SKI Report 2003:43

Research

Development of an Estimating Procedure for the Annual PLAN Process

- with Special Emphasis on the Estimating Group

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SKI perspective

Background

Since 1981 the nuclear power utilities annually pay fees to the Nuclear Waste Fund. The utilities must in addition provide financial guarantees. The purpose of the Fund is to cover future costs for the safe management and disposal of spent nuclear fuel and nuclear waste, as well as decommissioning and dismantling of the nuclear power reactors. The Fund must also finance the research and development programme.

The present method applied for the work of the yearly proposal for the level of the fees and guarantees is called the successive principle. This method is used to calculate the future expected costs for the safe management of spent nuclear fuel and for the decommissioning and dismantling of the Swedish nuclear reactors.

The task to assign appropriate financial means to the Swedish Nuclear Waste Fund is crucial for the sustainability and long term credibility of the financing system.

A deficit situation may for example arise if the level of accruals to the fund becomes inadequate in relation to the total disbursements. It is therefore highly important that provision to the fund reflects the real cost of performing the planned and described future tasks. All measures that enhance the overall quality of the calculation of fees to the fund, as well as the guarantees given by the industry, are from the standpoint of SKI essential research tasks if the studied object or cost items has a significant impact on the funding and/or guarantees.

Purpose of the project

The main purpose of the project has been to describe the different phases that an expert group faces in an authentic environment.

A secondary objective has been to identify and describe some possible ideas for improvements in the current method. The demands for more cost-efficient ways to derive the estimated cost items and a need for a higher degree of transparency in the process may put further demands on the identification and evaluation of applicable methods and/or modes of analysis. This in turn may put up the demand for some changes in the present context.

Results

This report provides an example of how the presently used procedure for estimation of future costs of management and disposal of spent nuclear fuel and nuclear waste may be improved. The study also demonstrates an alternative estimation procedure.

Continued work

The composition of an expert group is a crucial element in using the successive principle, as it may have a substantial impact upon the outcome from the analysis. An important task for the future is therefore to develop guidelines/directives - or rule of thumb - for how to select experts and how to compose an expert/analysis group.

Effects on SKI work

SKI will be able to use the conclusions from this study in the review of the annual cost estimates presented by the nuclear industry. The use of an alternative procedure will in addition provide SKI with a tool to enhance the evaluation of the cost estimates.

It ought to be remembered that this report only gives an example of how the context may be altered in order to develop the present estimation procedure for the annual calculation of fees and guarantees. Hence, this applied study demonstrates one alternative context.

SKI will be able to use the conclusions from this study in the ongoing monitoring of the yearly cost estimates presented by the nuclear power utilities. The development of an alternative procedure will gradually enable SKI to determine whether the previously estimated costs have been too conservative or not.

Project information

At SKI Staffan Lindskog have been responsible to supervise and co-ordinate the project.

SKI reference: 14.9-010559/01235

Swedish Nuclear Power Inspectorate (Statens Kärnkraftinspektion), SKI, Stockholm

RESEARCH STUDY:
Development of an estimating procedure for the annual PLAN process

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Management summary

Purpose & scope

This research study deals with the PLAN 2000 procedure. This complex annual estimating procedure is based on the Swedish law on financing, 1992:1537. It requires the Swedish Nuclear Power inspectorate, SKI, to submit to the Government a fully supported annual proposal for the following year's unit fee for nuclear generated electricity to be paid by the owners of the Swedish nuclear power plants. The function of this Fund, KAF, is to finance the future Swedish decommissioning programme.

The underlying reason for the study is current criticism of the existing procedure, not least of the composition and working conditions of the analysis group. The purpose of the study is to improve the procedure. The aim is (1) to maximise the realism and neutrality of the necessary estimates in order to allow the KAF Fund to grow steadily at the current rate to the desired target size, allowing it to pay all relevant costs associated with this large decommissioning programme; (2) to do this with a controlled degree of safety; (3) to improve the transparency of the whole procedure in order to avoid any distrust of the procedure and its results.

The scope covers all technical and statistical issues; and to some degree also the directly related organisational aspects, notably in respect of the present law and its administration. However, some details are dealt with which seem contrary to the aim of the law.

Analysis of the present situation and primary requirements

Since 1996, SKI has delegated to the Swedish Nuclear Fuel and Waste Management Co., SKB, the task of performing the basic part of the necessary annual estimating procedure. SKI has then evaluated and supplemented the base estimate before the drafting of the final proposals for the Government and the Board of the Fund, KAFS.

The existing procedure has been tailor-made for this particular task and includes several excellent features. Nevertheless, it has been subject to criticism. Its use of probabilistic methods as well as the composition and working conditions of the analysis group have been criticised. The technical complexity and handling of the influence of time also constitute problem areas.

Some basic requirements are crucial to the quality of the result of the study: (1) full identification of all potential sources of major uncertainty and the subsequent correct handling of these, (2) balanced and unbiased quantitative evaluation of uncertain matters, and finally (3) correct and transparent statistical calculations of the result.

The resulting proposed new procedure

The resulting proposals for a new procedure include a model structure for the analysis team and its procedures, the initial identification and handling of the sources of uncertainty, a choice of scenarios and alternatives to be examined, followed by some quantification phases, during which the data on timing, costs, etc. are evaluated and followed by a calculation. The result consists of information about the necessary size of the fee rates for various degrees of safety or probability, as well as the primary sources of the remaining uncertainty involved.

Discussion and testing

A workable procedure is always achieved through a balance between complying strictly with the relevant natural laws and being sufficiently simple and intelligible, with a minimum of ‘black boxes’. The relevance of the desired balance is discussed and verification is attempted. Special attention is given to a discussion on the application of the Bayesian statistical theory, the paradigm of which is still new to some professionals and decision-makers.

The procedure has been tested in several steps. So far, the procedure has lived up to or exceeded expectations. Some primary conclusions are summarised in the final chapter. More tests will be required. The results of this testing are to be published separately.

References and abbreviations

A list of references and abbreviations is given at the end of the report.

Ledningssammandrag

Syfte och omfattning

Denna forskningsstudie behandlar PLAN 2000 proceduren, vars komplexa årliga skattningsprocedur bygger på finansieringslagen (1992:1537) om finansiering av framtida utgifter för använt kärnbränsle mm. Denna uppdrager åt Svenska Kärnkraftinspektionen, SKI, att årligen överlämna till regeringen ett välunderbyggt förslag avseende storleken på nästa års avgift som kärnkraftverken har att betala till KAF, kärnavfallsfonden. KAF skall garantera finansieringen av det framtida svenska avvecklingsprogrammet

Forskningsstudien sker på grund av att den idag fungerande proceduren har utsatts för kritik; bl.a. sammansättningen av analys gruppen och dens arbetsätt. Studiens uppdrag är att förbättra proceduren. Målen är att (1) maximera realismen och neutraliteten i bedömningar och kalkyler så att KAF kan växa stadigt i den takt som gör det möjligt för fonden att finansiera alla relevanta kostnader för avvecklingsprogrammet; (2) att genomföra detta på en kontrollerad säkerhetsnivå och (3) att öka förståelsen och insynen och därmed höja förtroendet för proceduren och dess resultat.

Omfattningen av studien täcker alla tekniska och statistiska områden, samt till viss del även direkt berörda organisatoriska aspekter. Det senare med hänsyn tagen till den existerande lagen och hur den administreras. Vissa detaljer har dock påpekats där dagens procedur synes motverka lagens syfte.

Analys av dagens situation och grundläggande krav

Sedan 1996 har SKI delegerat till Svensk Kärnbränslehantering AB, SKB, uppgiften att utföra den grundläggande delen av nödvändiga årliga kalkyler med tillhörande bedömningar. SKI har sedan värderat och kompletterat dessa kalkyler innan det slutgiltiga förslaget har sammanställts till regeringen och kärnavfallsfondens styrelse, KAFS.

Dagens procedur är skräddarsydd för sin uppgift och innehåller många utmärkta moment. Inte desto mindre har den utsatts för kritik. Användningen av probabilistiska metoder så väl som analysgruppens sammansättning och arbetssätt har ifrågasatts. Den tekniska komplexiteten och hantering av tidsosäkerhet är också exempel på problematiska områden.

Vissa grundläggande krav är viktiga för att beräkningsresultatet skall uppnå hög kvalitet: (1) fullständig identifiering av alla potentiella påverkansorsaker, och att dessa därefter hanteras korrekt, (2) en balanserad och neutral kvantitativ bedömning av osäkra områden, och slutligen (3) korrekta och lättförstådda statistiska beräkningar av resultatet.

Den föreslagna nya proceduren

Förslaget innehåller en procedur, en organisation av analysgruppen, en identifiering och behandling av osäkerhetsorsaker samt val av de scenarier och alternativ som skall bedömas, följt av olika kvantifieringsfaser, under vilka data avseende tid, kostnader, etc. bedöms och beräknas. Resultatet består av information om nödvändig avgiftsstorlek vid olika sannolikhets- eller säkerhetsnivåer. I resultatet ingår också information om avgiftsstorlekens viktigaste osäkerhetsorsaker.

Argumentation och test

En användbar procedur är alltid en kompromiss mellan relevanta naturlagar och att proceduren upplevs som tillräckligt enkel och klok och med ett minimum av "black boxes". Relevansen i den föreslagna kompromissen diskuteras med ett försök till verifiering. Speciell uppmärksamhet ägnas åt en diskussion kring användandet av Bayesk statistisk teori, ett område som fortfarande är nytt för en del beslutsfattare.

Proceduren har testats i flera steg. Proceduren har hittills levt upp till eller överstigit förväntningarna. Se sista kapitel. Resultaten från dessa test kommer att publiceras separat. Ytterligare testning är dock nödvändig och kommer att genomföras.

Referenser

En förteckning över referenser och förkortningar återfinns sist i rapporten.

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Chapter 1
Objectives, the present situation, and basic issues

Chapter 1.1 Objectives and principal requirements

Objectives

The purpose of this research study is to provide the most reliable background information for building up the Swedish Nuclear Decommissioning Fund (Kärnavfallsfonden, hereinafter referred to as 'the Fund'). It is administered by KAF/KAFS. The objective is to build up the Fund to the level required, with a fixed margin as insurance against uncertainties.

The underlying reason for this research study is current criticism of the existing procedure. This procedure is certainly capable of improvement, by retaining and building on its strongest features while eliminating or at least reducing such potential local weaknesses as are embedded in this procedure.

The basic requirement of this updated procedure is to be able to (1) maximise the realism and neutrality of the necessary estimates in order to allow the Fund to grow steadily at the current rate to the desired target size; (2) to enable it to pay all relevant costs associated with this large decommissioning programme; (3) to do so with a controlled degree of safety; (4) to improve the transparency of the whole procedure in order to avoid any distrust of the procedure and its results.

Principal requirements

Five basic requirements are crucial to the quality of the result. They are outlined below and further dealt with in Chapter 4.

1. Unconditional identification of all potential sources of major uncertainty; the subsequent correct handling of these sources during the estimating process must be ensured.
2. Balanced, unbiased, free and accurate quantitative evaluation of uncertain matters must be ensured.
3. Correct statistical calculations of the result must be secured.
4. A sufficiently controllable detailing process is essential in response to the specific need for detailing.
5. The estimating process must be seen as a whole. A cost is a cost, irrespective of who is responsible for it.

Chapter 1.2 The current situation

The system

Since 1996, SKI has delegated to the Swedish Nuclear Fuel and Waste Management Co., SKB, the task of performing the basic part of the necessary annual estimating procedure. SKI has then evaluated the base estimate. Other parts of the programme costs, namely the costs arising from the related activities involving the relevant authorities, have been estimated by SKI, which has also drawn up the final recommendations for the Government and KAFS.

The existing procedure has been tailor-made for this particular task and it includes several excellent features. Nevertheless, it has been subject to criticism, expressed in refs. 4 and 17 and elsewhere. The fundamental elements of this criticism are summarised below, together with the author's comments.

Criticism

1. The existing procedure has been criticised for *using probabilistic methods*. The alternative would be to establish one or more sets of firm preconditions or scenarios, each of which would allow a definite and fairly exact estimate of the cost, assuming today's technology. This would, however, force the decision-makers to choose one of the scenarios without having the necessary background to do so in a sensible manner. And because the calculations rest upon historical conditions, the cost figures chosen might be far from the actual future costs, thus undermining the basic objective.

The result would be to accumulate either too large or – which is more likely – too small a fund. In the latter case the final parts of the decommissioning would have to be paid not by those who benefit now from production, but by the next generation. This part of the criticism certainly lacks supporting evidence.

2. Establishing *the body responsible for the estimating procedure, not least the analysis group*, which identifies, handles, and evaluates the costs and other related factors, is a highly important aspect. The body should be competent, broad-based and balanced, and not least sufficiently independent of those with special interests in the outcome.

SKB has not been able to *document compliance with this important requirement*. For example, a significant majority of the members are internal to or dependent on the nuclear power plant industry. In a situation in which subjective judgements of major importance have to be made, it is hard for society to rely on full neutrality, even with the best of intentions of the involved parties.

3. *The working conditions in this analysis group* are another major issue. So far, it has not been documented how the procedure ensures free and complete identification and evaluation of potential risks or problems.

4. Another set of problems is *the unnecessary degree of complexity* in the calculation of the results, not least unnecessary 'black boxes', as well as the extensive use of the 'emergency solution' – Monte Carlo simulation – instead of a scientifically-based direct, correct calculation procedure. This is further dealt with in Chapter 4.1.

5. *The timing and related discounting* as well as the future real interest rates constitute unsolved issues, and have therefore been handled in a problematic manner. This has been described by SKB itself in a recent report (ref. 2, Chapter 1.3).

Part of the reason for the above problems is that an early version of the Successive Principle has been applied. It has been necessary to supplement this old version with various tailor-made sub-routines. This set of problems has been solved and documented in the current version or 'generation' of the Successive Principle.

It is the aim of this research study to improve the current procedure, adopting the many valuable features and eliminating the weaknesses. It also seems possible to simplify certain sub-procedures, thereby reducing the estimate workload considerably.

Comments on the present organisational approach and related problems

Current legislation provides a common conventional principle for estimates; this is further developed below. Experts from the relevant area are asked to produce a solution, in this case a plan with a related estimate. The authorities then search for any errors, overlooked items and biases, and finally correct any which they identify. It is presumed that they will then be able to deliver a 'correct' result to the decision-makers.

In this particular case the industry, represented by SKB, is appointed, according to the law, to deliver a plan and a related 'expert estimate', albeit that it excludes the costs related to the authorities. The authorities, here represented by SKI, are appointed to estimate the authorities' costs (SKI and SSI) and also to correct any failure or bias in the base estimate which was received from SKB. The corrected estimate, with the authorities' costs added on, provides the final basis for their recommendations to the decision-makers. The above procedure is required by law and related administrative rules. Unfortunately, this procedure hinders an optimal result, as will be further developed below.

The industry is required to perform the greater part of this work. It does have the technical expertise, but not any special knowledge about the future societal conditions under which the resources and the related costs will operate; and nobody knows the future results of ongoing research in the area. These facts seriously reduce the quality of the estimate. Moreover, it is hard for such experts to avoid a certain understatement of future potential problems, and a belief that further research and development will be able to solve remaining unsolved matters. They will generally have a natural expectation that they will be able to handle these matters well. Such wishful thinking has proved to be able to impact on the estimate results even when the individuals involved honestly try to be neutral.

SKI's task of verifying and supplying the base estimate also suffers from problems which mitigate against an optimal result. They certainly do have experts in the area concerned. However, they do not have deep inside knowledge of all aspects, notably the estimate details and evaluations behind the figures. This fact hinders an optimal search for biases, potentially overlooked factors, banal errors, etc.

In addition to this, the authorities' costs are costs like any other cost item in this estimate. They therefore need to be fully integrated into the estimate, instead of being an appendix not necessarily catering for the general conditions of the overall estimate. The above reasons therefore significantly reduce the quality of the estimate result.

The basic objective of this research study is to search for an optimal solution. It will therefore necessitate analysing and discussing an adjusted procedure in which the above-mentioned hindrances are eliminated or at least materially reduced, even if this necessitates minor adjustments to the basic system provided by the current law and related administrative rules. Such improvements of laws are a natural and old tradition in all societies.

An adjusted organisational system is presented and analysed in Chapter 2, while a discussion of its relevance follows in Chapter 4.1 a.

Chapter 1.3

Comments on the law on financing (1992:1537)

SKI is required by law annually to submit to the Government a fully supported recommendation for values the following three sets of figures.

1. Next year's unit fee (in Swedish öre/KWH) for electricity produced by nuclear power for each of the existing four company units: Forsmark's Kraftgrupp AB (FKA), Oskarshamn's Kraftgrupp AB (OKG), Ringhals AB (RAB), and Barsebäck Kraft AB (BKAB).

The proposed unit fees should cover in full all future costs arising both from future handling of the waste and demolition of the plants and subsequent site cleansing: all duly executed in a safe manner. The costs include those incurred by SKI and SSI in relation to this programme.

In addition to the legal requirement, minimising the variation from year to year of the annual proposed unit fees is advocated. It follows from this that the uncertainty in the range of future data should be handled in a way which, with the greatest possible realism, allows for an expected value as well as uncertainty, expressed as the standard deviation.

Major unplanned events are included in the safety allowance (no. 2) (Säkerhetsbelopp II). Such events are further dealt with below. However, a considerable unavoidable uncertainty remains even if no major unplanned event occurs and even when the uncertainties are minimised during the estimating process.

It would therefore be natural to plan for the Fund to provide cover for a high level of probability (technically called the quantile), e.g. 70, 80 or 90%. This is important because none of the safety allowances covers this situation; see ref. 21, "Plan 2000", end of p. 11.

2. A financial safety allowance (no. 1) (Säkerhetsbelopp I) in million SEK is to be calculated for each of the four company units relating to the scenario in which all nuclear production is to be closed down in the course of the following year. The allowance is to be calculated as the difference between the 90% cost quantile of the estimate and the existing Fund.

3. An additional safety allowance (no. 2) (Säkerhetsbelopp II) in million SEK is to be calculated for each of the four company units. It must cover the costs arising from major unforeseen events. It is calculated as the 90% quantile derived from an estimate representing the potential impact of such events.

The law is open to various interpretations, such as a definition of ‘a Major unplanned event’. These can either be defined in more detail or introduced into the basic estimating procedure. See refs.1 and 4 for more information.

Chapter 1.4 The scientific paradigm behind the study

The primary scientific basis for this research study is the subjective probability theory or the Bayesian statistical theory. As the axioms behind this do not belong to classic or Newtonian science, in which experimental data plays a dominant role, further discussion is set out below.

About a hundred years ago, Rutherford, Bohr and other early nuclear scientists conducted some most surprising experiments. They did not follow the laws of Newtonian physics. Indeed, they found that the firmly established classic laws were useless at the atomic level. As nature cannot be changed, the Newtonian axioms had to be further developed through a lengthy process. A new paradigm had to be formulated and gradually verified through experiments and not least discussions. Decades later, modern nuclear physics was established and accepted. Without such a transition, nuclear power plants and many other systems would not exist today.

The classic or frequentistic statistical theory has met a similar challenge. An example illustrates this. During the 1960s the official Danish codes for large prefab concrete units in the construction industry were drawn up. The uncertainty in the geometrical sizes required a certain reserve or slack in the joints between structural units. Attempts to use the statistical theory on this problem resulted in requirements for the width of joints to be one to two feet or half a metre. This was simply considered ridiculous and impossible to live with. So the theory seriously failed when faced with the real world.

The classic statistical theory also failed in the area of planning and estimating, which developed rapidly after the last world war. The professionals met increasing uncertainties about future events and activities. Due to the rapid development and unforeseeable societal changes in the contemporary world, no historical ‘statistical population’ could still be accepted as a valid basis for estimates and planning of larger and generally unique tasks. It was impossible to find data or to conduct experiments which satisfied the requirements as to an acceptable ‘population’.

These and other problems supported or rather required the development of a new paradigm for the statistical theory with fewer restrictions. The most famous single step was probably the so-called Critical Path scheduling procedure, PERT, developed for the U.S. Defense Department in 1958. The subjective evaluation of a triple estimate was introduced for the first time.

During the following decades the philosophical transformation from the classic statistical theory to the new paradigm of the Bayesian statistical theory was developed. The restriction of an acceptable population of quantitative data as input was widened to include subjectively evaluated uncertain figures. The handling of such figures may even benefit from all the ‘classic’ formulae. During that period a great number of dissertations, papers in journals and conference papers discussed this transition, until this new paradigm reached a high and stable level of acceptance in the 1980s.

A thorough theoretical and general description of the Bayesian statistical theory is given by Georg Apostolakis (ref. 31). Professor Dr. Ove Ditlevsen describes applications and experiments in civil engineering in his dissertation (ref. 37). Conclusions from extensive Norwegian use of Bayesian statistical theory through two decades are described by professor Klakegg (ref. 32), and later summarised by Berg (ref. 30).

The first scientific description of the specific area of *subjective quantitative evaluations* was published as long ago as 1975 by the Swedish professors Spetzler and Stäel von Holstein in a prize-winning paper in the most respected journal, ‘Management Science’ (ref. 34), followed up by Lange in 1985 (ref. 33), and Lichtenberg (ref. 1).

Another form of verification is the vast series of full-scale ‘experiments’, in which an estimated project duration or investment is compared with the final actual result. Since 1980 several hundred such ‘experiments’ have served to verify the relevance of using the Bayesian theory.

Chapter 1.5
The cash flow and Net Present Value techniques

The well-known cash flow technique and the Net Present Value concept seem highly relevant here. However, these well-known basic tools must be adapted and tailored to meet the complexity in this situation. This is further developed below and in later chapters.

The cash flow table is a well-known basic tool. For every relevant year it indicates in tabular form the value in terms of annual ingoing and outgoing payments to and from the defined system over the lifespan of a project or programme. All values are measured against a so-called zero alternative. In this case it is the fictional situation of no payment and no demolition of any unit.

An example is given in figure 1.5a below. The annual values are given in columns (3) and (4) in the figure below. The discount factor (D) is shown in column (2). The discounted annual values are calculated by multiplying the annual values by the related discount factor (D). This is shown in columns (5) and (6) in the figure. The result depends on the chosen ‘annual discount factor’ (r). If another annual discount factor is opted for, such as 5% per year instead of 8%, the figures will change accordingly. The overall result will normally decrease with increasing values of the ‘annual discount factor’ (r).

Period	Discount			Discounted		Aggregated	Remarks
	factor	ingoing	outgoing	ingoing	outgoing	NPV	
(year)	D	<---------------------MSEK--------------------->					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0	0.962	000	-080	000	-077	-077	Investment period
1	0.891	000	-200	000	-178	-255	
2	0.825	070	000	058	000	-197	The operation period starts
3	0.764	119	000	091	000	-107	
4	0.707	119	000	084	000	-022	
5	0.655	119	000	078	000	056	
6	0.606	119	000	072	000	128	
7	0.561	119	000	067	000	195	The running-down period starts
8	0.520	119	000	062	000	256	
9	0.481	070	000	034	000	290	
10	0.446	025	000	011	000	301	End of the economic life
11	0.413	000	000	000	000	301	
12	0.382	000	000	000	000	301	
Grand total:		**879**	**-280**	**557**	**-255**	**301**	

Figure 1.5a A typical cash flow in tabular form. It deals with the lifecycle of an industrial product. The annual discount factor here is 8%. The resulting net present value (NPV) is shown at the bottom of col. 7. See figure 1.5b, which illustrates a similar context in diagrammatic form.

The correct handling of uncertainty related to NPV calculations requires a somewhat different approach. The reason is that the uncertainties of the payments from the individual years are generally statistically dependent on each other. If, for example, too high an estimate is made for an ingoing payment for year 4, then the next year’s payment is most likely also to err on the high side. These dependencies will at the very least disturb the proper handling of uncertain values, and often seriously distort the result.

This problem is solved by discounting the aggregated payments for a defined activity by the discount factor which relates to the point of time equal to the ‘point of gravity’ of the geometrical payment figures or cash flow diagrams. This issue is dealt with below in subsequent chapters.

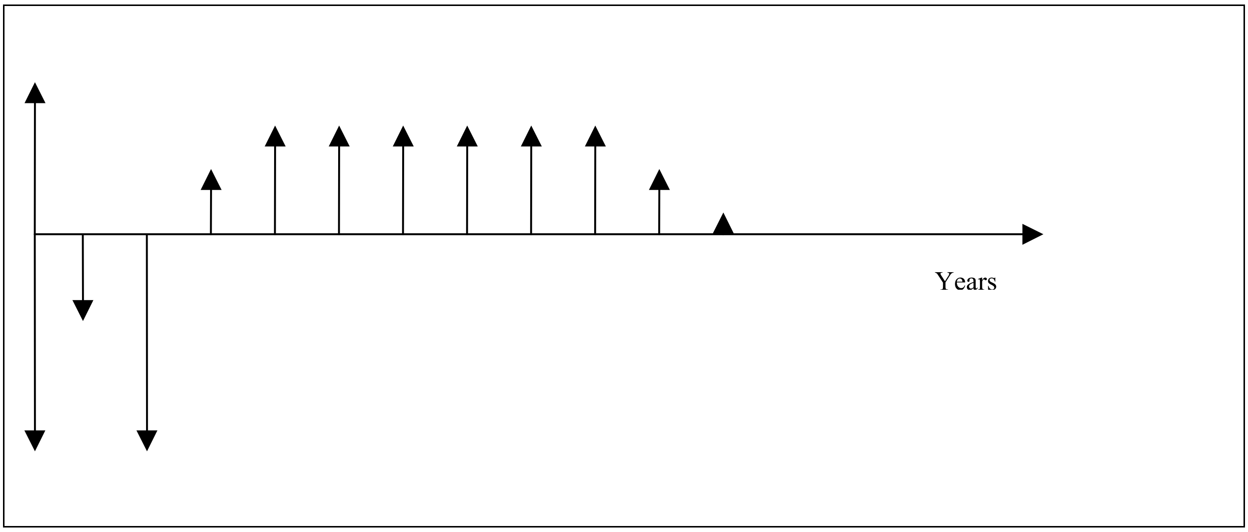

Figure 1.5b The cash flow from figure 1.5a in traditional diagram form.

The transformation of such a diagram from the traditional diagrammatic form into geometric figures is shown in figure 1.5c.

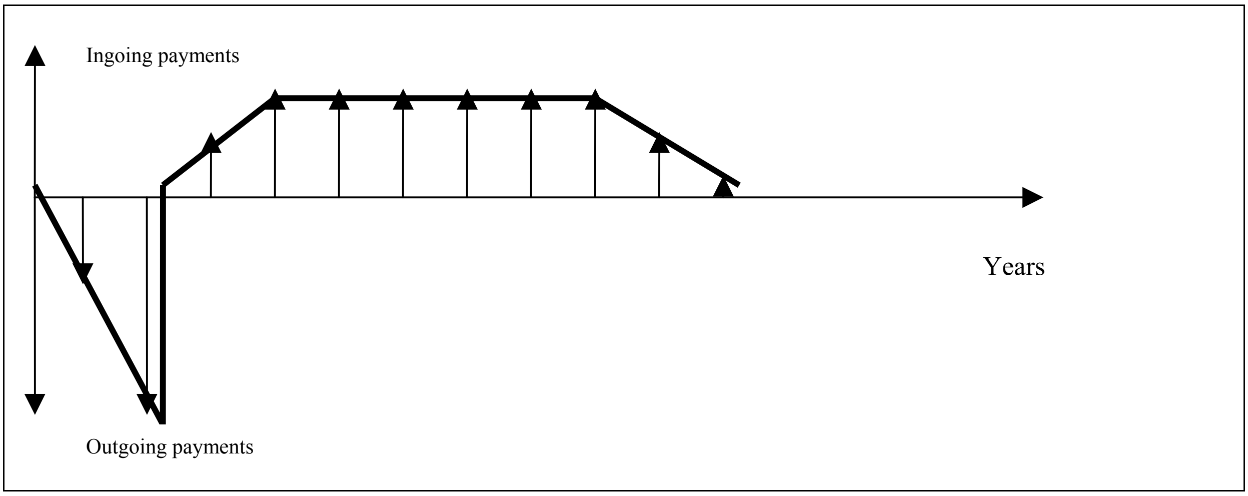

Figure 1.5c The same cash flow transformed into geometric figures.

The Net Present Value (NPV). The most important profitability criterion, the Net Present Value or NPV can be calculated from these cash flow diagrams. The Net Present Value criterion, NPV, is probably the most acknowledged criterion for profitability and for a situation like this. It is calculated as a sum *taking into account the signs of all contributing discounted cash flow values over the total lifecycle of the project.* In the example in figure 1.5a, it is simply calculated as the sum of negative and positive figures of columns (5) and (6), or directly as the final aggregated value in column (7), bottom line.

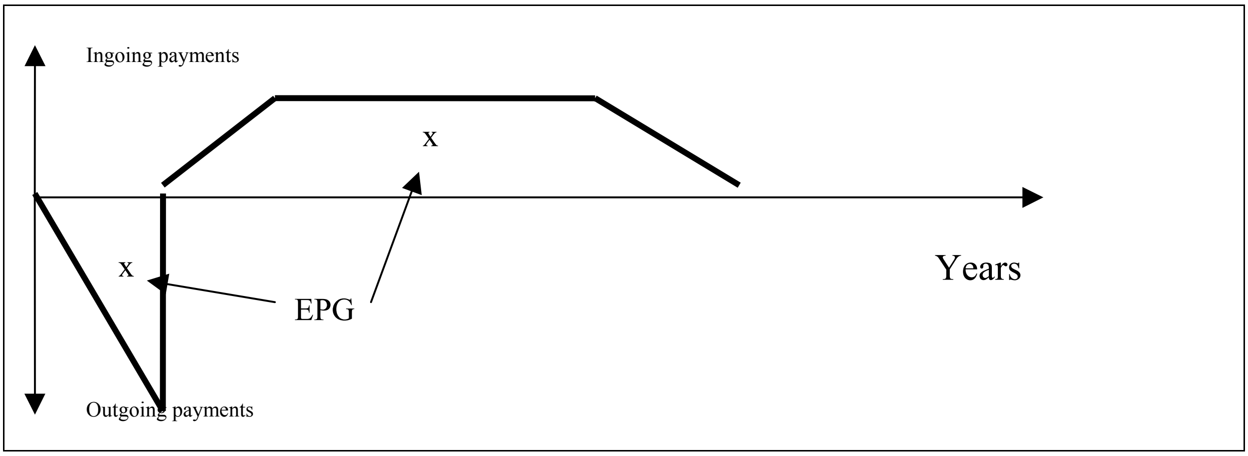

Figure 1.5d The cash flow in a suitable form for handling uncertainties. Note the 'Economic Point of Gravity', EPG. See the text below.

An alternative method for calculating the NPV is to multiply the total aggregated payments of a certain activity by the discount factor of the point of gravity of the geometrical figure shown in figure 1.5c. This point of gravity is therefore called the 'Economic Point of Gravity' or just EPG. This procedure offers the possibility of dealing with two statistically independent figures. The total of the payments will generally be sufficiently independent of the discount factor.

Chapter 1.6 The Successive Principle

Introduction

The Successive Principle with its underlying procedures is also considered a basic tool in this situation. Its ability to fulfil the above-mentioned basic requirements is well supported by theoretical findings and evidence from more than two decades of practical application, not least in Sweden. As this procedure is rather untraditional, it is further outlined below.

The basic philosophy behind the Successive Principle is (1) to make more efficient use of human common sense, creativity, intelligence and group synergy in order to identify all relevant factors; (2) to provide an unbiased evaluation of their impact; and finally (3) to handle the many subjective uncertainties in a scientifically correct manner.

The principle has been used for many years in most private and public areas to support, improve and facilitate decision-making, planning, scheduling, estimating, allowance & guarantee discussions, commercial risk and opportunity analyses, strategic planning, project audits, follow-up, recovery of delays, as well as a support during the start-up and team-building phase of new ventures.

Applications

The applications and benefits are primarily the following three:

(1) It is possible to make extremely realistic budget estimates, commercial prognoses, project durations, etc., and thus largely eliminate overruns and other unpleasant surprises. This can even be done at a very early phase of the plans.

(2) The responsible managers receive a "top-ten list" of critical and/or promising aspects, which allows them to exploit the positive opportunities for further progress and to protect the project or programme against risks in good time.

(3) The mutual understanding among the key individuals involved of the given project or programme, its aims and characteristics is radically improved, thereby also improving the crucial thrust and team-building process.

The major issues

The basic facets are (1) consciously to include all factors of importance: not only the physical and formal items, but also 'fuzzy' and even sensible matters; (2) openly and correctly to control and handle uncertainty according to recent scientific knowledge, and even to consider uncertainty as a highly exciting aspect of planning and management.

For reasons of overview and rapid performance, a third facet is (3) to work top-down, starting with main items, and successively developing a work breakdown structure in those few areas where local uncertainty is absolutely critical. See figure 1.6a, next page.

Due to the complexity and fuzziness of projects and other activities today, it is considered essential to perform the analyses jointly in a group of key persons. This also has positive side effects, such as greater consensus and improved team building.

The application of the Successive Principle is linked to a management style which focuses on cooperation and includes a degree of openness which allows the participants to speak out about all sorts of relevant uncertainties.

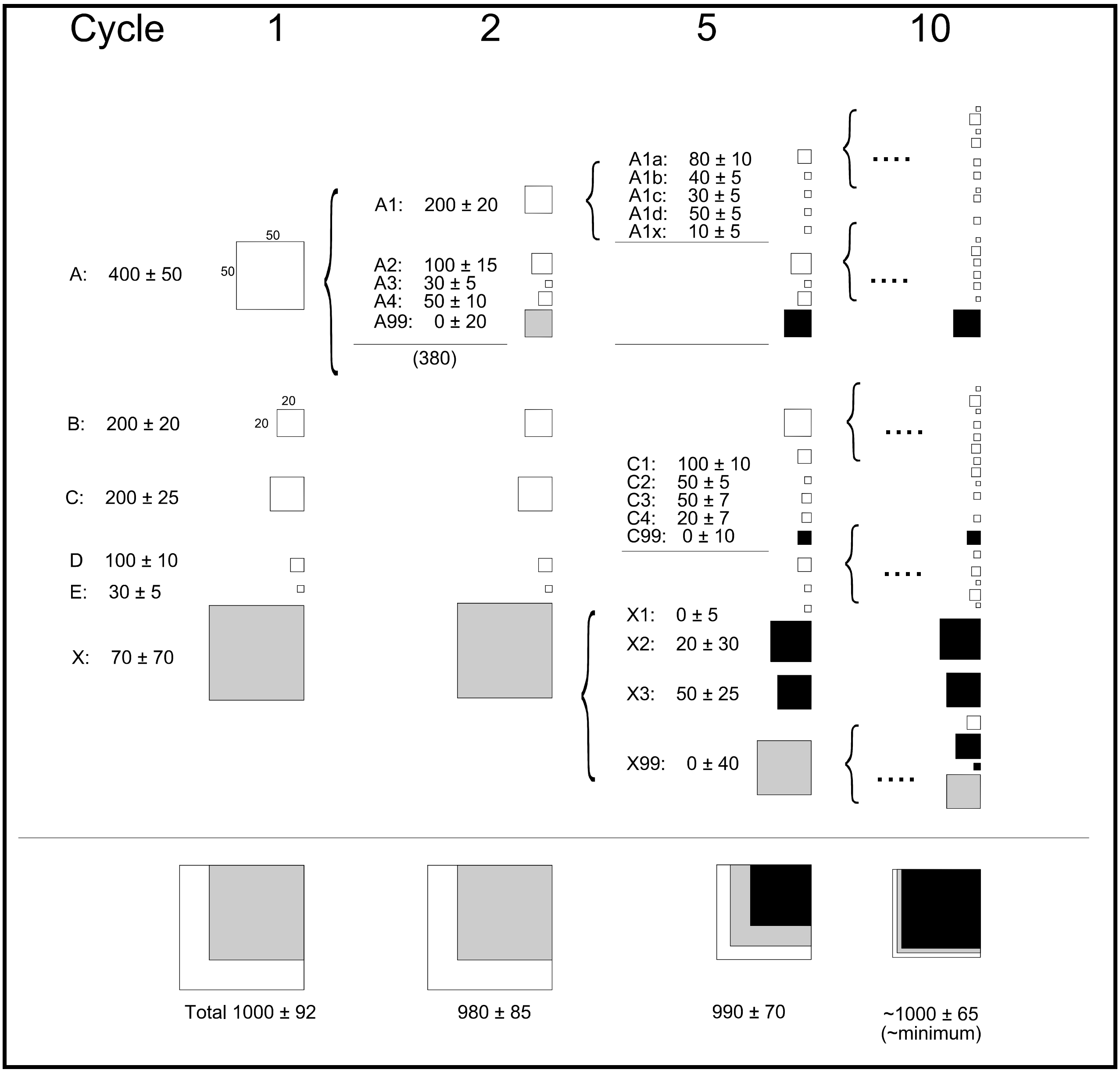

Figure 1.6a An illustration of the strong "intelligent" successive detailing process embedded in the Successive Principle. The left column represents an estimate of 5 main items denoted A, B etc, plus an allowance, X, for 'unknowns',. The sides of the squares represent the local uncertainty while the areas of the squares indicate the local contribution to the uncertainty of the grand total. Adding all the squares together therefore results in the grand total uncertainty. The large square on main item no. 1 indicates that the next relevant step is to detail this item. The uncertainty is in this manner broken down into small elements. This detailing process continues until no further reduction of the uncertainty is possible. The white areas indicate local uncertainty which can be reduced through further detailing. The grey areas relate to uncertainty from Overall Aspects, while the black areas represent remaining, unavoidable uncertainty. In this manner we focus successively and efficiently on a grand total with a minimum of uncertainty. The squares below the bottom line indicate intuitively to the user how close we are to the optimal result.

The general procedure outlined

The procedure follows the steps below:

1. A proper **group of key persons** is established, its composition determined by the purpose of the specific analysis. The first task of the group is **to discuss in depth the project or task**, its firm preconditions, limits, and objectives.

2. All **general sources of potential uncertainty** are identified, organised into groups and defined into a base case reference and potential deviations according to relevant sub-routines.

3. **A set of specific main items/main activities** (in the following abbreviated to items) is chosen and described. Their numerical values are evaluated, using the group triple estimating technique. A set of overall correction items is added, based on potential deviations from the base case reference, defined as per item 2 above.

4. **The numerical calculations** are performed, using statistical rules, ending in the mean and the uncertainty of the total and not least a priority figure for every item. It indicates the relative importance of the individual items to the total uncertainty, and is further developed below.

5. The most critical items are **successively detailed**. The priority figure, is a powerful guide in this detailing process. This successive detailing and re-evaluation continues until a practical minimum uncertainty is reached.

6. **The result** consists of a highly reliable mean value, the related uncertainty, and not least a "top-ten list" of the remaining major sources of uncertainty in order of their relative importance or priority. This last list is typically followed by a set of action plans, proposed by the analysis group.

Some key aspects

a. Identify Potential Sources of Uncertainty

An analysis group is formed and headed by an individual with sufficient competence and experience in the Successive Principle.

The first task of the group is in-depth discussion of the project or task, its scope, its firm preconditions, its unique aspects, as well as the formal and informal objectives and priorities of the primary stakeholders. All participants should share the same understanding of this remit.

All general sources of potential uncertainty, called ‘Overall Aspects’, are then identified (using brainstorming techniques), organised into statistically independent groups, called ‘General Issues’, and given a base case reference definition, as well as a description of potential deviations due to the actual situation.

b. Quantification

A set of specific main items/main activities is chosen and described. This list is supplied with correction factors or items related to the above-mentioned set of Overall Issues. The numerical figures are considered to be uncertain and dealt with according to the Bayesian statistical theory, which has proved highly valid in this area.

The numerical value of each main item is evaluated, using the group triple estimating technique (see Chapter 3.6 and 4.3). The main items are evaluated subject to the defined calculatory base case reference situation, while the correction factors reflect the conditional potential *deviations* from the above reference situation. All items and factors are in this manner sufficiently statistically independent of one another.

This solves the old problem of statistical dependence and related correlation coefficients, which has hitherto seriously undermined either the relevance of the results or the practical operability. The quantification is further outlined in Chapter 3.6.1.

c. The mean and variance of the total result

All input items, whether costs, volumes, unit prices, durations or percentage additions to other items, are transformed from a triple estimate (min, most likely, max) to their mean values, m, using the approximate formula: (min + 2.9 x likely + max)/4.9. The uncertainty is most efficiently measured as the standard deviation, s = (max – min)/4.65. The relative standard deviation, s/m, is applied where an item consists of more than one factor.

The mean, M, of the total is then calculated by using all mean values, m, as deterministic figures.

For each local uncertainty **its conditional effect, S, upon the total result is derived**. Adding together the square of all values of (S x S) will equal the (S x S) of the total result. The individual values of (S x S) are called the local priority figure, P, because it illustrates the relative importance of the item to the uncertainty of the total result. It is analogous to the statistical concept of variance.

The uncertainty of the total result, as has already been indicated, equals with sufficiently good approximation the sum of all priority figures. Only a second-order marginal addition is needed. The statistical distribution function of the total result can normally be assumed to follow the so-called Normal distribution or Gauss curve. Only in the case of a dominant and skewed local uncertainty will the resulting curve be slightly skewed. In such cases it is possible to make a more exact calculation of the resulting curve. Either/or events also require a supplementary sub-routine.

Statistical dependencies and their related correlation coefficients and co-variances are deliberately eliminated to the appropriate degree. This is primarily achieved through the handling of the Overall Issues, and by consistently working with the conditional uncertainty.

d. Successive detailing and results

Guided by the priority figures, the most critical items are successively detailed. In this manner the group performs a highly efficient and "intelligent" detailing of the most critical items. After relatively few such steps (typically 4 to 12), of which some may be further specifications of sub-items, the items carrying unavoidable uncertainty will dominate more and more. After a while they typically represent 80 to 90% of the total uncertainty (variance).

This means that we have come close to the minimum uncertainty of the total, and also to a highly reliable mean value, a derived uncertainty, and not least the top-ten list of the remaining major sources of uncertainty in order of their relative importance or priority.

The total mean value (and the uncertainty) is reliable and realistic for four reasons: (1) all significant matters are included, directly or indirectly; (2) the uncertainty is dealt with in a controlled, scientifically sound manner; (3) evaluation biases are kept under control using a proper evaluation technique as discussed below, and (4) detailing has been performed in all critical areas.

A top-ten list is typically followed by a set of action plans, proposed by the analysis group by way of conclusion. At its best, the action plan in tabular form lists the proposed actions as key words, each with the initials of one of the group members together with a date by which he/she agrees to have achieved a result.

At a supplementary session the group may introduce the new information from the resulting actions into the analysis and thereby efficiently improve the result.

e. Evaluation technique

“Hunch evaluations” play a dominant role in these procedures. Many pitfalls threaten "hunch evaluations" or "qualified evaluation". The evaluation technique has therefore been developed in order to improve the quality of the analysis results.

The evaluation technique implements knowledge of evaluation pitfalls and indicates sub-procedures to avoid systematically any errors from such pitfalls. Casual errors, on the contrary, will in part eliminate each other in a controlled manner, according to the classic statistical laws.

Originally inspired by research from Stanford Research Institute in the 1970s, conducted by S. Spetzler & Stäel von Holstein, further research in 1984 at the Technical University of Denmark by Nils Lange and Steen Lichtenberg has identified a set of pitfalls and, to some degree, also the underlying mechanisms.

Experiments have shown (1) that most of us are very untrained; and (2) that we can learn and train ourselves to be considerably better. But above all the procedure of the so-called *group triple estimating* has proved to be able to yield non-biased results, if conducted in the right manner. The essence of this procedure is (1) to establish a balanced evaluation or analysis group, (2) to allow each participant in the group analysis session to make his/her entirely personal triple estimates without any interference; and (3) to use the most extreme maximum and minimum in the group, while the most likely is the average of the individual evaluations. Due to limited space, detailed discussion continues in ref. 1.

Chapter 1.7 Comments on the discount rate

KAF has established a certain series of annual discount factors, namely 4% p.a. until 2020 and 2½% thereafter (in this report called the 'KAF rate'). The first figure is based on the existing financial contracts. The second figure seems to have been chosen deliberately as being on the 'safe side'.

The absolute interest rate depends in the short run on the investment policy, which can be more or less speculative. In the long run this variation may to some degree be levelled out, the reason being that some more speculative and high-rate investments may yield a loss, which again level out the average profit towards that of more conservative investments.

Inflation will also have an impact on interest rates unless future financial contracts specifically deal with real interest rates. The lenders will subtract their anticipated future inflation in the short run. This anticipation will often be biased towards recent historical inflation. The result of this is supported by historical evidence. The historical annual real interest rates show waves with a length of 5 – 10 years. They correspond to the general economic trends/waves. After a period of high inflation people cannot imagine that low inflation could ever be a reality and vice versa. Taking the long view, it is not without interest that safe investments over the 150 years leading up to 1980 yielded an average real interest rate of 3.3% p.a. Updated to today, the corresponding figure would be approx. 3.5% p.a.

The relevant series of future rates is uncertain. Among the reasons are future inflation, the investment policy, the future world economy, etc. All these matters cannot be calculated but have to be evaluated using a qualified guess.

For this reason the best obtainable expected value is realised using a series of group triple estimates covering the parameters outlined above and below. The reason is that this sub-procedure reduces the many pitfalls to a minimum, and thus minimises the final bias. As an additional benefit the uncertainty is also measured. This allows the relative importance of these uncertainties, compared with the other sources of uncertainty, to be documented.

It is stressed that the relevant analysis group differs in this respect from the main analysis group dealt with in the rest of this report.

A similar evaluation process has been performed in Sweden a few times, to the author's knowledge. The results of these shall not be mentioned here, as the evaluation that is advocated here must not be biased by past evaluations which may have been made under different conditions.

The resulting three series of future annual real interest rates, which are relevant to this particular situation, can be based on the present/historical interest rate, future changes, the current rate of inflation, the future changes of that parameter, the differential rate of inflation for the sectors which are relevant here, the future investment policy, etc. If an unbiased evaluation is conducted of each of these parameters, their sum will benefit from the statistical levelling effect.

The practical handling of this issue is further discussed in Chapter 3.6.

Chapter 2 Organisation of the procedure and the analysis group

Chapter 2.1 Organisation of the procedure

Responsibility

The responsible body (called the 'analysis sponsor' in this study) needs to be independent of any private interests and at the same time to have professional knowledge of the area. The first requirement follows from the need to ensure an unbiased result; see the critical aspects 1 and 2 in Chapter 1.1 above. The second requirement is vital to the ability to exercise efficient, ongoing quality control throughout the process.

Organisational and political aspects

The above-mentioned requirements indicate SKI as having clear, high-level responsibility for the estimate procedure. In fact it is seen as the only body which fulfils both criteria. The question of which parts of the procedure can and will be delegated to SKB or to other parties is outside the scope of this study. However, the overall responsibility should never leave SKI. Those parts of the procedure that will be delegated out must be followed by detailed requirements as to the procedure and the process, as well as to efficient methods of follow-up and control.

There is, however, one point at which the four nuclear power plant company units should be given authority, possibly represented by SKB. All four should discuss and decide upon a precise model of apportionment of the total costs between them. Such a model allows SKI to calculate fair and accepted specific unit fees for each unit, and also the final values of safety allowances 1 and 2 for each unit.

The ideal solution would be that SKI, as analysis sponsor, adopts the role of managing and responsible body for establishing the analysis group and for implementing the procedure. This, however, may diminish SKI's traditional role as controller. According to newer public attitudes, concepts such as Private-Public-Cooperation, PPC, may relieve this hindrance to the above-mentioned ideal solution. It must also be remembered that the procedure suggested in this study is an integration of the estimate performance and the quality control, using the synergy optimally.

However, the possibility remains of keeping to the traditional divided roles of the 'doers' and the 'controllers', whereby the function of procedural manager (in the following called *'Analysis Management'* or '*analysis facilitator')* is delegated out, while SKI retains the high-level role of supervisor and controller. In any event, the appointment and payment of the facilitators should be undertaken by SKI. Similarly, the final appointment of the analysis group members should be left to SKI, albeit based on suggestions from SKB.

SKB could technically do this job according to a set of rules laid down by SKI. But they would always be open to suspicion that their particular interests bias the outcome. The fact that this might not be the case does not alter this unacceptable situation. However, as identifying the body which will perform the function is not a matter for this study we shall use the non-specific term ‘the Analysis Management’ in the text below.

It is a prerequisite that the procedure is structured and operated in a way that will give ordinary people, and not least politicians, board members and other decision-makers confidence that no particular interest group has undue influence on the result. In other words, that they will immediately trust that the result is a neutral one.

Many details in the procedure are designed to obtain such independence of any parties’ interests. However these matters will not be apparent to ordinary people and their representatives, the politicians. Only the organisation and *composition* of the analysis group is visible and understandable. This should therefore be transparent and so arranged as to leave no grounds for suspicion.

This situation seems to favour the above-mentioned ideal solution.

Comments on evaluating future political decisions

Another issue which has been raised is whether it is acceptable that an analysis group evaluates the outcome of future political decisions, decisions not yet reached. It seems that this is indeed acceptable and even necessary for two reasons. First, that the analysis group will need to evaluate the full range of possibilities before assessing the odds for the available alternative decisions. The political decision-makers are still completely free to choose whichever solution they feel is the relevant one. Secondly, it will be in the best overall interests of the political decision-makers that the future is evaluated with maximum realism. This implies that the overall outcome or impact of future decisions is properly included in the analysis result.

The practical organising of the procedure

A contract should be negotiated and signed between SKI and those parties to whom responsibility is delegated, and who will manage the procedure or parts of it. SKI will have the initiative, due to its ultimate top-level responsibility in this matter. For the same reason, SKI will in principle function as the analysis sponsor.

The two appointed facilitators (one principal and one deputy) will be one party in this matter. They should be highly competent and experienced in the relevant analysis techniques. Another important party is the body that will be responsible for the practical implementation. In addition to SKI itself, SKB seems to be one of the natural candidates for this role as the ‘Analysis Management’.

A steering group should be established to coordinate and follow the process. In addition to the facilitators, it could consist of one or two representatives of the analysis sponsor and the Analysis Management respectively. The objective of this group is to ensure correct and efficient implementation of the procedure, and not least to handle proactively any misunderstandings, disagreements or other problems which may arise.

Chapter 2.2 Establishing the main analysis group

One of the first tasks of the Analysis Management would be to establish a main analysis group according to criteria outlined below. Such a group will be a highly important instrument during the whole process. Because of the importance of the right composition of this group, SKI should, as has already been mentioned, in any event retain the right to authorise the composition of the group before the process starts.

The constitution of the analysis group

The main analysis group should include a balanced mix of between 15 and 20 competent experts and generalists. A number of the experts will for obvious reasons be involved in the programme. They may therefore generally tend to be somewhat optimistic about a successful implementation and to risk understating difficulties, and thus be biased on the optimistic side. Some of the external appointees should therefore play the role of the devil's advocate, i.e. focus upon problems and obstacles of any kind.

A suitable balance might be: approx. 60% of the members could be experts in this area, while the remaining 40% would be external to the company units or their organisation, SKB. Half of the latter fraction or approximately 20% should be external to the whole national programme and not involved in the related political discussion. Among this fraction, at least two members should be known to have a negative stance on nuclear power programmes. These suggested rules are illustrated in the table below.

Experts from the industry and related bodies (approx. 60%)	Experts and generalists, external to the industry in question (approx. 40%)	
	Professionals from SKI or related bodies (approx. 20%)	*Professionals or generalists, external to the national program (approx. 20%)*
People whose personal stance toward the nuclear power concept is positive, neutral or unknown (approx. 85%)		People known to have a negative stance on the nuclear power concept (approx. 15%).

Figure 2.2a Suggested rules for manning the analysis group.

In the interests of maintaining the balance of the group in case of absences due to sickness or other causes members should (1) be invited in good time, e.g. 5–8 weeks before the first analysis session; and (2) a qualified deputy should be appointed for each member.

Each member of the analysis group should be instructed to participate as an independent person without bringing any 'agenda' or restriction from his/her organisation. He/she participates because he/she is supposed to be able to contribute to an optimal result.

Under such circumstances it should be permissible for personnel from SKI to participate without damaging SKI's role as an independent top-level controller.

Reconstitution of the group is dealt with in Chapter 2.3 below.

The practical establishment of the analysis group and other initial preparations

An 'Analysis Management' should be established, consisting of the facilitators and one or two representatives of the analysis sponsor and analysis manager. One of its first tasks will be to realise the practical establishment of the analysis group, inclusive of deputy members.

The search for the right persons and coping with diary problems for the planned sessions should be given ample time. During the process of establishing this group the Analysis Management may consult significant involved parties and interest groups. Representatives of some of these parties may, if appropriate, be included in the process as observers. This would enable them to gain a better understanding of the background and to accept the results. During the process, sub-groups may be set up. This may for example be appropriate when detailing the authorities' costs.

In addition to corresponding with members of and candidates for the analysis group and organising the calendar for analysis sessions, the Analysis Management has the task of organising the physical facilities for the following analysis group sessions. The Analysis Management also produces drafts about the following issues:

* A summary of the procedure and underlying principles.
* A few possible scenarios as suggestions for the first session.
* A detailed set of provisional firm preconditions.
* A proposed schedule structure and a calculation structure.

The above suggestions are mailed to the members of the analysis group, as well as to the deputies, well ahead of the first analysis group session.

Chapter 2.3
Comments on the periodical updating of the analysis

The period between two consecutive analyses

The procedure which is suggested in this report, relates first of all to the 'first performance', which may be performed in the year 2004 or later.

The period between two consecutive analyses is left as an open question here. Such a period might be one, two or three years. However, SKI has annually to make a final evaluation as a basis for its recommendation to the Government. Only the basic information delivered to SKI might not be revised annually.

It seems appropriate to continue the present annual update analyses, in order to improve the estimate steadily, while introducing new or more specific information acquired during the year.

On the other hand, the procedure may risk stiffening into a mere ‘mechanical’ process, where ‘the same procedure as last year’ may be supplied by ‘the same figures as last year’. The considerable investment of resources involved will also support the solution of updating every second or even every third year.

The basic procedure described in this report could by and large be repeated at each update, benefiting from an increased ‘routine and repetition’ effect. However, it seems to be a problem that existing visible data tends to “shadow” emerging new or changed data. The following detailed corrective actions might reduce this potential problem.

As a first action, the participants should agree that a new evaluation is in principle more relevant and updated than data from the previous analysis. Secondly, everybody should avoid looking at the relevant previous data, when updated data has to be evaluated. The facilitator will have the primary responsibility of ensuring that such previous data are not visible during the analysis sessions.

A critical view of the firm preconditions will also be of importance. It is also very important to conduct a new brainstorming process on every updated analysis, in order to optimise the rational process of identifying new upcoming issues. Experience shows that studying the previous year’s list will seriously hinder the emergence of such new issues. After the brainstorming process the previous list can be used as a control for any topic which may have been overlooked.

It will hardly be necessary to establish brand new detailed evaluations from the technical analysis sub-groups. However, they should focus on any specific or gradual changes and make a new independent evaluation in all such cases.

During the important sub-procedure during which the main analysis group evaluates the impact of the overall Issue Groups, a new independent evaluation should be performed without knowledge of the previous figures. Slight casual differences between figures from year to year should be allowed and accepted. It is much more important that the overall picture of any given year is healthy, fully updated and not biased by previous data. The above casual local differences will level each other out in the total result, following the basic statistical ‘law of large sets of figures’. In conclusion, an annual analysis process seems most appropriate.

Reconstitution of the analysis group

In the long run, an appropriate balance should be established between considerations of continuity on the one hand and a focus on gradually ensuring new blood within the analysis group. A policy of replacement and terms of reference should be drawn up reconstituting the analysis group while at the same time ensuring a sufficient degree of continuity. One model could be that participants in the new initial group draw lots for either 1, 2 or 3 periods. The effect would be that one third of the participants would be newcomers, and two thirds would ensure sufficient continuity.

Chapter 3 A proposed procedure

Chapter 3.1 An Overview

The whole estimating procedure is summarised below in two steps in order to give an overview. The first phase, the preparations before the first analysis session (sub procedure no. 1, next page), has already been dealt with above.

The major sub-procedures, nos. 1 – 9, are broadly outlined in table 3.1a below, while the individual sub-procedures are illustrated in greater detail in the following table 3.1b.

All procedures are then developed in detail in the following Chapters 3.2 to 3.9.

Sub-procedures	**Comments**
1. Organising the procedure and the analysis group	SKI initiates the establishment of an analysis organisation and delegates responsibility to the relevant parties. An Analysis Management group is also established. One of its first tasks is to establish a proper analysis group.
2. The qualitative analysis phase	The scope of and preconditions for the evaluation are defined. Also a comprehensive hierarchical list of 'General Aspects' of uncertainty, grouped into a few 'Overall Issues'.
3. Scenarios, alternatives and structures	A few relevant scenarios are defined together with a minor set of agreed 'major either/or alternatives'. A schedule structure and a cost calculation structure are also defined.
4. Cost-sharing modelling	SKB coordinates an agreed cost-sharing model for the four individual company units.
5. Definitions of a base case reference, worst and best extremes	The list of overall issues of uncertainty (established in sub-procedure 2) is supplied, with a base case reference as well as key words on potential deviations from the defined base case.
6. Quantification I Schedule, interest rates and other preparations	For each scenario and alternative, the expected programme duration is evaluated, followed by a calculation of the expected start and finish of the primary activities . Cash flows are prepared as well as the expected future real interest rate.
7. Quantification II The total base case estimate	Total estimates for each alternative and special scenarios under the base case conditions. This includes sub-estimates of the authorities' costs and other important elements.
8. Quantification III Finalising the estimating process	The above estimates are supplemented by the effect of the previously defined overall issues, resulting in realistic, expected total results. Some special simulation runs result in the size of impact of uncertainties in the timing and the real interest rates. A corresponding unit fee for each unit is calculated as well as proposed values of the two safety allowances.
9. Final reporting	A final report with summaries and conclusions is produced.

Table 3.1a Initial short overview of the procedure.

After the completion of each sub-procedure a working report should be drafted by the facilitator and then checked by the participants until consensus is reached.
The sub-procedures are further specified and described in table 3.1b below.

Sub-procedures	**Active parties**	**Results**[1]
1. Organising the procedure and the analysis group		
1.1. Initiate and delegate the procedure	SKI	A clear organisation, and delegation of responsibility to the relevant parties.
1.2 Establish the main analysis group and other initial preparations	Analysis Management (abbreviated AM)	A competent, broad, and balanced group, including deputy members; drafts concerning the scope and other preconditions; and finally, physical locations prepared.
2. The qualitative analysis phase		
2.1 Scope and preconditions for the evaluation	AM/Main analysis group	A well-defined scope and basis for the whole analysis procedure.
2.2 Identification and grouping of major sources of uncertainty	Main analysis group	A comprehensive hierarchical list of overall issues (in terms of time as well as costs).
3. Scenarios, alternatives and structures		
3.1 Principal scenarios	AM/Main analysis group	Definition of a few relevant scenarios[2]
3.2 Major either/or alternatives	AM/Main analysis group	A minor set of agreed 'major either/or alternatives'.
3.3 Schedule structure	AM/Main analysis group	An agreed schedule structure.
3.4 Cost calculation structure	AM/Main analysis group	An agreed cost calculation structure.
4. Cost-sharing modelling	SKB/units	An agreed cost-sharing model.
5. Definitions of a base case reference as well as deviations	Main analysis group	A well-defined basis for the technical sub-estimates.
6. Quantification I, schedule, cash flows and interest rates		
6.1 Quantification in general		The ability to obtain unbiased figures.
6.2 Standard schedule analysis[3]	Main analysis group	The total duration of the defined scenarios and alternatives.
6.3 Expected timing of activities	Main analysis group	The expected start and finish of the principal activities for the defined scenarios and alternatives (see footnote 3).
6.4 Cash flows and EPGs[4]	Main analysis group	Cash flows and EPGs with expected values.
6.5 Real interest rate	SKI/KAF	A triple estimate of the set of rates deemed relevant to this particular programme.
6.6 Discount factors	Facilitator/AM	Tables of discount factors based on the decided rates.
7. Quantification II, the total base case NPV estimate		
7.1 The first total base case estimate	Main analysis group	A total base case estimate for each defined alternative and special scenario (however not for the 'earliest', 'most likely' and 'latest' scenarios)
7.2. NPV of authorities' costs	A sub-group	A neutral base case estimate of this share of the total costs. **The table continues next page**

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[1] Each sub-procedure includes that a sub-report is drafted, reviewed by the participants, and adjusted according to their comments. Then finally accepted, if needed. This ensures current consensus.

[2] Including a fictive 'Zero scenario', which presumes that all company units close down within a year. Other scenarios include at least 'earliest', 'likely', and 'latest' scenarios.

[3] The activities are all evaluated assuming the same defined base case reference, while the overall issues appear as a final contingency activity.

[4] EPG stands for 'Economic Point of Gravity'. This value is used for discounting.

Continued from the preceding page		
7.3 NPV of the income flow	A sub-group	A neutral base case estimate of this part of the total NPV for each alternative and specific scenario.
7.4 Other selected detailed estimates	Technical sub-groups	Other selected base case sub-estimates.
8. Quantification III, finalising the estimating process		
8.1 Evaluation of the total base case estimate	Main analysis group	Consensus about the base case estimate.
8.2 Evaluation of the impact of the overall issues, the discount factor, the timing as well as the impact of alternatives and any special scenarios	Main analysis group	Results of some special simulation runs on the scale of the impact of the timing and the real interest rates. An expected total value of the final NPV covering all alternatives[5] and any specific scenarios.
8.3 Calculation of unit fees	AM/Main analysis group	Optimal unit fees for each unit.
8.4 Calculation of safety allowance 1	AM/Main analysis group	A proposed value of the safety allowance 1.
8.5 Calculation of safety allowance 2	AM/Main analysis group	A proposed value of the safety allowance 2.
9. Final report and proposals	SKI/Analysis Management	Final report and summaries.

Table 3.1b A more detailed overview of the procedure.

Chapter 3.2 The initial analysis session in the main analysis group

3.2.1 Presentation and opening

After a mutual presentation of the group members and guests, a briefing on the actual procedure and its underlying principles should follow.

A ‘demo case’ representing the procedure should be presented and thoroughly discussed in order to establish full understanding of and agreement on the analysis work.

The group will then discuss, adjust and finally agree upon the draft of the set of firm preconditions for the entire programme and analysis process.

The group should also be able to agree that there should be absolute freedom to present issues of any kind which any member judges to be relevant, without receiving a negative response. If there is the slightest risk of such a negative response, whether directly or indirectly by affecting the future working conditions of a participant, the relevant sub-procedures applied should be subject to complete anonymity. This is of particular relevance to the brainstorming process and the subsequent processing of this information, as well as to quantification of the overall sources of uncertainty and many either/or events.

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[5] Preliminary unit fees are still applied in this sub-procedure. The final ones to be calculated in sub-procedure 8.3.

In such cases the individual suggestions of each participant are collected in anonymous form by the facilitators, who then make a summary of all this information.

3.2.2 The brainstorming process

The first principal sub-procedure in this analysis session is a brainstorming process identifying all possible sources of overall deviations (referred to as 'General Aspects' here) from the plans and other sources of uncertainty. They may consist of risks, possibilities or just uncertainties arising from currently deficient knowledge. This information is organised into specific main groups, called 'Overall Issues' here. As previously stated, anonymity may be introduced if the facilitators judge it appropriate to do so. This activity should cover issues of costs as well as of a time-related nature.

The left-hand column of the table below shows a fraction of such a hierarchical list of General Aspects grouped into Overall Issues.

General Issues/ Overall Aspects	Base case reference	Potential opportunities (+), risks (-) or two- way uncertainties (+/-)
B TECHNOLOGY ❖ Delayed SKB programme ❖ The degree of re-establishment ❖ Re-use of power plants ❖ Competition from other types of energy ❖ The quality of the SKB programme ❖ New technology/Technical advances ❖ Principles of decommissioning	• Level of technology during 1996-99 • Decommissioning is assumed to start 8 years after end of operation. Some of these years are a mothballing period • Decommissioning not before 2010 • A 'brown field' clean-up is assumed • SKB plans accepted • No external effects included	+ New technology may reduce costs +/- Technology from other types of energy is a two-way uncertainty +/- Timing uncertainty in the SKB programme is a two-way uncertainty - Technological problems - Timing uncertainty in the SKB programme is a two-way uncertainty
C PERMANENT STORAGE ❖ Number and locations of storage stations ❖ Technical rock issues/Geology/Hydrology ❖ Rules for acceptance ❖ Permanent disposal of pure material ❖ Delayed acceptance of permanent locations ❖ Municipal versus governmental interests ❖ Schedule/Methods/Solutions ❖ The final choice of location	• Present plans (from 1996-1999) • The localisation problem will, it is assumed, be solved in due time	+/- Timing and methods are two-way uncertainties +/- The same applies to rules for acceptance - The problem of an accepted location - Rules for acceptance
D INTERNAT. & ECONOMY D1 INTERNATIONALISATION ❖ Business globalisation ❖ Contributions from the EU and EU integration ❖ More international cooperation ❖ Effects of other nuclear plants in neighbouring countries	• No particular effects or synergies included	+ Cooperation synergy + Use of experience - Handicapped by other sets of rules - EU may complicate matters - More travel costs due to intensified international cooperation
D2 ECONOMY ❖ Conversion of the Fund from SEK to EURO ❖ World economy and political developments	• No consideration of conversion to EURO • The previous year's world economy and political situation will not change significantly	+/- Economic development is a two-way uncertainty +/- The same applies to conversion of Swedish currency

Table 3.2a An example of the identification and handling of the general issues of uncertainty. The 'General Aspects' are grouped into the 'Overall Issues' in the left hand column. The two other columns are discussed later in Chapter 3.5.

Chapter 3.3 Scenarios, alternatives and cost structures

3.3.1 Scenarios

The group discusses and finally agrees on a few scenarios. One obligatory scenario relates to the fictive situation in which all nuclear plants close during the coming year (the ‘Zero scenario’). This is used to calculate safety allowance 1.

At least these three principal scenarios are selected and defined: (1) one representing the earliest possible closure and subsequent demolition; (2) one representing the most remote closure and subsequent decommissioning; and finally (3) one representing the most likely timescales involved.

A scenario means here that an important source of uncertainty is ‘frozen’.

> *The most likely scenario*: current political attitudes and discussions/ negotiations remain materially unchanged.
>
> *The earliest possible scenario:* strong political pressure develops towards the earliest possibly closure and decommissioning (e.g. due to an accident in the near future).
>
> *The latest possible scenario:* strong political pressure develops to operate/produce for as long as possible (for reasons of the energy situation and/or lobbying).

An alternative here is the fictive situation in which a larger unplanned event is assumed actually to take place, for example a major nuclear accident somewhere. See the text below.

Other scenarios, which differ to a greater or lesser extent in the schedule, are discussed. The purpose is to integrate them into one of the above scenarios if deemed appropriate. The duration of some activities will be uncertain, primarily the ‘waiting time’ between closure and demolition. However, these minor uncertainties can be handled using the triple estimating technique.

Only if scenarios differ in terms of major either/or uncertainties do they have to stay as specific alternatives as outlined below.

3.3.2 Major either/or events

What is a Force Majeure event?

Examples of 'major force majeure events' may in general be heavy storms, flooding and other 'acts of God’, or more 'technical' events such as explosions, larger fires, severe construction collapse, etc. A third group includes hostage dramas, other forms of criminal activity, political unrest, terrorism and so on.

A force majeure event is typically an 'either/or' event which either occurs or does not occur. It is also generally assumed that it is difficult to influence the occurrence of such events. The calculations in the procedure discussed in this work are designed to handle continuous uncertainties, and cannot directly deal correctly with either/or uncertainties. If the occurrence of such risks makes a real difference to the result of the analysis, we cannot handle it the normal way. But how can it be handled?

The identification phase
The participants in the analysis should be asked to include possible major force majeure events within the brainstorming process. Then follows a specific discussion during which key words of this nature are classified into various classes according to their type. Each class of such force majeure events is handled differently during the succeeding part of the analysis process.

First, those fatal events that simply must not happen. They cannot be handled in the analysis process and should therefore be excluded from it. They are prominently listed as fatal events in the fixed conditions and later in the management summary. Examples are major explosions or collapses, including those caused by criminal acts. The costs and time consumption of preventive measures against such events should be included in the estimate.

Next, those events that may have a considerable financial and/or technical impact on the result. Examples are flooding or storm damage to a large construction site or a fire which spoils important parts of the project. In spite of the fact that they are typically of an ‘either/or’ nature, they may be defined as a group of Overall Issues. However they are dealt with separately, as indicated below. Unsuccessful results of ongoing research, as well as location-related problems, also belong to this group.

Thirdly, a group of minor or moderate events, each of an ‘either/or’ nature. The aggregated impact on the analysis result, however, is a fairly normal range of possible values. Such groups are defined as Overall Issues and dealt with in the normal manner. Examples are misunderstandings, minor errors and, for outdoor construction projects, events caused by ‘Mother Nature’, such as rain, storms, heat, frost, wind, ground water or combinations of these events.

Handling the first group of fatal events
During the brainstorming part of the analysis, some fatal force majeure events might be identified. These are placed in a separate list and are not introduced into the basic successive analysis procedure. However, they do of course have to be dealt with.

As one of several solutions, the following procedure has been used in offshore projects in connection with a successive analysis. Each of these events was first described in brief.
A number of working groups of specialists and other competent people were then established. For each of the identified events a plan was developed for reducing the risk to an acceptable level. These plans were further discussed and evaluated until senior management found them acceptable. The project was not started before all these risks had been successfully dealt with in this manner and the costs involved in preventive measures or alternatively in insurance costs had been added to the cost estimate.

Handling the second group of major events by a set of alternative analyses

A concrete example may illustrate a solution of this situation. A large electricity generating company used a nuclear power plant for normal operation, but it had a coal-fired plant on stand-by.

When analysing the five-year budget, we identified three types of major 'either/or events'. One was *a major plant breakdown*. Such an event would cause several months of production at the coal plant, resulting in significantly higher production costs. Secondly, there was uncertainty over whether *an electricity tax would materialise* in the future. If it were introduced, it would have to be paid by the company. A *third major either/or event* was also identified.

As the first step, these three events were introduced as Overall Issues. The minimum of these corrections was of course zero, while the maximum was evaluated to be the expected loss if the event should materialise. The most likely was also a zero. The variance and thus the important priority figure would, however, be severely underestimated because of the odd nature of the statistical distribution curve in this case. But if you enlarge the range of all such items from minimum to maximum by 250%, the variance will be of the correct magnitude. Alternatively, the priority figures of these issues must be multiplied by six, in order to be ranked together with the ordinary uncertainties.

If one of these items appears in the top-ten list, the analysis is divided into two. This was the case with the *major breakdown event*. First an 'either-analysis', which did not include a major plant breakdown, and then a similar 'or-analysis' in which a breakdown occurred. The quantification and related variance indicated above were eliminated in both these new alternative analyses.

The tax event now appeared in both top-ten lists. So the dividing process was repeated, resulting in four alternative analyses, thus dealing with the tax risk. The third ‘either/or’ event was also handled in the same way, resulting in eight analyses. Luckily we did not find more than the three events! If an either/or event does not appear in the top-ten list during the process, it can be left as an uncertainty like any other. However, as has already been stated, it may be appropriate to manipulate the event further using triple estimating, in order to find a reasonable mean value.

Having completed the eight analyses, the analysis group evaluated the likelihood of the three events actually taking place. This allowed us to integrate the eight S-curves into one, which could only loosely be described as an S-curve. Rather, it was shaped like a worn-out staircase, with each step showing a different combination of events. This is further described in ref. 1, p. 147-49. In this manner, senior management was allowed to establish a budget with what they judged to be the appropriate degree of safety.

Handling the third group of major events using triple estimating

Alternatively, the above situations can be handled in a simpler manner, as the following example will show. The strategic profitability of a large cruise liner programme was analysed a few decades ago using the Successive Principle. Hijacking of aeroplanes had already occurred at that time, but a cruise liner had never been affected. The analysis group nevertheless saw this as a potential threat.

An overall additional effect of the hijacking threat was included in the profitability model. The triple estimating was quantified with a zero as the optimistic and the most likely value (i.e., the event would not occur). The pessimistic value was evaluated to cover a certain degree of loss of paying passengers during the next few years due to such an event. In this manner such a potential (and at that time unprecedented) risk was introduced into the calculated profitability of the project. As some of you may remember, a cruise liner was actually hijacked in the Mediterranean Sea. But this happened later.

3.3.3 The schedule structure

The structure in general
A schedule structure is developed as a basis for the later evaluation of the expected duration of the programme, as well as the expected start and finish of major activities.

The different scenarios, which are agreed at this point of the process, could in all probability use the same overall structure. This seems to be the case for the four essential scenarios (the Zero scenario, the extreme earliest, the most likely and the extreme latest possible scenario).

The major non-critical activities are incorporated after the successive scheduling procedure has been performed, and after the start and finish time of the critical activities has been determined.

The structure shown below is an appropriate example for the evaluation and calculation of the programme schedule as a whole. According to the standard version of the successive scheduling procedure all proper activities are evaluated on the basis of the same base case reference. Any deviations due to Overall Issues are evaluated and placed separately as a ‘contingency activity’, typically as a final contingency activity. This ensures the appropriate quality of the analysis of the duration of the programme as a whole. The expected timing of the individual activities follows in the subsequent part of this Chapter 3.3.3.

Proposed activities for use in the standard schedule analysis

05 The political decision-making process. The end status of this activity is the point of time when the first of the current reactors, except Barsebäck, will close.
10 CLAB ready. The end status is the point of time when CLAB is ready to receive the necessary fuel and other material from a closed reactor.
15 Plant decommissioning, phase 1. The decommissioning of fuel and primary components of the system for the first reactor as a whole, except Barsebäck.
20 Plant decommissioning, phase 2. The 'mothballing period' of the first reactor, except Barsebäck.
25 Plant decommissioning, phase 3. The decommissioning of the structure etc., incl. all cleaning to brown field level for the first reactor, except Barsebäck.
30 Remaining time. The period from the completed decommissioning of the first reactor to the completed decommissioning of all the reactors.
35 SFR-3, *CLAB, transport, etc.* All aggregated activities related to transport and the reception and processing of fuel and waste from the decommissioning process. It includes non-permanent, but not permanent storage.
40 Localisation, incl. acceptance. The whole localisation process, until the final location is basically accepted, and detailed design etc. can start. All basic principles and concepts accepted.
45 Permanent storage, phase 1. Detailed design and construction of all facilities, which are necessary for receiving the first trial volume of fuel and waste.
50 R & D, including acceptance. R & D, including acceptance of all fundamental principles, up to readiness for detailed design and erection of the facilities.
55 Encapsulation plant. Design, construction and testing this plant until it is ready to receive and process the first trial volume of fuel, etc.
60 Encapsulation and storage, phase 1. Encapsulation and permanent storage of the first test volume of fuel, etc.
65 Evaluation. The planned evaluation period for ensuring the workability and safety of the system. This includes any adjustments.
70 Regular encapsulation and storage. The encapsulation and storage of the remaining fuel and waste.
72 The final sealing and decommissioning of CLAB and all other facilities, including final acceptance.
75 Encapsulation and storage operations. All operative activities related to these two functions, e.g. transport.
80 The administration of SKB and the authorities, etc. All work related to the functions of SKI, SSI as well as the administrative work of SKB.

Table 3.3a Activities 10, 35, 50, 75 and 80 need not be included in the network calculations. Their start and finish will follow the critical activities. They are introduced into the procedure after completion of the standard schedule analysis. For the logical links, see the bar diagram below.

This example is one among many other possible structures. It is illustrated below.

A bar diagram with the logical links

Key
The activity in bold contains the overall corrections while the activities in dotted lines are considered non-critical.

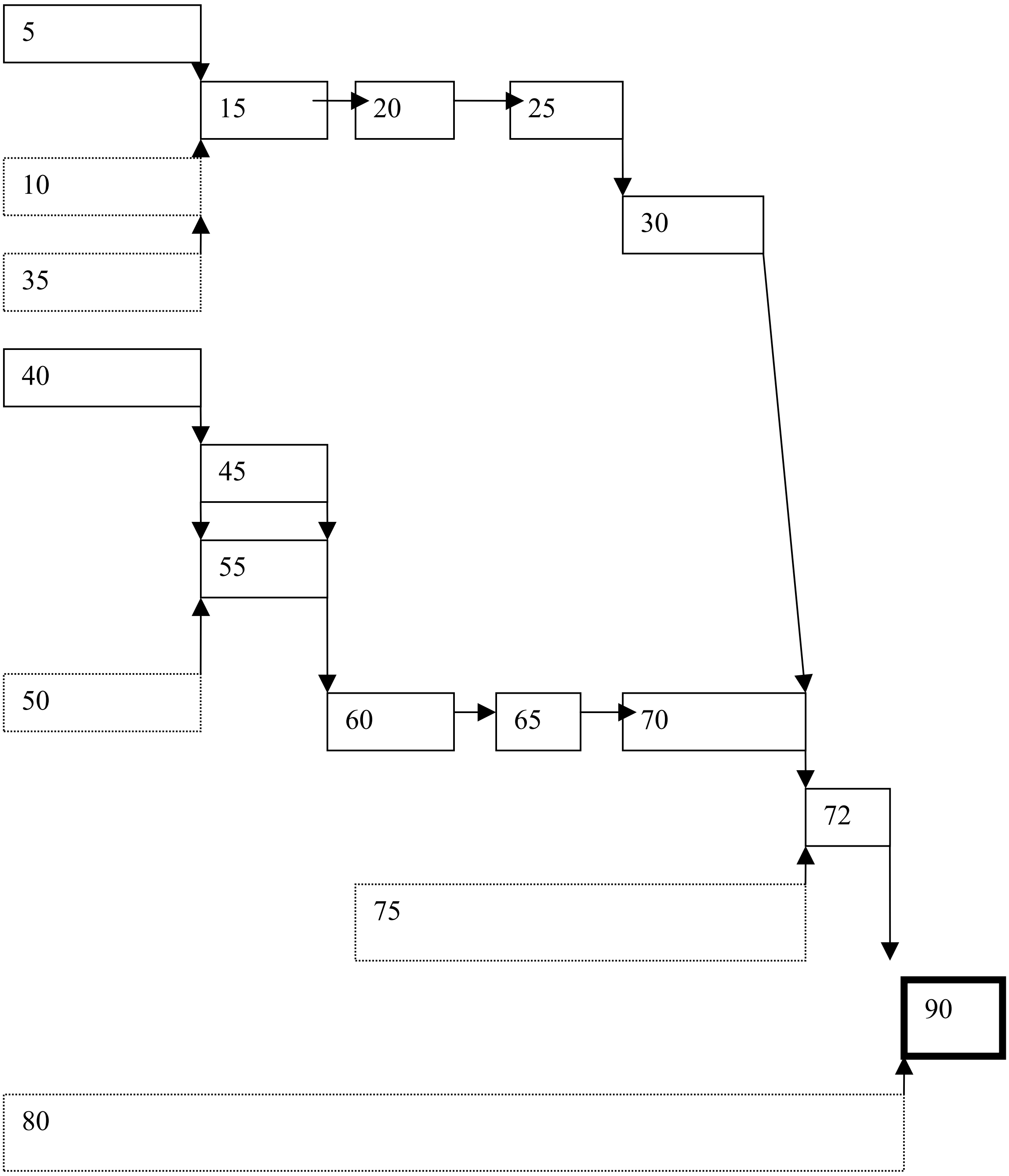


Figure 3.3a An example of activities and their logics.

Any of the activities in the figure may be broken down into sub-nets. Other activities may also be introduced when it is deemed relevant to the evaluation process.

Redefinition or timing of the activities to fit the cash flow calculations
Following the standard schedule analysis, activities 05, 15, 20, 25 and 30 are redefined in order to fit the forthcoming cash flow calculations. During the scheduling procedure it was appropriate to work on the basis of the time of the closure of the first reactor (act. 05 – 25), then adding a period of time representing the period between the closure and decommissioning of the first and the last reactor/plant (act. 30).

However, in order to establish relevant cash flows it is now appropriate to redefine activities 05 – 25 so as to include not only the first plant but also all the other plants. It seems reasonable to assume that this requires the same additional length of time as act. 30, 'Remaining time'. See the figure below.

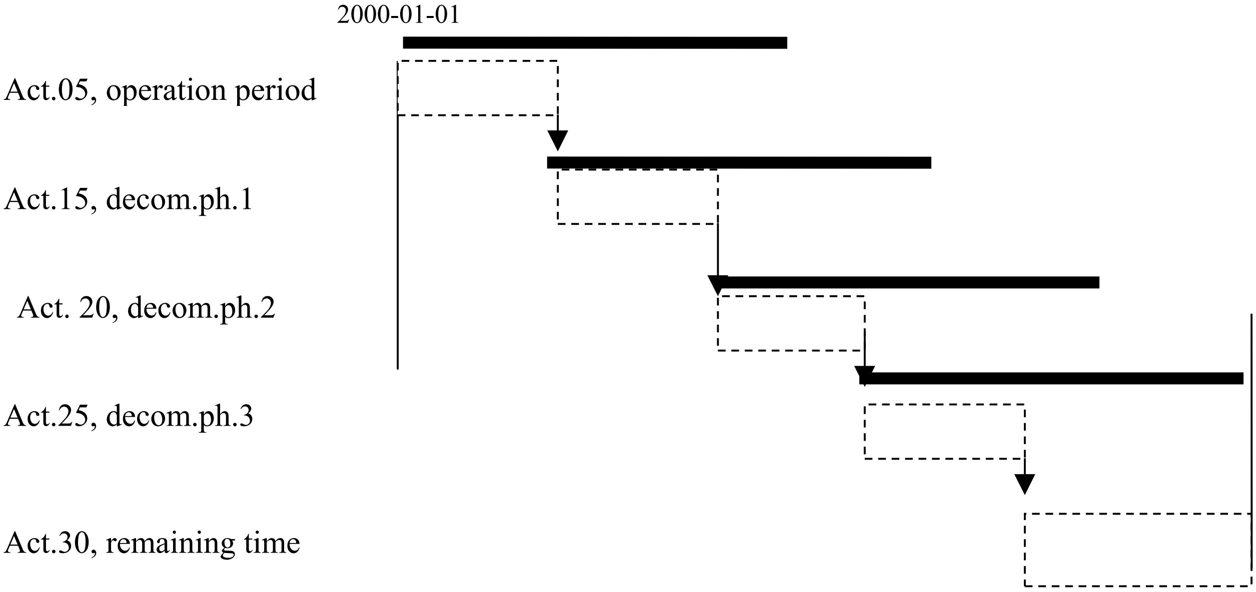


Figure 3.3b Redefinition of some activities; see the text.

After redefinition, the activities below have the following meanings:

05 The political decision-making process. The end status of this activity is the time of the closure of the last of the current reactors .
15 Plant decommissioning, phase 1. The decommissioning of fuel and primary components of the system in all the current reactors.
20 Plant decommissioning, phase 2. The 'mothballing period' of all the reactors.
25 Plant decommissioning, phase 3. The decommissioning of the structure, etc., incl. all cleansing to brown field level for all plants.
30 This activity is now idle.

3.3.4 The cost calculation structure

The structures in general
Two different structures are necessary: one for calculating the fee rate and safety allowance 1, and another for calculating safety allowance 2.

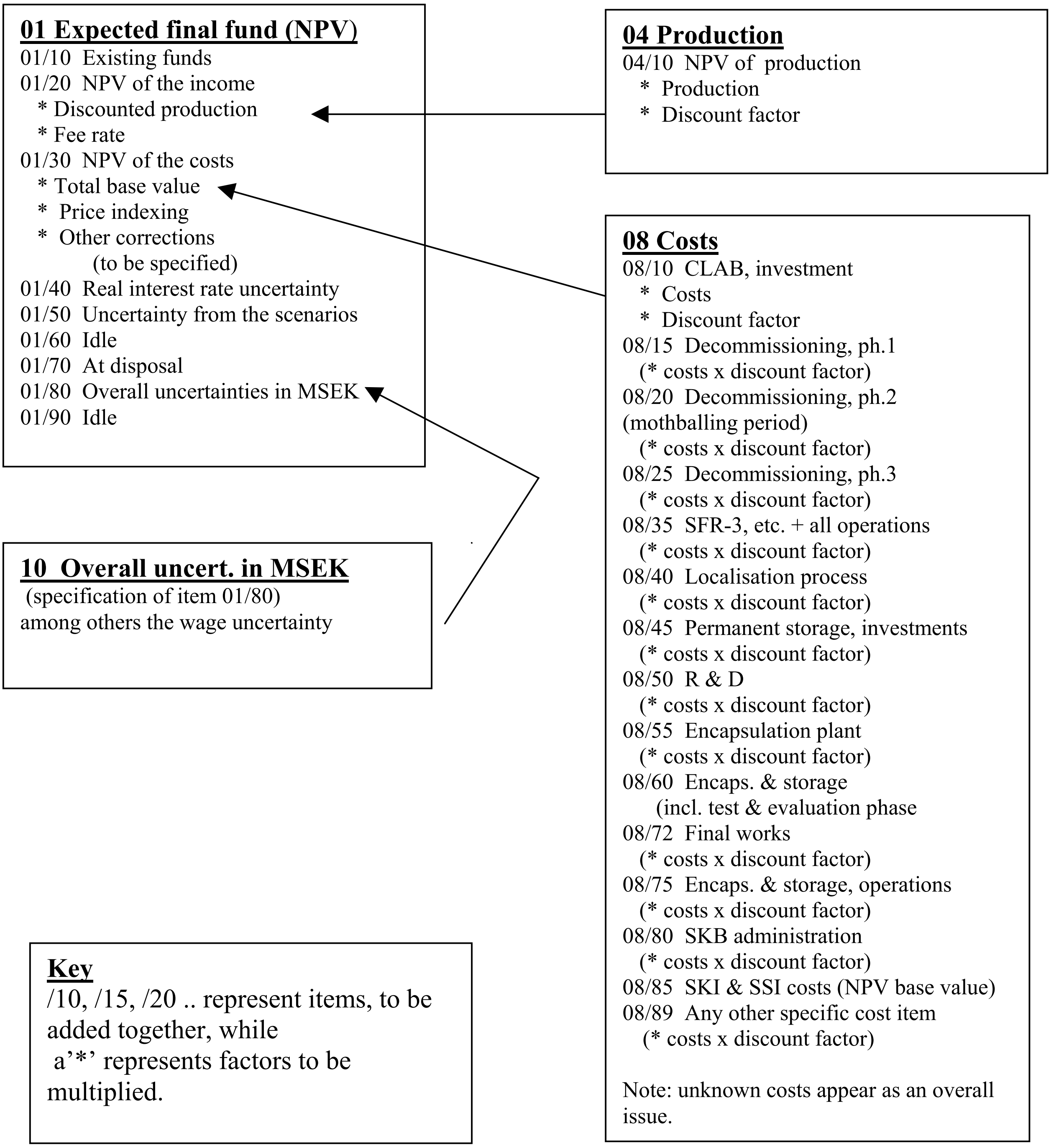
The Analysis Management prepares drafts of the structure of the cost calculation. It is discussed in the analysis group, adjusted and finally agreed. The necessary degree of detailing of the primary sub-estimates may also be touched upon and agreed. It will typically be limited to ensuring that local uncertainties will be less than1/10 of the potential overall sources of uncertainties. Information in support of this part of the sub-procedure is set out below.

The structure for calculating the fee rates and safety allowance 1
The estimate consists of a hierarchical system of estimate sections 01, 02, 03 and so on. Each section consists of one or more items: 10, 20, 30 and so on, which need to be added together. Each item is either a directly evaluated figure or consists of two or more factors, which are to be multiplied. For example, volume x, a unit cost or cost x, a discount factor. Factors (to be multiplied) are indicated with an “*”.

The result of a section is transferred to a higher-level section as an item or factor. It all ends up in the top-level section, 01, which yields the final result. The structure should allow all ingoing items and factors to be sufficiently statistically independent of each other.

In this particular Net Present Value calculation two sources of uncertainty require special handling because of their importance and atypical character. It is (1) the uncertainty arising from the timing; (2) the influence of uncertainty on future real interest rates. They are placed in item 01/40, and item 01/50 in the example in figure 3.3b below, and are further discussed in Chapter 3.8.

An illustration of the above basic structure is set out below.



01 Expected final fund (NPV)
01/10 Existing funds
01/20 NPV of the income
  * Discounted production
  * Fee rate
01/30 NPV of the costs
  * Total base value
  * Price indexing
  * Other corrections
    (to be specified)
01/40 Real interest rate uncertainty
01/50 Uncertainty from the scenarios
01/60 Idle
01/70 At disposal
01/80 Overall uncertainties in MSEK
01/90 Idle

04 Production
04/10 NPV of production
  * Production
  * Discount factor

08 Costs
08/10 CLAB, investment
  * Costs
  * Discount factor
08/15 Decommissioning, ph.1
  (* costs x discount factor)
08/20 Decommissioning, ph.2
(mothballing period)
  (* costs x discount factor)
08/25 Decommissioning, ph.3
  (* costs x discount factor)
08/35 SFR-3, etc. + all operations
  (* costs x discount factor)
08/40 Localisation process
  (* costs x discount factor)
08/45 Permanent storage, investments
  (* costs x discount factor)
08/50 R & D
  (* costs x discount factor)
08/55 Encapsulation plant
  (* costs x discount factor)
08/60 Encaps. & storage
    (incl. test & evaluation phase
08/72 Final works
  (* costs x discount factor)
08/75 Encaps. & storage, operations
  (* costs x discount factor)
08/80 SKB administration
  (* costs x discount factor)
08/85 SKI & SSI costs (NPV base value)
08/89 Any other specific cost item
  (* costs x discount factor)

Note: unknown costs appear as an overall issue.

10 Overall uncert. in MSEK
(specification of item 01/80)
among others the wage uncertainty

Key
/10, /15, /20 .. represent items, to be added together, while a'*' represents factors to be multiplied.

Figure 3.b An example of a cost estimate structure.

The discounted production in section 04 may be specified into the individual reactors. The cost items in sections 08 may also be further broken down, either as sub-items for various sub-systems or activities or resource categories. Another solution is a specification into three or more factors, such as:

* The original figure
* Development, see ....
* Local potential & risks, etc.
* Price index correction

The structure for calculating safety allowance 2
The calculation principles for the uncertainties of class 2 have already been discussed. The structure depends on the seriousness of the consequences of the calculations. A simplified example is shown below.

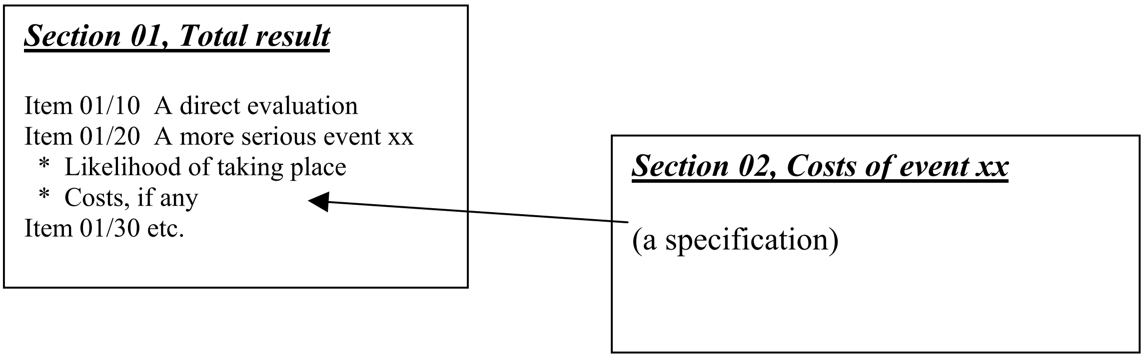


Figure 3.3c An example of a cost estimate structure for class 2 uncertainties.

Chapter 3.4
Cost-sharing models (sharing between the four company units)

As soon as the calculation structure of the total estimate has been agreed, the relevant parties should make an agreement on a cost-sharing model. A cost-sharing model could consist of one or more sets of percentage figures, called cost-sharing factors here, totalling 100%. Each of these indicates the share of a specific cost group, which should be associated with each of the four company units. Various cost groups may carry different sharing factors. It is provisionally anticipated that three sharing factors are sufficient. However, other models may be established.

In the current suggested procedure it should be up to the company units and KSB to decide on the sharing models. For illustrative purposes three different elements - A, B and C - of a model are shown below. The first is based on the total electricity output, both past and future. The second is based on the number of reactors, while the third is based on the total of the specific costs, which in the main estimate are associated with each unit (primarily the cost of demolition).

Unit	Electricity output TWh[6]	Type A%	Number of reactors	Type B%	Specific costs (NPV)	Type C%
FKA	872	33	3	25	1710	31
OKG	590	22	3	25	1541	27
RAB	915	35	4	33	1361	24
BKAB	255	10	2	17	991	18
Total	2632	100	12	100	5603	100

Table 3.4a Examples of elements of a cost-sharing model.

Chapter 3.5
Definitions of a base case reference, and extremes

For each of the agreed main groups of Overall Issues of uncertainty (see table 3.2a in Chapter 3.2.2) *a base case reference* is defined. It has to relate clearly to the historical and present conditions and to the experience of the analysis group members, not least those who are experts. It must exclude all significant uncertainty which is common to more than one of the selected cost items. The middle column in table 3.2a demonstrates this. The right-hand column contains *the potential deviations* from the defined base case reference. The effect of these deviations is included in the calculation as correction items or correction factors, which will be added to the base case calculation later on in the process (see Chapter 3.8.2.). It is stressed that the definitions in the actual case will be more detailed and specified than shown in the table.

Chapter 3.6
Quantification I, schedules, cash flows, and interest rates

3.6.1 Quantification in general

A practical procedure has been developed to cope with biases and evaluation pitfalls. It has been verified that a so-called ‘group triple estimating’ can be arranged to be almost foolproof. The procedure is outlined below.

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[6] From ref. 21, ‘Plan 2000’, p. 16.

Before performing a set of quantitative evaluations, for example the eight main items of a master estimate section, the analysis group may briefly discuss the subject matter, particularly the scope of each item, but strictly without mentioning any figures. It is stressed that all evaluations are conditional, i.e. evaluated on the firm precondition that all other uncertain parameters are in their normal state (theoretically correctly: in their mean value state).

Then, in complete silence, all participants concentrate and find their intuitive personal triple estimate for the whole set of items or factors and write them down on paper. A triple estimate consists of evaluations of the most extreme limits followed by an evaluation of the most likely value. One triple estimate is made for each of the items or factors in the actual set. Conferring is not permitted. When the analysis participants have written down all their figures, the facilitator asks for and identifies the lowest minimum and the highest maximum in the analysis group as a whole for the first item or factor.

In analysis groups larger than 12 persons an average of the two most extreme values may be used as a group result. The reason for this is that the extreme values may be too far from each other in larger groups to represent the theoretical limits of 1 and 99 per cent. Then an average of the participants' most likely values is calculated for this item or factor.

In this manner, a group triple estimating is established for all the items or factors in the actual set. *Alternatively, if the facilitators are not sure that there has been complete freedom of expression, they may collect all the evaluations anonymously.*

The mean value, m, is calculated as (minimum + 2.9 x most likely + maximum)/4.9, while the standard deviation, s, is simply (maximum less minimum)/4.65. This procedure is further discussed in Chapter 4.3.

To compensate for the serious bias of over-optimism/pessimism, the very last group evaluation at the end of the quantification phase (but before the action plan) addresses the participants' honest feelings of whether the analysis group has been too optimistic or too pessimistic throughout the analysis process. This last evaluation will also be performed as a group triple estimate, which compensates in part for the assessed bias.

During this procedure, a figure may arise which somebody in the analysis group considers to be seriously erroneous. Unless the author of this figure admits to a decimal point error or the like, it should nevertheless be accepted without discussion or criticism at this stage of the process. If it is a most likely figure, it will only marginally influence the group's average; if an extreme figure, it will usually result in a wider range, which will bring this item onto the top-ten list. The next cycle will then "automatically" call for further discussion and for more information on this aspect to be brought to the table by the participants. This will generally ensure that any errors are eliminated before the very end of the analysis process.

Eventually, further clarification will be included in the final result of the proposed action plans, which finalise the analysis process. In extreme cases, an alternative solution may be provided using the opinion of the minority. This alternative case is analysed in the same manner as the main analysis and is to be published in a coming test analysis report.

All evaluations submitted by the analysis participants are received and accorded equal weight. It is tempting to allocate different weighting factors to various participants according to their assumed level of specific knowledge, but it is advisable to avoid this. As is apparent from the discussion above, the risk of errors is highly limited. The advantages are first that better conditions for creativity are provided; secondly, it is not always the case that the expert knows the true future figures better than others; thirdly, when nobody's opinion has precedence over another the vital final consensus among the participants is promoted. However, participants who have no knowledge at all of the element which is to be evaluated, even of the scale involved, should be allowed to 'pass'.

More than 15 years' extensive practical experience and documented experiments show that the procedure outlined above will cater for most pitfalls. For a further discussion and verification, see Chapter 4.3 and the appendix.

3.6.2 The standard schedule analysis

The next sub-procedure in the analysis sessions aims to calculate realistic schedules for each of the defined scenarios. As a minimum, the 'Zero scenario' as well as the shortest possible, the likely and the longest possible scenario are analysed.

Both the schedule structure and the estimate structure are hierarchical in character. The schedule should include all activities or groups of activities which may contribute to the total duration of the programme. This includes 'activities' of an external nature, such as the time needed to reach a political decision. Non-critical activities are included when they are related to considerable costs. They are included in order to facilitate the subsequent establishment of cash flows.

The main schedule may be established as a very rough one, comprising only a few activities or groups of activities. See the examples in Chapter 3.3.3. This is permissible because the successive process includes a systematically more detailed specification of those activities which the analysis process reveals to be relevant.

The final corrective factors derived from the defined Overall Issues, which have a potential impact on the schedule after the evaluation, are finally spread out over the whole range of time. The analysis group performs this, taking into account whether the individual issues are 'front-end heavy' or more linked to the final phases of the programme. This is done in order to maximise the realism in the cash flow diagrams in the subsequent sub-procedure.

3.6.3 The expected timing of the individual activities

Due to the later discounting procedure the final corrective factors have – as already mentioned - to be distributed amongst the individual activities in order to establish their expected start and finish times under actual conditions. At this initial approximation stage, a uniform procedure may be applied.

If it is deemed appropriate, each group of overall correction items may be distributed according to its nature. Some may be 'front loaded', while the impact of others may be spread more evenly.

In order to fit the cash flow calculations, some of the activities may need to be redefined. This is dealt with in the final part of Chapter 3.3.3. Following the example of activity structure, activities 05, 15, 20, 25 and 30 are redefined in order to fit the forthcoming cash flow calculations. During the scheduling procedure it was appropriate to work with the first reactor to be closed (act. 05 – 25), and then add a period of time representing the duration between the first and the last reactor/plant to be closed and decommissioned (act. 30).

However, in order to establish relevant cash flows it is appropriate to redefine activities 05 – 25 so as to include not only the first plant, but also all the other plants. It seems reasonable to assume that this requires the same additional length of time as act. 30, 'Remaining time'. See figure 3.3b in Chapter 3.3.3.

3.6.4 Cash flows and the 'Economic Point of Gravity', 'EPG′

Cash flows in general
The cash flows of the primary cost and income items are evaluated and an apposite profile is selected during this sub-routine.

The classic way of discounting is to discount each annual cost or income separately by the relevant discount factor. This procedure cannot be used here because it would introduce an unacceptable set of dependencies, which would mitigate against a correct result.

Instead, an alternative way of discounting is introduced. It can be shown mathematically that it yields the same results as the conventional method.

An alternative procedure using the 'Economic Point of Gravity', EPG
According to this procedure, the cash flow of a given activity covering more than a year is illustrated as a column diagram. Each annual column covers a full year in the diagram. Any such cash flow diagram has a geometrical 'point of gravity'. The correct Net Present Value can be obtained if the total costs are discounted according to the discount factor of this 'point of gravity'. This concept is called the 'Economic Point of Gravity', or just EPG.

It is now possible to make a correct calculation of the mean value of the NPV contribution from an activity which is uncertain in terms of both time and cost/income. The mean value of the cost has to be multiplied by the mean value of the discount factor related to the relevant EPG. The local uncertainty contributions arising from both the cost and the timing will be correctly identified and derived.

The advantage of this procedure is that both the time-related and the cost-related uncertainties can be handled correctly, by using the present Successive calculation procedure. As an additional benefit, it is much simpler to perform.

In order to simplify the group evaluation process, a set of various typical and relevant geometrical shapes of such cash flows are defined below, together with their EPGs as a percentage of the duration of the activity. See the figure below.

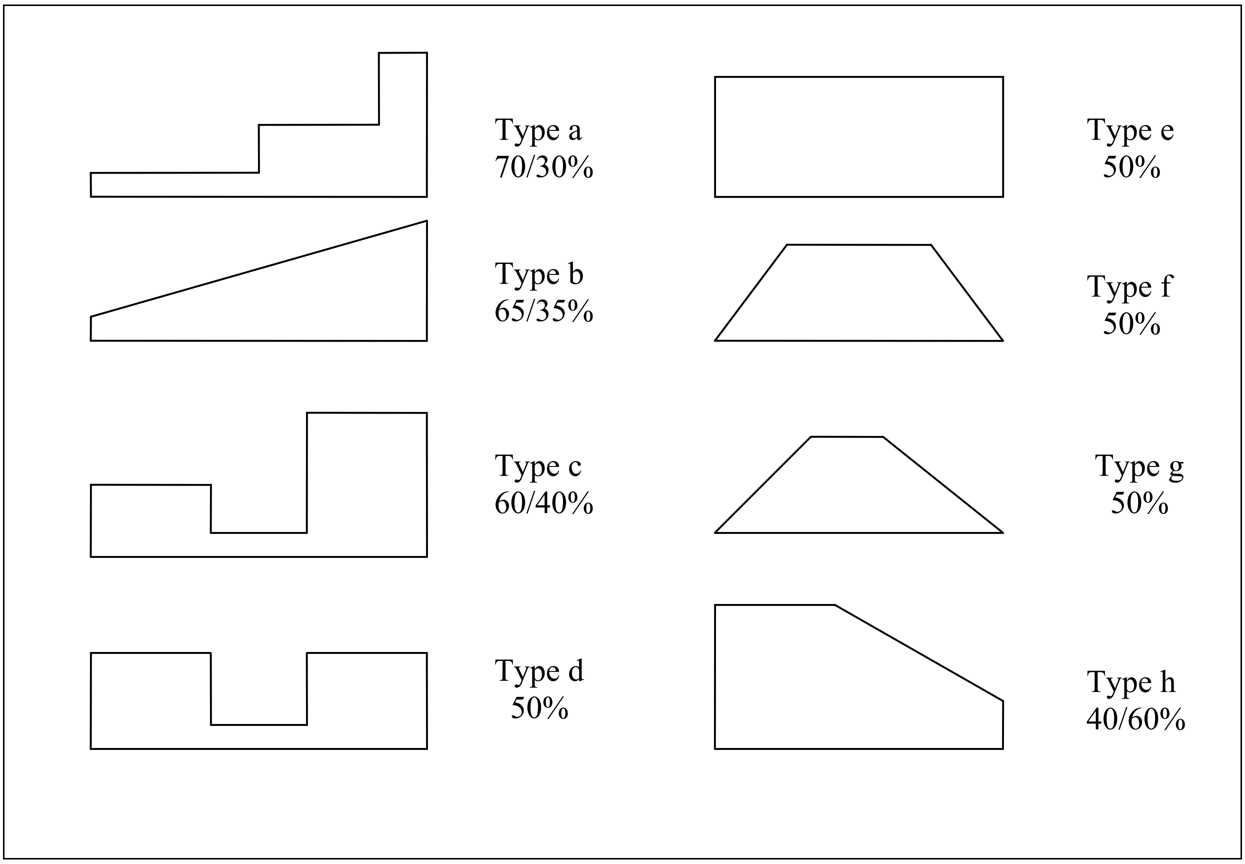

Figure 3.6a Examples of standard geometrical shapes of cash flows.

During the group evaluation, the participants will select the type which they deem appropriate to the related activity or cost/income item. Types a, b, c and h can be used in the reverse order.

Take as an example an activity with a 2010 start and 2020 finish, having a rectangular cost/income distribution or another symmetrical cost shape. Its EPG will be 2015. If the distribution were judged to be more triangular, such as type c, the related EPG would be 2010 + 0.60 x 10 = 2016

As the actual shapes may be somewhat fuzzy, the triple estimating technique is recommended for the first run, followed later by a more exact study of those items which prove to be sufficiently critical with respect to the discount factor.

Evaluation of the 'Economic Point of Gravity', EPG, of the activities/cost items

The previous tables, representing the expected timing of the activities together with the group evaluations of the relevant standard shapes, allow the EPG of every activity/cost item to be calculated. A test case of this is shown below for an early possible scenario.

Note that some non-critical activities (act. nos. 10, 35, 50, 75 and 80) are included.

Earliest scenario **Redefined activities**	**Geometrical shape/ rel. EPG**	**Start/finish (years)** .	**EPG (triple estimates)** (unit: 2000+)
Column: (1)	**(2)**	**(3)**	**(4)**
05 Period of production	h / 40%	2000 – 2018	6 / 7 / 8
10 CLAB ready (0 to start 15)	e / 50%	2000 – 2007	3/3/4
15 Phase 1, all power plants	e / 50%	2007 – 2021	12/14/16
20 Mothballing period, all plants	e / 50%	2010 –2024	15/17/19
25 Phase 3, all power plants	e / 50%	2013 – 2027	18/20/22
35 SFR-3, CLAB, transp., etc. (Start 15 – finish 25)	e / 50%	2007 – 2027	15/17/19
40 Localisation process	e to b / 50 – 65%	2000 - 2009	4 / 5 / 7
45 Permanent storage	b / 65%	2009 - 2016	13 / 13 / 14
50 R & D, incl. of acceptance (0 – finish 65)	h to b (rev.) / 35 - 40%	2000 – 2027	9 / 10 /11
55 Encapsulation plant	e to b / 50 – 65%	2009 - 2016	13 / 13 / 14
60 Encaps., etc., test phase	e / 50%	2016 - 2020	17/18/19
65 Evaluation	e / 50%	2020 - 2027	23/24/24
70 Regular encapsulation, etc.	e / 50%	2027 - 2047	35/37/39
72 Final works	b (rev.) / 35%	2047 - 2055	49 / 50 / 50
75 Encapsulation and storage operations (Start 60 – finish 70)	e / 50%	2016 –20 47	30 / 31 / 33
80 The administration of SKB, SKI, and SSI (0 – finish 72)	h / 40%	2000 – 2055	19 / 22 / 25

Table 3.6a Calculation pinpointing the Economic Point of Gravity, EPG, for the activities within the appropriate time periods.

The first column in the table above lists the previously redefined main ‘earliest possible scenario’ activities supplemented by a few new activities, which represent more administrative or operational costs.

The analysis group evaluates the contents of column (2). In most cases, one of the standard shapes will be appropriate, while the result has in some cases been found to be a combination of two standard shapes. In such cases the associated relative timing of the EPG is uncertain. Column (3) lists the earlier defined start and finish times of the activities. This supports the calculation, shown in column (4), of the period of time which relates to each EPG. As this is generally somewhat uncertain, the triple estimating technique is once again used here. In most cases this will just demonstrate that the uncertainty related to this source is insignificant.

A more accurate procedure

The uncertainties related to this part of the evaluation are likely to be insignificant. However, if some of these results appear to be crucial, the more accurate, classic calculation can be used to replace the previously evaluated value. This may well be in relative figures. The objective is to calculate discount factors for the primary cost and income items, and in particular to calculate the local uncertainty of the discount factors with greater accuracy than was possible using the previous procedure. This is demonstrated in the figure below. In row 3 and below, the costs or income are shown in relative figures. The first three are triple estimates of the nominal values, and the following three are the corresponding discounted values.

Year	--05	06	07	08	09	10	11	12	13	14	15--	Total	Total
Discount factor (KAF)	838	806	775	745	716	688	662	637	612	588	607		
Extreme early	0	80	100	85	80	80	75	45	30	20	0	595	100%
Most likely	0	50	70	80	80	80	80	60	50	45	0	595	100%
Extreme late	0	20	60	70	80	80	80	80	70	55	0	595	100%
Discounted early	0	64	78	63	57	51	50	29	18	11	0	421	71%
Discounted likely	0	40	54	60	57	51	53	38	31	24	0	408	69%
Discounted late	0	16	47	52	57	51	53	51	43	29	0	399	67%

Table 3.6b Table showing the necessary calculations and evaluations for calculating a triple estimate of the discount factor related to a specific cost group. See the text for a detailed description.

The result is a more accurate triple estimate of the discount factor of 67%/69%/71% which will replace the former figures in col. 2 in table 3.6a.

3.6.5 Evaluation of neutral, realistic annual discount factors

A special analysis sub-group is now established by SKI and KAF. Its objective is to evaluate a series of extreme pessimistic and extreme optimistic annual real interest rates as well as the most likely real interest rates for all the relevant future years. The years from about the 2040s are of lesser importance, because the larger part of the programme is most likely to have been completed by that time, and furthermore the discount factors will in this distant future be relatively small.

The related set of discount factors has been calculated and this information is integrated into the estimating procedure, allowing the uncertainty related to the future real interest rate to be ranked together with all other sources of uncertainty. Some overlap between this special analysis sub-group and the main analysis group is advocated in order to ensure the necessary degree of integration. It would at least be appropriate to use the same facilitators as in the main analysis group. As previously discussed, this evaluation can follow the standard Successive Principle.

3.6.6 Discount factors

Tables of the discount factor for every relevant year are calculated as a routine, based on the result of the procedure described above. This is the necessary input into the calculation of the influence on the total result related to the uncertainty around the real interest rate. This is further outlined in Chapter 3.8.2.

Chapter 3.7 Quantification II, the total base case estimate

3.7.1 The first total base case estimate

The main analysis group is now able to establish the first total base case estimate (the estimate under the base case reference). Initially the group discusses the following two aspects:

(1) Proposed adjustments to the firm preconditions and/or to the overall issues. Such information is discussed and decided on.

(2) A general discussion of the earlier findings recorded in previous reports is allowed, especially where there are inconsistencies. If deemed appropriate by the group, the findings are adjusted accordingly.

The group will then evaluate triple estimates for all the defined cost items and production volumes. The size of the cost or production is evaluated in normal absolute values assuming the base case references. The group will use the group triple estimating procedure described in detail in (ref. 1).

The evaluations of the costs and production should in this first part of the procedure be based on direct evaluations submitted by the participants in the analysis group. However, existing conventional estimates may provide background information, in that their preconditions are incorporated into the base case references. It should in particular be ensured that both oversights and any overlap are minimised. However, if a specific precondition deviates from the base case references, a local correction factor may be established to account for this aspect. This is especially relevant to the authorities' costs. The estimate might for example be based on another inflation index. The related set of discount factors is taken from the table which was the product of the interest sub-group's evaluations.

It is important that all these evaluations are made by reference to the previously defined base case references. Otherwise the important overall sources of uncertainty are at risk of being double-counted. Only specific local uncertainties should be included at this point of the procedure.

A base case estimate is made for all scenarios and alternatives: still on the basis of the defined base case reference. The addition of overall effects will follow at a later stage, as described below in Chapter 3.8.2.

Note also that a preliminary unit fee rate is still applied. The final fee rates are calculated in the sub-procedure described in Chapter 3.8.3.

3.7.2 Authorities' costs

A special analysis sub-group is established with the objective of estimating the expected total costs incurred by SKI and SSI. This should still be subject to the preconditions of the defined base case reference. However, Overall Aspects may emerge which impact to a greater or lesser extent on the whole group of authorities' cost, although they belong within the framework of base case reference. They must of course be included and handled according to the general procedure.

As already stated, some Overall Issues may relate especially to this cost item. They should therefore be evaluated and included in this part of the procedure.

3.7.3 NPV of the income flow

This part of the total estimate may well be of special interest. The main analysis group evaluates whether it is appropriate to conduct a detailed estimating procedure. If so, a sub-group is established to do so.

3.7.4 Other selected detailed estimates

The composition of this and any other special groups should be proposed by the participants and finally approved by Analysis Management. They have to be moderated by one of the facilitators from the main analysis group. The other facilitator could be another experienced facilitator. At least one of the participants of the main analysis group should participate in each of these groups in order to achieve good transfer of information and sufficient integration.

During the next phase, each of these groups establishes its own part of the cash flow profiles and related total base case estimates for each defined scenario by conducting its part of the Successive Analysis. New overall issues may emerge during these sessions; any such issue will be reported and brought forward for discussion during the following analysis session in the main analysis group.

The main analysis group evaluates whether other sub-analysis groups should be established, with each one analysing its own part of the calculation by reference to the defined base case reference and to the expected values of defined alternative schedules and scenarios.

The results of the initial sessions described above consist of NPV estimates under reference conditions for all specified scenarios and alternatives. All this is reported as indicated above. Together, they form a total base case estimate under base case references. This is an important part of the basis for subsequent analysis work.

Chapter 3.8
Quantification III, finalising the estimating process.

3.8.1 Evaluation of the total base case estimate

The main analysis group meets and discusses this basic result in detail. Adjustments are made until consensus is obtained.

3.8.2 Evaluation of the impact of the overall issues

Handling the 'typical' overall issues

The potential effect of the overall issues is now quantified, following the relevant rules for this important part of the process. A successive series of further specifications and/or re-evaluations is performed if appropriate. These specifications may cover the overall correction factors and items as well as the specific 'physical' items which are established by the technical groups. This successive process continues until it is agreed that the results have achieved a level of accuracy which is acceptably close to the best obtainable. These results consist of the defined alternatives and any special scenarios.

Handling the timing and real interest uncertainties using a few simulations

So far, the calculation has used the most likely versions of both the real interest rates and the timing. As already noted and as further discussed below, the timing and real interest uncertainties will need special attention.

Two versions of the basic (and most likely) calculation are copied and two simulation runs are performed. The discount factors related to the most pessimistic set of real interest rates are applied in the first of these two simulations, while sets of the most optimistic discount factors are used in the second.

The two resulting total NPV values will indicate the total conditional impact of the real interest rates on the uncertainty of the result. These two NPV values, together with the basic 'most likely' result, are simply used as a triple estimate in item 01/40. This triple estimate indicates the correct value of the local uncertainty from this source. The mean value needs compensation. This is realised in a 'technical' item, 01/41, with the negative value of the 'most likely result'.

The impact of the timing uncertainty is calculated in the same manner. Two new simulation runs are performed using the same structure, but applying the extreme earliest and the extreme latest timing respectively. The most likely real interest rates are used in both these simulations. However, the cost items will vary, due to the differences in the volume of waste.

The two resulting total NPV values will indicate the total conditional impact of this uncertainty. These two NPV values, together with the result of the basic (and most likely) calculation are simply used as a triple estimate in item 01/50. This triple estimate indicates the correct value of the local uncertainty from this source. A 'technical' item 01/51 serves the same purpose as item 01/41 above.

The total calculation finalised
A set of total NPV estimates has now been produced with final costs, but still including a preliminary average unit fee. The following final sub-procedure is now ready to be performed.

3.8.3 Calculation of the unit fees

Four copies are now made of the calculation: one for each power plant company unit. During this sub-procedure, an NPV estimate is made for every unit, using their specific production profiles and the agreed share of the common costs. They follow the previously outlined cost-sharing model. The individual necessary unit fees are calculated iteratively and are used to balance the result. Finally, these adjusted unit fees are introduced into the total NPV estimate as a control. After this, the total NPV estimate should still be in balance i.e. close to an agreed degree of confidence .

3.8.4 Calculation of safety allowance no. 1

The income items are deleted for each of the four ‘unit estimates’. The main analysis group then re-evaluates the relevant cost items by reference to the special conditions for this particular ‘zero-scenario’. After consensus is obtained, the relevant quantile (80 or 90%) is calculated for each unit.

3.8.5 Calculation of safety allowance no. 2

During the final procedure, the main analysis group evaluates the total effect of the selected class 2 events. They may eventually be included with an agreed weight. It results in a statistical S-curve. After consensus is obtained, the value related to the decided quantile is derived.

Chapter 3.9 Final reporting

The final report and relevant summaries are now produced in draft form by the Analysis Management in cooperation with SKI, then checked, adjusted and agreed by the participants before it is finalised. SKI is then able to produce its recommendations to the Government.

Chapter 4 Critical evaluation

Chapter 4.1
Does this procedure satisfy the previous criticism?

Using probabilistic methods

The existing estimating procedure has been criticised for using probabilistic methods. The alternative would be to define one or more sets of firm preconditions or scenarios. Each of these might allow a definite and fairly exact estimate of the costs given today's technology. The decision-maker, however, is thus forced to choose one of these scenarios without having the necessary background to do so sensitively. And he/she may be sure that the cost figures chosen are far from the actual future costs and thus violate the basic objective. Uncertainties cannot be avoided in a unique and long-range programme such as this. However, uncertainties can be minimised and the expected results can, as extensive documentation demonstrates, be forecast with a high degree of realism.

The result would be the building up of a fund which is either too large or, which is more likely, too small. In the first case, today's consumers and/or the nuclear power industry pay too much, and in the latter, the final stages of decommissioning would have to be paid for not by those who have benefited from the production, but by the next generation. There are few arguments in support of this part of the criticism. There is no clear alternative to using the Bayesian statistical theory.

The analysis group

The composition of the analysis group which identifies, handles and evaluates the costs and other related factors is a most important consideration. It should be competent, broad-based and balanced and not least sufficiently independent of those with special interests in the result. We can never reach a perfect, controllable result, as we have to deal with human beings. However, the rules set out in Chapter 2.2 for the composition of this group should ensure a high degree of neutrality, competence, creativity and 'predictive intelligence'.

The working conditions of this analysis group

The working conditions of this analysis group represent another major consideration. As described in Chapter 3.2, the rules specify full anonymity in case of the slightest risk of inappropriate personal reactions to the issues brought on the table. This should facilitate freedom of expression in the identification and evaluation of potential risks or problems.

Complexity, 'black boxes' and the use of Monte Carlo simulation

Another part of the aforementioned criticism is the unnecessary degree of complexity in the calculations of the results, including unnecessary 'black boxes' and the extensive use of Monte Carlo simulation instead of a scientifically based direct, correct calculation procedure. The procedure presented in this work uses a set of well-established and well-documented calculation methods without any 'black boxes'. A simple version of Monte Carlo simulation without black boxes is only recommended for a critical path calculation of the schedule.

The Monte Carlo method

The Monte Carlo technique is highly valued, and it can do a good job within its limitations. In the Successive Principle, for example, it is used in the scheduling module. But sometime it is over-valued.

One reason may be that it seems to deliver a set of 'experiments' as required in the classic statistical theory. But the user sets the parameters before the MC runs and these parameters are often subjective (and often even without a control for biases). The MC run cannot convert this subjectivity into 'objectivity'.

The better MC programs can handle dependencies. But for the professional user it is even more impossible to yield a sensible 'correlation coefficient' between two parameters. And in principle he/she is required to produce numerous such coefficients between all the primary parameters. Logically, the result cannot be too reliable under such conditions. A further practical problem is that the impact of these important dependencies is often not visible in the result.

The MC technique can in itself neither ensure independence or 'objectivity'. The users must handle this problem. In the Successive Principle detailed rules exist to ensure independence to a sufficient degree as well as subjective evaluations in a controlled manner.

The quantification

The quantification process is beset by an extensive set of pitfalls. It did not ensure that the previous quantification procedure would achieve unbiased results. The proposed 'group triple estimating' procedure has minimised this problem of evaluation biases. This fact rests upon theoretical findings as well as on practical experiences. The use of the so-called Beta distribution function has little to recommend it, as it has no specific relevance to this area, other than a 45 year-old historical association.[7]

The recommended family of Erlang distribution functions has a theoretical as well as an experimental connection with this area. See the detailed discussion in the appendix about methodology errors in this area.

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[7] The critical path method, PERT, proposed this function in 1957, because in those days computers could not handle more appropriate functions.

Unsolved issues around timing and discounting
The timing and related discounting, as well as the issues around real interest rates, have hitherto constituted unsolved issues. They are, as demonstrated in Chapter 3.8.2, solved and integrated in the present proposed procedure.

Chapter 4.2
Correct identification and handling of major issues

The rules set up for this procedure lead to a balanced, broad-based and competent group which is optimally qualified to identify all major positive as well as negative issues which can have a potential impact on the result. The process adopted during the initial part of the procedure allows the members to express their findings and attitudes freely. This leads logically to comprehensive coverage and balanced grouping of such Overall Aspects.

This grouping of all these aspects into smaller sets of Issue Groups serves two main purposes. First, it leads to a practical overview and manageable dimensions to work with and later evaluate. Secondly, it allows the individual Issue Groups to be sufficiently independent of each other. The question of statistical correlation or dependability is discussed in Chapter 4.4.

The definition of a base case reference which functions as a common, firm precondition for all 'physical' items and technical factors will also serve the purpose of establishing and maintaining independence between all evaluated variables. The final phase of the so-called qualitative part of the procedure is to describe best case, likely case and worst case scenarios for each group as well as other sources of uncertainty. The balanced composition of the analysis group will also lead to a balanced and comprehensive description. This description will later provide vital support for the crucially important evaluation of the possible impact of the defined groups of Overall Issues.

Chapter 4.3
An unbiased quantitative evaluation of uncertainties

The odds that an uncertain figure will be true within a certain interval of values are expressed by a so-called statistical distribution curve. The Gaussian distribution curve, also called the 'bell curve', is the best known of such curves.

A basically correct evaluation of an uncertain figure should follow this sub-procedure or one which fulfils the same requirements.

1. Three characteristic values are evaluated. This is called a triple estimate, and it consists of an extreme minimum value, a similar maximum value and finally the apparently most likely value. The extreme values are considered to give 1% and 99%

probability of not being overrun. In some cases two more values are used, e.g. the 10 and 90% values or the 20 and 80% values.

2. One of the many probability curves is chosen which matches the three or five figures. This is further discussed in Chapter 4.4.

3. The geometrical 'point of gravity' of the curve equals the mean value, while the standard deviation and variance are derived according to established formulae.
4. A simplified calculation of the mean value is to add together the three figures and an appropriate relative weighting. The standard deviation is also calculated in a simple, approximate manner as a percentage of the full range from minimum to maximum.
5. The mean value and standard deviation are the only figures used in the remaining statistical calculations. The effect of the shape of the probability curve is automatically embedded in these two figures.

For a further discussion, see the appendix.

Chapter 4.4 Securing basically correct statistical calculations of the result

Introduction

The Successive Principle is, as already indicated, based on the subjective probability theory or Bayesian theory. According to this theory, subjective numerical evaluations are accepted and can be dealt with according to the rules set out in the classic or 'frequentistic' statistical theory (literature LIN-92 and APO-90 in ref. 1). The object to be analysed is organised into independent elements using special sub-routines, as described above. Such elements may be items, activities, correction factors, unit prices, volumes etc. This basically eliminates the problem of statistical dependency, related co-variances and dependency or correlation factors.

The principle of independent conditional uncertainties

The various sub-procedures, among other factors, are used to establish sufficient statistical independence between all uncertain data. The mean of the total result can then be calculated by using the local mean values of all local data. This has been shown to be very close to the theoretically correct value. The uncertainty of the total result is calculated as the sum of the squares of the effect on the result of the conditional uncertainties of all local data, whether volumes, costs or unit costs, factors, etc. See Chapter 5.1, in ref. 1. This will further safeguard the crucially important statistical independence.

The local mean value and standard deviation

The local mean, m, and local standard deviation, s, for an uncertain parameter are calculated using these approximate formulae:

$$m = (\text{min.} + 2.9 \times \text{most likely} + \text{max.})/4.9$$
$$s = \text{numerical } (\text{max.} - \text{min.})/4.65$$

The formula for m depends marginally, but not disturbingly, on the skewness involved. The extreme values should reflect both the 1% and the 99% limits. Other limits, such as 10% and 90%, may be used, on condition that the calculations of the mean value and standard deviation are adjusted accordingly. Other techniques than triple estimating may also be used, as long as the mean value and the standard deviations can be calculated; you may, for example, use five evaluations. However, more than twenty years' experience with the triple estimating technique has shown it to be user-friendly and able to cater satisfactorily for nearly every practical circumstance. This is especially true when using the ‘group triple estimating’ procedure (except in the case of major ‘either/or’ situations).

The mean value and standard deviation of the total result

The mean value of the total result has been proved by Poul Thyregod, Professor of Statistics at the Technical University of Denmark, to be very close to the result of using the local mean values as deterministic figures throughout the calculations.

A high degree of independence among the various parameters has been obtained (1) using the first qualitative phase of the procedure; and (2) using conditional evaluations. Co-variances are consequently not significant and this allows us to operate exclusively using variances.

The standard deviation of the total result is calculated stepwise, as follows. All local values of the standard deviations must first be converted into a value, S, which reflects the specific conditional effect on the total result from a single local standard deviation, all other factors being in their mean value state. The term ‘standard deviation’ will hereafter mean ‘conditional standard deviation’. An example will illustrate this: the conditional uncertainty of a volume has to be multiplied by the mean value of the related unit price. To this may also be added the calculated mark-up (still defined as a mean value). In this manner we have calculated the conditional effect of the uncertainty of the volume on the grand total. This calculation process is systematised in the practical hierarchical calculation set up, using product sums, which are transferred upwards to the level above as a factor or item. A similar systematic is applied to network scheduling analyses.

The product S x S or the square of S, S^2, of each local unit is calculated. This figure is called the variance, and it is a major concept in statistical theory as a measure of variation. The variance of the total result can now simply be calculated by adding together all the conditional local variances, S^2. We only need two smaller contributions to this aggregate variance, namely (1) a second-order co-variance from any remaining marginal dependencies; and (2) a second-order variance contribution. These ‘second-order’ contributions are so small that they can be assessed by a subjective evaluation.

Finally, the standard deviation of the total result is calculated as the square root of the resulting aggregate variance (including the two last-mentioned contributions). The above calculation of the global or grand total standard deviation has been proved to be appropriate for more basic calculation models. However, practical results over 25 years also confirm its relevance to even more complex calculation structures.

The distribution function of the total result

The famous statistical law of large numbers, the central limit theorem, deals with a result which is aggregated from many and varied uncertain parameters of the same order of magnitude. Such a result tends to approximate to the symmetrical 'Normal distribution' or 'Gauss distribution', irrespective of the skewness of the individual parameters.

The conditions in these analyses, which are relevant here, will often comply adequately with the above requirement. Accordingly, we may assume that the result largely reflects the Gaussian or Normal distribution. However, in cases where the majority of the remaining uncertainty stems from a few high-level and skewed factors, the resulting distribution function may instead approximate to the Lognormal distribution. This should not be the case to any significant degree in this particular context, where a relatively large number of uncertainties will exist.

Verification

Theoretical studies and practical experience, especially during the 1970s, have shown that the really significant sources of error do not stem from the above choice of a distribution function, but (1) from the lack of complete and/or accurate identification of all items and factors which may influence the result; (2) from remaining undetected statistical dependencies; and (3) from the remaining risk of evaluation pitfalls in the analysis group in spite of using the previously mentioned evaluation technique.

The above applied formulae deviate somewhat from the strictly correct ones, according to the value assigned to k. However, the resulting error is only a few per thousand for the local mean value, while the error for the related local standard deviation (s) is only a few per cent of s. Both of these methodical errors are insignificant compared with the normal practical uncertainties. This is further developed in appendix.

A more crucial question concerns the handling of statistical dependencies. This specific problem is therefore further discussed below.

Handling statistical dependencies

Statistical dependencies and related dependency factors[8] constitute both a major theoretical and also a difficult practical problem when dealing with statistical models and related calculations.

Difficulties arise *first* because there may be a dependency between all combinations of parameters: this will typically add up to a huge number of dependency factors; *secondly*, because the professional specialists, who analyse the task and later have to use it, will often have difficulty understanding and evaluating the reality embedded in the various dependency factors. The appointed statistical expert, who, on the other hand, may not know a great deal about the project or task in question, will therefore often quantify these values; *thirdly*, the crucially important effects of the Overall Aspects will not generally be explicit in the calculation results.

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[8] The correct mathematical expression is correlation coefficients.

The Successive Principle is deliberately structured so as to reduce the dependencies to a level which has no significant influence on the result. This has two major advantages: (1) statistical calculations are much simpler and understandable for ordinary users; (2) dependency factors, which cannot be proactively applied by the user, are transformed into important, meaningful sources of uncertainty which can be used proactively by the management user.

Because of the difficulties involved in handling dependencies, many models and systems neglect them. Consequently, their results will be biased and, frankly, often either useless or misleading.

It is assumed here that a dependency generally has a specific cause (which it may be highly useful for management and planners to know). The analysis group is encouraged to identify all such causes of potential dependencies (called 'Overall Aspects' for the purpose of this text**)**. They are grouped in essentially independent groups (called 'Overall Aspects' for the purpose of this text). For each of these groups a dual definition is established: (1) a fixed base case reference, i.e. a simple and fixed definition linked firmly to the historical experience and knowledge of the analysis group; (2) another definition which reflects the specific, related uncertain future conditions (potential opportunities and risks). This qualitative analysis phase, previously discussed, forms the basis of the following quantitative modelling.

A structure or network of specific main items/main activities is then chosen, determined and described in writing. This is the basis of the quantitative model. It is supplied with correction factors or items according to the set of Overall Aspects indicated above. All "physical" items are evaluated according to the fixed base case reference conditions indicated above. Thus, any remaining conditional uncertainties are essentially local and therefore by and large independent of each other. The potential effect on the total result of the difference between the fixed base case reference and the actual future overall conditions are evaluated for each correction factor. This means that the uncertainties of these parameters are largely independent of the "physical" items, and also broadly independent of each other.

The remaining dependencies are further reduced by consistent use of the principle of conditional uncertainty, i.e. all evaluations are assessed on the basis that all other uncertain elements are in their mean value state.

More important dependencies may, however, be identified during the analysis process: for example, between the correction factors "management efficiency" and "human resources problems". If two such elements are considered to be too dependent on each other, they will be grouped together and later evaluated as one single factor. The informative value to the user is somewhat reduced, particularly because this item will typically appear on the top-ten list. However, this "emergency solution" is seldom necessary.

For each uncertain element in the analysis, the conditional effect of the uncertainty on the total result is calculated and squared to give local contributions to the total variance. The sum of these is considered to be close to the variance of the total result. There will of course remain dependencies. They will result in a minor co-variance contribution. It is treated as a "hunch" evaluation and added to the sum of variances. The result should therefore give a sufficiently close approximation and, in any case, be without systematic bias.

This solves the old problem of statistical dependency and related dependency factors, which so far seems to have undermined either the relevance of the results or the practical operability. The procedure described above is of course a simplification. By and large, any errors arising from the methodological approximations do not affect the most important results, which are the mean value and a "top-ten list" of remaining sources of uncertainty, ranked according to their importance.

Discussion

The above technique deals with continuous statistical distributions only, in which the future result may be located anywhere in a timespan, within specified limits. Distributions of the 'either/or' type require a special sub-routine previously outlined in Chapter 3.3.

As has already been mentioned, the total mean value resulting from the procedure was proved in 1982 by Professor P. Thyregod of the Technical University of Denmark to be very close to the true value, on the basis that all items and factors are statistically independent of each other. This result was later confirmed by comparing the actual subsequent result with the corresponding result of the analyses of all the several hundred tasks for which documentation shows that the procedure has been followed correctly. The actual results have generally been surprisingly close to the mean value of the analyses.

A proof of the uncertainty of the total, which was similar to Professor Tyregod's previously mentioned mean value findings, was not completed due to its complexity and lack of time. However, the controls mentioned above indicate that the uncertainty of the analysis was sound, and possibly somewhat on the safe side. However, the unavoidable remaining statistical dependencies, which we estimate finally under a factor called 'analysis-related uncertainty', constitute a risk of an error[9]. The same is true of the similar assessment of the likely biases of the analysis group. However, if the extremes are reasonably correctly evaluated, we should generally be on the safe side with the total result. In fact, many other analysis methods do not go so far as to include the uncertainty associated with the method itself. Finally, it should be remembered that these analysis-related errors would affect neither the total mean value nor, significantly, the top-ten list, i.e. the most essential part of the results.

The theoretical errors inherent in the method seem to be far outweighed by the potential risk of errors caused by (1) a less experienced facilitator not sufficiently well-versed in the procedures and underlying theory; (2) insufficient openness among the participants; (3) any undetected evaluation biases; and finally (4) shortening the length of time allowed for the analysis sessions.

Research has therefore been conducted into these matters. They have resulted in (1) special sub-routines for identifying and handling items and factors; (2) the evaluation technique, both dealt with in previous chapters.

See the appendix for further details.

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[9] The term 'analysis-related uncertainty' is used, as we normally do not want to alarm analysis participants with terms like co-variance, etc.!

Chapter 4.5
Controllable detailing according to specific need

The evaluation and calculation process runs in successive cycles from a few main items and factors in greater and greater detail. Each cycle result in a 'top-ten list' of the items and factors which are chiefly responsible for the overall uncertainty. One of these top priority issues is further broken down and evaluated in greater detail. After a series of such specification cycles, the top-ten list will increasingly consist of overall issues which cannot be further clarified. For example, there will still be inevitable uncertainty inherent in the impact of a future winter, future management discontinuity, etc. The successive specification process will normally continue until the remaining 'physical' items and 'technical' factors will only be responsible for 10% of the total uncertainty (both values measured as a variance). The resulting standard deviation of the total result cannot be reduced by more than approximately 5%. In all practical decision situations this is totally without significance. It would be interesting to ascertain whether the result will be the mean value minus the standard deviation or plus the standard deviation, but this cannot be answered.

In conclusion, all further specifications are unnecessary. They will not improve the result.

Chapter 4.6.
The estimating process should be seen as a whole

All costs and all income contribute equally (in discounted form) to the result, irrespective of their origin. Therefore, for example, technical costs and authorities' costs must be integrated into the same procedure. Similarly, all sources of uncertainty should be integrated into the procedure. Some of these sources are local and stem from uncertainty about the volume or complexity of a specific item. Others stem from Overall Aspects, such as future market conditions. The timing of the whole programme generates its own set of uncertainties, while future inflation and financial conditions result in uncertainties around the real interest rate, which again is a basis for the discount factor. All these various types of uncertainty contribute to the same overall result, its mean value and its uncertainty. They have therefore to be integrated into the same procedure, as has already been discussed and advocated in this work.

Only major uncertainties of the either/or type have to be dealt with separately as previously stated, and subsequently integrated at a higher level in the procedure.

Chapter 5 Comments on the analysis tests

The tests

In addition to a set of fictive tests, four 'semi-full-scale' test sessions have been accomplished using a smaller test analysis group. The first was completed in February 2002 during two day-long sessions. The group calculated the NPV of the authorities' costs in relation to the decommissioning programme. The objective of this test was (1) to verify a realistic value of the authorities costs; and (2) obtain an initial verification of the relevance of the procedure, and not least a practical and theoretical response to it. The test report is published as ref. 5.

The second and third tests were each completed during two day-long sessions in April and August 2002 respectively. These two tests dealt with the full scope of the decommissioning programme. The objectives were basically the same as those of the first test. A fourth and final test in this test series was performed in December 2002.

Some conclusions drawn from the tests

Some conclusions from the tests are summarised below.

* **Major sources of uncertainty.** They exist at more than one level and should be placed accordingly. The correction item 'Future wage costs' is a typical example.

* **Specific scenarios and alternatives.** The situation in which production is augmented to e.g. 20% above the present level might be an alternative. Refer to a recent report from SKI.

* **The cost calculation structure.** The suggested structure was tested and approved. The detailing into approx. 15 items seems reasonable. It was a surprising fact that only a few of the selected main items are most likely to need further detailing into sub-groups.

* **The real interest rate and discount factors**. An example of two extreme sets of rates and related discount factors was discussed. It was suggested that the costs (as well as production) were fairly equally distributed over the year. It is suggested that the discount factors relate to the middle of each year in order to reflect this. Continuous discounting could be applied instead of operating on a mid-year basis-. However, it will only differ by less than approx. 2% of the value of the final NPV, which is without significance in relation to the actual uncertainties.

* **The effect of the uncertainty arising from the timing and future real interest rates.** A simulation test was performed which resulted in a correct calculation of the effect on the total result.

* **Evaluating the cost items from scratch or from the existing deterministic estimates?** This question was discussed. The conclusion seems to be that the majority of the participants in the main analysis group would not be able to make sensible estimates. It was therefore concluded that the existing deterministic estimates should provide a basis for the group's evaluations of the physical items.

This necessitates preliminary work defining a detailed set of the base case reference assumptions and rules behind the calculation of the base values. This will be a basis for the final base case reference made by and accepted by the main group. It will then be a firm precondition basis for all physical main items and related sub-estimates.

The main items should initially be subjected to a triple estimate evaluation. The few items with the more critical uncertainties could be further specified and clarified in relevant sub-groups. A specific example from the capsule plant and capsule production demonstrated that a satisfying degree of detailing was obtainable.

The second and subsequent times the new procedure is applied, some of the major physical items might be re-calculated.

* **Dependencies between the authorities' costs and SKB's administrative costs.** There were several dependencies. First of all is the risk of higher wages for highly qualified personnel relative to average inflation. However, new possible requirements in respect of the administration and indirect wage costs may be another common source of uncertainty. This fact supports the idea that the authorities' costs must be integrated into the procedure.

* **The test analysis.** The result of the quantitative part of a test analysis was significant uncertainty. It reinforced the necessity of estimating the physical subjects/items under the base case assumptions and excluding the overall uncertainties from these evaluations. One single subject, for example, will hardly be twice as costly under base case assumptions. Later cycles will normally remedy this error. It was a remarkable result, that the physical subjects did not dominate the 'top-ten list'.

Further work

* **Understanding the new principles, the paradigm**
An education and training input is required. As an initial step, a special session on the principles internally in SKI is suggested .

* **Practical resource consumption**
A more detailed procedure is advocated, which allows the total future workload to be estimated.

* **A full-scale test series**
It is recommended that a full-scale test should be conducted at a later stage using a larger and broader analysis group, more or less in line with the proposed composition of the main analysis group. In addition to objectives such as those of the earlier tests, it could verify the number and duration of analysis sessions needed.

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[10] This term is frequently used in Norway instead of the term 'the Successive Principle'.

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List of abbreviations

AUB (in Swedish, Avgiftsunderlagsbeloppet): The fee base amount
A value that gives the total estimated cost of the Swedish programme for managing all nuclear waste and dismantling nuclear power plants. This value shall include all measures that have to be taken after the reactors have served their productive life span. The law requires this cost to be calculated on the basis of the most probable future scenario, i.e. the base case that describes all measures which need to be taken for the final solution of the waste problem and the decommissioning of the nuclear power plants. See also GB below.

CLAB, Central Interim Storage Facility for Spent Nuclear Fuel
The spent fuel elements are transported by ship, in specially designed containers. These containers are stored at CLAB in fuel depots for approximately 40 years. During this timespan the radioactivity diminishes and less heat is generated.

CUF, Coefficient of Utilisation (Fuel)
In Swedish: Uttnytningsgrad,

CUP, Coefficient of Utilisation (Production)
Actual production relative to maximum production, in Swedish: Verkningsgrad.

EPG, Economic Point of Gravity
A technical term used in capital budgeting to express an estimate of the shape of the payment streams. The EPG is an estimate of the mid-point of all disbursements and incomes spread over time for a specific activity.

FMK (in Swedish, Försvarets Materielverk): Swedish Defence Materiel Administration.

Fortifikationsförvaltningen: The Swedish administration of Military Installations.

GB (in Swedish, Grundbeloppet): The basic amount (see also AUB above)
An estimate of all future costs, that will prevail if, and only if, the Swedish nuclear power programme is closed down during the coming year. This amount is only applicable to the actual date when the calculation is made, e.g. this amount describes the total cost of a decision to halt the programme instantly.

KAF (in Swedish, Kärnavfallsfonden): The Swedish Nuclear Waste Fund.

KAFS (in Swedish, Kärnavfallsfondens styrelse): *The Board of the Swedish Nuclear Waste Fund*
Since 1996, the Board of the Swedish Nuclear Waste Fund has been responsible for the administration of the accumulated funds.

KBI is the official Swedish consumers' cost index/inflation index.

KBS-3 is a special construction sector cost index, more or less tailored to actual decommissioning projects.

NPV, Net Present Value (in Swedish, nuvärde)
NPV is a term used in capital budgeting to describe the total discounted value of all receipts and disbursements that an investment or activity generates. In other words, net present value is a measure of how much value is created or added today by undertaking an investment.

KTH (in Swedish, Kungliga Tekniska Högskolen): The Royal Technical University, Stockholm.

PLAN process
The concept PLAN process is used to describe the yearly activity of analysing and calculating the future cost of the final solution of the waste problem and the decommissioning of the nuclear power plants for the Swedish nuclear power programme. The aim of this process is to find an optimum level for the fees for the Board of the Swedish Nuclear Waste Fund.

RKG (in Swedish: Rigsgældskontoret): Office of national debt.

SEK (in Swedish, Svenska Kronor): Swedish Crowns
The current value of one SEK is approx. equal to 0.1 EURO (10 European cents).

SFL - or more correctly SFL 3 – 5
A planned facility for permanent storage of low and intermediate level waste.

SKB (in Swedish, Svensk Kärnbränslehantering AB): Swedish Nuclear Fuel and Waste Management Company
Common abbreviation for Svensk Kärnbränslehantering AB, a commercial company under the Swedish Companies Act, which is jointly owned by the Swedish nuclear industry. The reactor's owner holds all the shares and it is a non-public company.

SKI (in Swedish, Statens Kärnkraftinspektion): Swedish Nuclear Power Inspectorate.

SSI (in Swedish, Statens Strålskyddsinstitut): Swedish Radiation Protection Institute.

The Successive Principle or the Lichtenberg Principle
An analysis methodology which is specially designed to analyse, calculate and describe complex projects. The method may best be described as a non-deterministic approach that is based on the use of Bayesian statistical analysis. In brief, the aim of the method is to derive a neutral, or objective, quantitative result in spite of uncertain input figures, and to visualise the principal sources of risks and other uncertainties.

Appendix
Evaluation and handling uncertain input values

Introduction

The Successive Principle is, as previously stated, based on the subjective probability theory or Bayesian theory. According to this theory, subjective numerical evaluations are accepted and can be dealt with according to the rules set out in the classic or ‘frequentistic’ statistical theory (literature LIN-92 and APO-90 in ref. 1). The object to be analysed is organised into independent elements using special sub-routines, as described above. Such elements may be items, activities, correction factors, unit prices, volumes etc. This basically eliminates the problem of statistical dependency, related co-variances and dependency or correlation factors.

The principle of independent conditional uncertainties

The various sub-procedures, among other factors, are used to establish sufficient statistical independence between all uncertain data. The mean of the total result can then be calculated by using the local mean values of all local data. This has been shown to be very close to the theoretically correct value. The uncertainty of the total result is calculated as the sum of the squares of the effect on the result of the conditional uncertainties of all local data, whether volumes, costs or unit costs, factors, etc. See Chapter 5.1, ref. 1. This will further safeguard the crucially important statistical independence.

Mathematical probability distribution curves for the input

Many possible types exist. The well-known Gaussian function, also called the normal distribution function, is one example. But it is symmetrical and it is evident that many practical probability distributions are skewed; so it cannot stand alone.

Any distribution function will approximate to the normal distribution function according to the central limit theorem whereby the parameter is a sum of many smaller independent contributions. An example is a main item of raw material costs composed of many sub-items. Similarly, if our parameter value is actually a product of many factors, its distribution will approach the so-called Log-normal distribution function[11]. This function is quite skewed.

The famous scheduling procedure, PERT, from 1958 (one of the original critical path techniques), used the so-called Beta distribution function. It is mathematically simple and has the advantage that it covers many types of skewness. However, it has no known connection to the physical realities of uncertain technical or financial parameters. The same is applied to the triangular distribution used by Swedish researchers among others.

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[11] If you draw this function on a horizontal logarithmic scale, it is identical to the normal or Gaussian distribution.

The so-called **'**Erlang distribution'[12] is interesting in this context. There is a certain connection, between the Erlang distribution and many real-life uncertainties, which is relevant here. A man-machine system, such as a process in the manufacturing or construction industries, or even the developing of a computer program, will proceed more or less at a given pace until something happens and the process 'dies'. The theoretical minimum duration of production and related costs depend on the given capacity of a man-machine system. The related uncertainty is insignificant as long as it runs, and as long as it works to the normal rhythm. Estimates of related resource consumption, cost, income or time requirement would therefore also be of similarly insignificant uncertainty, as long as nothing intervenes.

It follows that uncertainty is basically related to unplanned interruptions to the above regular rhythm. The process "dies", so to speak, but "revives" after some time. If there is only a single cause of such unplanned stops, we could apply the famous distribution function of lifespan, the Exponential distribution function. Within the areas of biological science and reliability, this is called the 'Death function'.

In practice, we experience more than one set of causes of unplanned stops: for example (1) mechanical break-down and other technical stops; (2) lack of appropriate design or management information; (3) weather problems (in particular in connection with earthworks); (4) human factors; (5) external influence. The number of such types of reasons for stops is denoted k here (for obvious reasons, k will be an integer between 1 and 20). After each stop the process usually springs back to life, so to speak. It is analogous to "a cat with nine lives". In conclusion, we are looking for the distribution function of the life expectancy of a cat with k lives instead of the proverbial nine. The family of Erlang distributions is precisely the distribution functions of "a cat with k lives". This "family" of functions therefore seems to cater for our requirement reasonably well. The verification of this is discussed below.

The family of Erlang functions (see figure 4.4a), is thus a generalisation of the Exponential function or Death function. The Erlang function, where $k = 1$, is identical to the exponential function, as a lifespan usually follows this extremely skewed distribution.

Using smaller values of k, the function gives a reasonable picture of man-machine systems. Their uncertainty distributions stem basically from the fact that the system "dies", but "revives" again. Using $k = 5$, the function is very much akin to the Log-normal distribution which is also relevant when the parameter is a product of factors. When $k > 10$ it brings the distribution closer to the Gaussian distribution, which again is relevant when a cost parameter is the sum of many elements.

Two experiments have been conducted to analyse the distribution curves of typical man-machine activities, which again lies behind economic uncertainties. The first experiment analysed a large set of American heavy construction activities. They proved to be closely related to the Erlang distributions. See ref. 38. The other and more recent experiment analysed activities from the Danish construction industry. After being cleaned for the repetition effect they, too, showed a close correlation with the Erlang functions. See ref. 36.

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[12] Named after Erlang, an engineer and scientist at the Copenhagen Telephone Company. Around 1900, he developed the stochastic laws of telephone capacities which are still being used world-wide.

The family of Erlang functions therefore seems to represent quite well the vast majority of the 'real-life' uncertainties that are relevant in this context. However, it is stressed that other distribution functions may be used when deemed more relevant. If so, the transformation formulae for the mean value and standard deviation below must be adjusted accordingly. In the following, the family of Erlang distributions is assumed.

It has proved feasible, among the many possible models, to use the old PERT principle of a triple estimate, evaluating the 1% and 99% limits together with the most likely value. Here, the actual distribution parameters of a local parameter are calculated from a triple estimate, performed by an analysis group according to a specific procedure set out in Chapter 4.3.

The user need not worry about the degree of skewness. This is "automatically" taken into account when we calculate the mean value and the standard deviation from the triple estimate. We simply need to evaluate this triple estimate carefully, avoiding evaluation pitfalls.

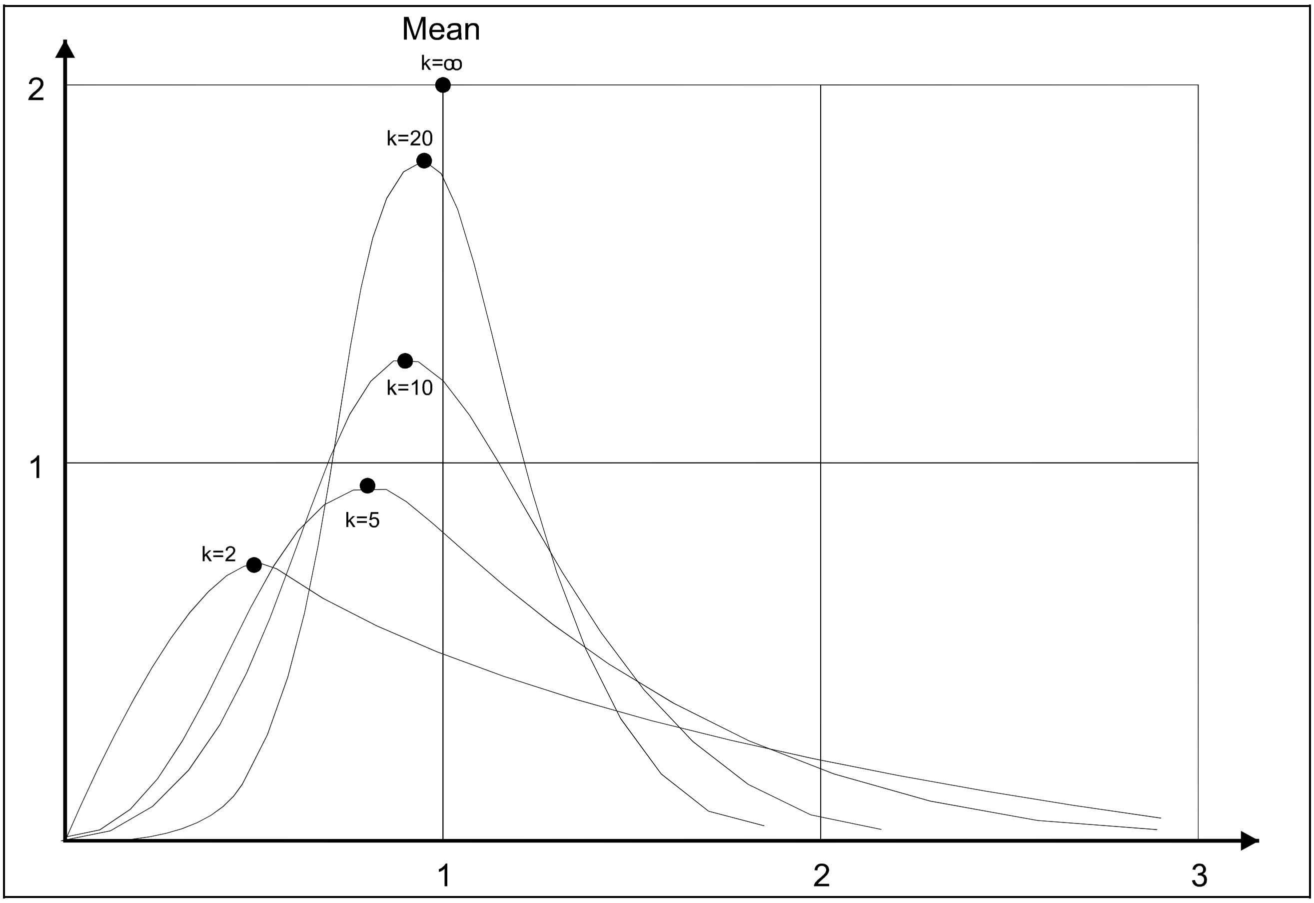

Figure The family of Erlang distributions. k is the skewness parameter. k = 1 relates to the exponential distribution (not shown here) and k = 5 is close to the Log-normal distribution. For k > 10, the functions come closer to the Gaussian or normal distribution. See ref. 1, Chapter 5.1 for the mathematical formula.

In conclusion, the evaluation technique and group evaluation are used to cope with a set of evaluation pitfalls. On this basis it is appropriate to use the 1% and 99% limits. The well-documented difficulties in evaluating these extreme values have been overcome by using this ‘group triple estimating’ technique.

All evaluations are conditional. This means that the evaluations are made on the basis of all other parameters being in their mean state. As previously indicated, we have already structured the analysis so as to ensure sufficient statistical independence; using the conditional uncertainty is a further safeguard.

The famous statistical law of large numbers, the central limit theorem, deals with a result which is aggregated from many and varied uncertain parameters of the same order of magnitude. Such a result tends to approximate to the symmetrical ‘Normal distribution’ or ‘Gauss distribution’, irrespective of the skewness of the individual parameters.

The conditions in these analyses, which are relevant here, will often comply adequately with the above requirement. Accordingly, we may assume that the result largely reflects the Gaussian or Normal distribution. However, in cases where the majority of the remaining uncertainty stems from a few high-level and skewed factors, the resulting distribution function may approximate instead to the Log-normal distribution. This should not to any significant degree be the case in this particular context, where a relatively large number of uncertainties will exist.

Subjective evaluation
- an analysis of the robustness towards errors of methodology

If the group as a whole is not balanced it may result in serious systematic biases. This source or error is prevented by the requirement to establish a balanced, broad and sufficiently competent analysis group. Some other sources of errors are analysed below.

1. One source of errors deals with an erroneous evaluation of an extreme value in a triple estimate. The worst case is that it proves to be the most extreme in the group, and therefore appears in the subsequent calculations. An example will indicate the resulting impact on the total result.

Assume that the group has overestimated an extreme max. by as much as 50% in a specific typical and average item among the 20 items. It will bias the resulting total mean value by the order of 0.5 / 4.9 / 20 or 0.5%. The Priority figure will at least double. For this reason it will generally appear in the top-ten list, and call for closer verification. This will often eliminate such an error.

2. Another source of errors arises if one participant evaluates a most likely value say 30% too high for a typical and average item among the 20 items. Assuming 15 participants, it will bias the total result by as much as 0.3 x 0.59 / 15 / 20 or 0.06% of the total mean value.

3. The distribution function may deviate from the assumed Erlang distribution. It could be an extreme member of the ‘family of Erlang functions’, a Beta function, or even close to a triangular function (it can be proved that it can never be an exact triangular function). A given

triple estimate will in such a case correspond to a different mean value than that which we calculate by using the standard weight of 1 : 2.9 : 1. The largest among such deviations of the mean value ranges in size from – 1% to + 2%. The related mean value will deviate by approximately (1 + 2) / 5 = 3/5% or 0.6% of the single item or 0.6 / 20 = 0.03% of the total mean value.

The actual uncertainty will typically range from 5% to 15%. It is seen that by comparison with this level of uncertainty, the errors arising from the methodology are without importance. This is true even if several such errors occur. In the latter case we enjoy the levelling effect of the ‘law of great numbers’.

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(end of the report)