the data contained in the workbase under a specified name of a case are processed in a number of phases: (i) calculating for each subsidy scheme of each stage of a project the expected subsidy, the repayments and the utilities (cf. section 2,3,4), (ii) identifying a minimal subsidy scheme (section 6 and 8), (iii) calculating budget trade-off values and optimal subsidy selections (cf. section 8). The results are temporary stored in the workbase and after completion available for report writing and for implementation in the corresponding data entity "case" in the workbase. The latter, being effectuated by the command ACCEPT, changes the data content under the heading "next period". In the program OPTIMIZE several consistency tests on input data are adopted. Apart from this, the procedure terminates either with the finding that no feasible selection exists (i.e. the fund budgets are not sufficient to finance the minimal subsidy schemes), or with budget trade-off values and corresponding (approximate) optimal subsidy selections. The optimization procedure also is available in a (so called) parametric version to be activated by the adittional instructions: PARAMETRIC. In this mode the optimization procedure is executed sequentially five times, corresponding with mix-coefficients 1, 3/4, 2/4, 1/4, 0 resp. on two fund parametersets being indicated by the data entity "case". Other functions are MINIMAL (identifying the minimal sybsidy schemes) and SINGLE (single project optimization under given budget weigts).
Together, all data handling functions constitute (what we have called) the Fund Information System. The nature of the Fund Information System is interactive: after having typed in a key commnand, the user will be guided (if necessary) by automatized questionnairs, asking for additional information and instructions, testing consistency, and executing the instructions.

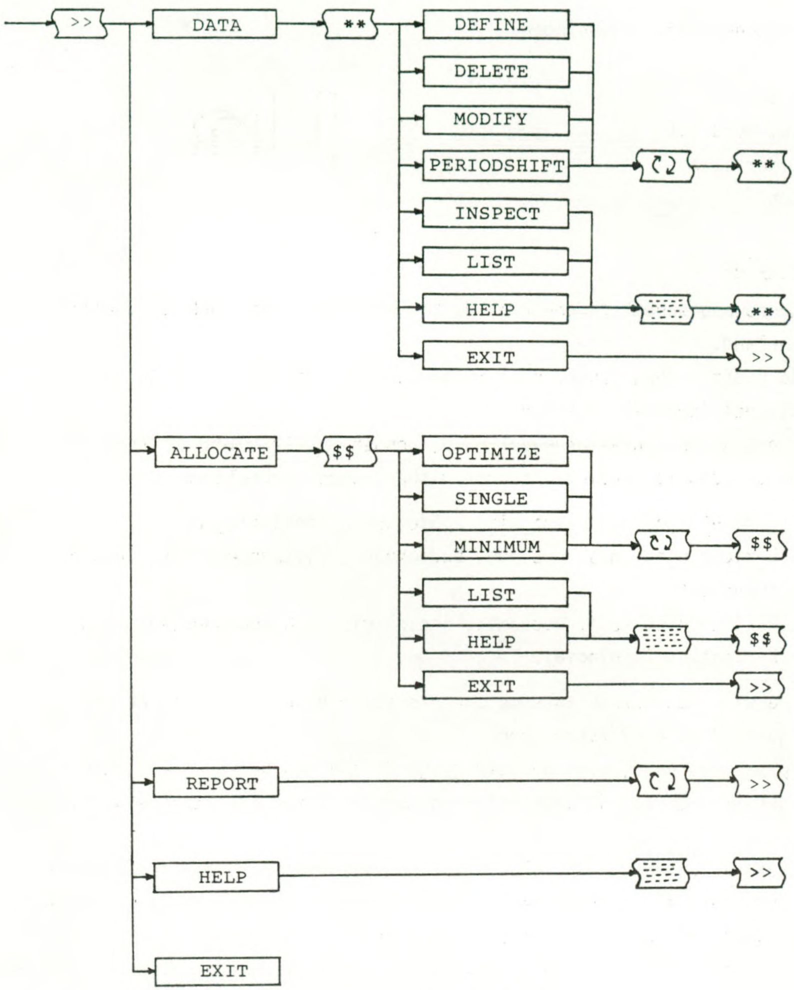
The key commands will be discussed with the help of the instruction diagram at the end of this section. We stress the point that, armed with the instruction diagram and an explanatory list of key commands, only a global understanding of the budget allocation system as being introduced in the previous sections suffices in order to have fully access to the Fund Information systems and its data handling facilities.

Explanatory list of key commands	
Key commands	Type of data handling activity
DATA	transfers system into data mode, indicated by **
DEFINE	creating new data entity (questionnaire)
DELETE	cancelling a data entity, indicated by name
MODIFY	modifying data content (questionnaire)
PERIODSHIFT	implementation periodical progress realizations
INSPECT	displaying and eventually modifying (questionnaire)
LIST	(data mode) displays all names in current data base
ALLOCATE	transfers system into allocation mode, indicated by $$
OPTIMIZE	calculates trade-off values, policies (questionnaire)
SINGLE	optimal policies under given trade-off values
MINIMAL	calculates minimal subsidy figures (questionnaire)
LIST	(allocation mode) displays all cases
REPORT	reports about case data etc. guided by questionnaire
HELP	displays supporting text in context of execution
EXIT	return to higher execution level

Having started up the Fund Information System (which depends of the specific computer implementation), a name of a data base has to be typed in. In case the name refers to an existing data base, all of its data will be transfered to the workbase. Under a new name, only a new base can be created. Having inserted the name, the system returns with the sign >> on the display. The sign >> indicates that the system is in the command mode. Next, as shown by the instruction diagram, the system can be transfered into the data mode (indicated by ** on the display), or into the allocation mode (indicated by $$). With the help of the key-command EXIT, the system can be transfered back into a "higher" execution level; i.e. from the data mode or from the allocation mode into the command mode, or from the command mode into termination.

The data mode contains facilities both for bookkeeping actions and for preparing data to be used in a budget allocation trial. For instance, the automatized questionnaire following the key-command PERIOD-SHIFT contains all facilities for updating a budget allocation "case" with respect to the progress realizations of a periodical shift; as a matter a fact such an shift operation only will change the data under the headings "current state of each project" and "current state of the fund" from the "case" being involved.

The allocation mode contains the facilities for experimentation on subsidy allocation being discussed in section 6 and in the present section. The starting point always consists of a "case" indicated by its name. With the exception of the "trade-off values" (as being used in SINGLE), none of the allocation operations will use any data under the headings "next period data for each project" and "next period data of the fund". Being in the allocation mode, the user only can change (of course under appropriate commands, being indicated by the automatized questionnaire) the data under these headings "next period data......". In fact "next period data....." functions both as a storage for the next period decision lasting storage for the allocation outcomes. Finally, the (FIS) instruction diagram just indicates the order of the key-commands and their consequences; the defining symbols are listed separately.



Instruction diagram

Fund Information System