Project P901-PF

Extended investment analysis of telecommunication operator strategies
Deliverable 1.
Investment analysis framework definition and requirements specification
Volume 2 of 2: Annexes

Suggested readers:
Managers, strategic planners, researchers and consultants involved in development of and investments in advanced telecommunications networks.

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Executive Summary

The key questions to be answered in the EURESCOM P901 Project, *Extended investment analysis of telecommunication operator strategies*, are all related to strategic investments under uncertainty. Currently the telecommunications arena, and in particular the residential domain, is characterised by a high uncertainty with respect to the rapid technology evolution, market development and regulatory environment. Uncertainties in service take rates, willingness to pay, future technology capabilities, cost levels, technology and market convergence introduce new and significant risk elements into telecommunications investment projects.

Market response, pricing strategies, handling of uncertainty, strategic interaction between competitors and external effects influence the value chain and economics of telecommunication operator investment projects. Furthermore, there is a competition between investment projects, (with very different business environments and strategy decision criteria) within telecommunication operators.

The P901 Project concentrates on quantitative analyses, relying on the establishment and use of a common assessment framework, including common models for costing, market assessment, competitor behaviour and external effects, and risk analysis. The major contribution from the Project is expected to be a methodology and framework enabling a harmonised evaluation of different types of telecommunication operator investment projects.

Aspects addressed in these Annexes

The Annexes to Deliverable 1 of P901 provide additional details to the text in the main body.

Annex A provides more in-depth information on methodology requirements for the definition of an investment analysis framework, as well as more background to the selection of possible investment projects for applying the methodologies and models developed in this Project. It also looks at possibilities for collaborating with other EURESCOM Projects and bodies performing work on similar subjects.

Annex B gives detailed technical information on the possible methodologies and tools. It also contains an elaborated reference list with references on those methodologies and tools.
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Abbreviations

ABI  Allied Business Intelligence
ACTS  Advanced Communication Technologies and Services
ADSL  Asymmetric Digital Subscriber Line
ATM  Asynchronous Transfer Mode
BP  Business Plan
BU  Business Unit
CAPM  Capital Asset Pricing Model
CATV  Community Antenna Television
CF  Cash Flow
DCF  Discounted Cash Flow
DNLP  Discontinuous Non-Linear Programming
DSL  Digital Subscriber Line
EBITDA  Earnings before Interest, Tax, Depreciation and Amortisation
EP  Evolutionary Path
EU  European Union
EVA  Economic Value Added
FAC  Fully Allocated Costs
FDM  Frequency Division Multiplexing
FITL  Fibre in the Loop
FSN  Full Service Network
FTTB  Fibre to the Building
FTTC  Fibre to the Curb
FTTCab  Fibre to the Cabinet
FTTH  Fibre to the Home
FTTN  Fibre to the Distribution Node
GII  Global Information Infrastructure
GSM  Global System For Mobile Communication
HFC  Hybrid Fibre Coaxial
IFC  Installed First Costs
IN  Intelligent Network
IP  Internet Protocol
IRR  Internal Rate of Return
ISDN  Integrated Services Digital Network
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<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>LCC</td>
<td>Life Cycle Costs</td>
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<tr>
<td>LEX</td>
<td>Local Exchange</td>
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<td>LMDS</td>
<td>Local Multipoint Distribution Service</td>
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<td>LRAIC</td>
<td>Long Run Adjusted Incremental Cost</td>
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<td>MIP</td>
<td>Mixed-Integer Programming</td>
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<tr>
<td>MS</td>
<td>Market Share</td>
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<tr>
<td>MTBR</td>
<td>Mean Time between Repair</td>
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<td>MTTR</td>
<td>Mean Time to Repair</td>
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<td>NPV</td>
<td>Net Present Value</td>
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<td>NRA</td>
<td>National Regulatory Authorities</td>
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<td>NT</td>
<td>Network Termination</td>
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<tr>
<td>OAM</td>
<td>Operation, Administration And Maintenance</td>
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<td>ONP</td>
<td>Open Network Provisioning</td>
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<tr>
<td>OPTIMUM</td>
<td>Optimised Network Architectures for Multimedia Services</td>
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<tr>
<td>PC</td>
<td>Personal Computer</td>
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<td>PDH</td>
<td>Plesiochronous Digital Hierarchy</td>
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<td>PI</td>
<td>Profitability Index</td>
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<td>PNO</td>
<td>Public Network Operator</td>
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<td>PON</td>
<td>Passive Optical Network</td>
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<td>POTS</td>
<td>Plain Old Telephone Service</td>
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<tr>
<td>PSTN</td>
<td>Public Switched Telephone Network</td>
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<td>PVCF</td>
<td>Present Value of Cash Flow</td>
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<td>QOS</td>
<td>Quality of Service</td>
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<td>RACE</td>
<td>Research For Advanced Communications in Europe</td>
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<td>RMINLP</td>
<td>Relaxed Non-Linear Mixed Integer Programming</td>
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<td>RMIP</td>
<td>Relaxed Mixed Integer Programming</td>
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<td>ROC</td>
<td>Rate of Capital</td>
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<td>ROE</td>
<td>Rate of Earnings</td>
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<tr>
<td>RSU</td>
<td>Remote Subscriber Unit</td>
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<tr>
<td>SDH</td>
<td>Synchronous Digital Hierarchy</td>
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<td>SME</td>
<td>Small and Medium Enterprise</td>
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<td>STP</td>
<td>Signalling Transfer Points</td>
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<td>STS</td>
<td>Signalling Link Sets</td>
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<td>SWOT</td>
<td>Strengths, Weaknesses, Opportunities and Threats</td>
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<tr>
<td>TELRIC</td>
<td>Total Element Long Run Incremental Cost</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>TERA</td>
<td>Techno Economics Results from ACTS</td>
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<td>TFM</td>
<td>Three Factor Model</td>
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<tr>
<td>TITAN</td>
<td>Tool for Introduction Scenario and Techno-Economic Evaluation of Access Network</td>
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<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunications System</td>
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<td>USO</td>
<td>Universal Service Obligation</td>
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<tr>
<td>VCI</td>
<td>Virtual Channel Identifier</td>
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<tr>
<td>VDSL</td>
<td>Very High Speed Digital Subscriber Line</td>
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<td>VOD</td>
<td>Video on Demand</td>
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<tr>
<td>VPI</td>
<td>Virtual Path Identifier</td>
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<tr>
<td>WACC</td>
<td>Weighted Average Cost Of Capital</td>
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<td>WDM</td>
<td>Wavelength Division Multiplexing</td>
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<td>WTO</td>
<td>World Trade Organisation</td>
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Annex A: P901 Framework Definition

Structuring the work

Analysing the emerging and future technical solutions, market and economy related to the next generation of telecommunication services is complex. Therefore it is extremely important to structure the work in this study to be able to manage this expected complexity. In order to keep it simple, a top-down approach should be used and further reflected through the selection and investigation of P901 investment projects. Generic simple building blocks has to be implemented avoiding too detailed technical analysis. Existing material from previous studies will be reused in this work when applicable, but put together in a new setting. Identifying uncertainty and corresponding risks is an important target of this work and should be clearly identified in the investment projects selected.

Network levels and services – layered architecture

The current network trends are influenced by the general technology evolution, which typically characterised by digitalisation, miniaturisation, high capacity and mobility, the latter both in terms of terminal, user and service mobility. An indeed, we are currently witnessing a change in network technology with respect to price and functionality, for instance through the introduction of WDM (wavelength division multiplexing) ATM (asynchronous transfer mode) and IP (Internet Protocol) technology.

The telecommunications network operators already have integrated the traffic from the different platforms in the transport network at long distance and junction level and also in parts of the access network. The technology used today is mainly fibre and plesiochronous digital hierarchy (PDH) or synchronous digital hierarchy (SDH) transmission systems and in addition radio links in rural areas. But still network operators commonly introduce new services by means of a new service network with dedicated equipment. This may very well be the case for several years to come, resulting in an incoherent mixture of technologies remaining also in the future [1, 2]

However, in the EURESCOM P901 project the network investment projects will be analysed in view of a development towards the future telecommunications network which may be considered as representing a paradigm shift from dedicated service networks towards a layered architecture with common service production platform utilising common network technologies. This shift is shown in Figure 1.

![Figure 1 Paradigm shift from dedicated service networks towards a layered architecture with common network technologies](image-url)
The layered architecture divides the telecommunication network into separate parts representing different functions, or roles, in the telecommunication network. The complete layered architecture is shown in Figure 2.

Service / Applications represent software developed for specific target in the value chain and with a specific user interface.

Application environment represents generic software components for management, service-/application development and execution of services.

Middleware represents a software layer with generic, service independent components including component based communication, security, catalogue, transaction, event, database storage and protocol translation.

Service network covers the network nodes like switches and routers. Issues like e.g. IP, ATM, QoS, scalability etc. is relevant for this network layer.

Transport network covers transport between network nodes. Issues like ATM, SDH, WDM, fibre, optical networks etc. is relevant for this network layer.

Access network covers transport between the customer and a switching point in the network. Issues like DSL, FTTx, LMDS, HFC is relevant for this layer.

The investment projects in the EURESCOM P901 Project should be related to the layered architecture to ensure a consistent and common understanding of the network structures proposed.

**Network layer versus driver matrix**

Figure 2 shows the relation between the layered network architecture and the main drivers already described. A horizontal view represents a technical oriented focus. A vertical view represents a service oriented, or value chain, focus.

To illustrate, a business case like e.g. UMTS covers in principle all layers in the model ranging from access through service network (core) issues up to the service/application level. Broadband access studies, like the ones in the EURESCOM P614 Project, [3], were horizontal oriented focusing on the different technical architectures for providing broadband access to the customer.

The number of network layers involved will clearly also impact on the market modelling approach.
Figure 3 The main drivers will have large impact on all network layers

As indicated in Figure 3, network elements (with corresponding costs) have to be implemented at each layer depending on the needs given from the specific driver. Network elements (and costs) can be divided into two main groups:

- Common network elements (costs)
- Specific network elements (costs)

Where do we find the major driving cost elements with respect to the different layers? Furthermore the network/cost elements will clearly have different risk-profiles to be sorted out by the project.

It is important to note that business cases, with respect to technology and investment, in many situations can not be completely isolated from each other. Identifying common building blocks with corresponding costs will give a more correct picture and could also simplify the work. An overall target could be to establish a matrix of network/cost elements for late use.

Synergies through common network elements should be identified through the further investigation of the investment projects. When defining an investment project, the horizontal or vertical focus should be identified.

**Generic models for strategic planning**

In order to be able to carry out thorough analyses of telecommunication operator investment projects, a modular framework with clear and logical interfaces is needed. Furthermore, the framework must be general enough in order to handle very different types of projects for example backbone network projects versus access network projects, greenfield vs. non-greenfield situations etc. The methodology framework is best understood as a set of “sub-frameworks” or modules. A module generally receives inputs from other modules and generates outputs to other modules. The specification and requirements of the modules, the interfaces between modules and the content of the modules in terms of necessary parameters and variables lays the foundation for the modelling work and the generation of results.
Given the overall objective of the work, a generic framework for the investment analysis and the associated requirements has been defined in the project. The features of the framework area:

- Identification and definition of investment project types under consideration
- Identification of the assessment criteria to be applied in the analysis
- Identification of the information required for the investment models
- Identification of the outputs required from the investment models

Figure 4 illustrates the framework on which the investment analyses are based.

![Extended telecommunication operator investment analyses framework](image)

**Figure 4** Extended telecommunication operator investment analyses framework

The framework illustration is seemingly very similar to investment project evaluation processes in general. The difference and contribution of the P901 framework lies in the implementation of the modules and the inter-working between them, which will be described in the following.

The highlighted boxes show where new models are expected. These three groups of models are deeply analysed in the Deliverable 2, [4]. The scenario definition must be clear and follow the philosophy of the layered architecture in order to identify the most important parameters and their impacts. In each investment project, a number of relevant scenarios are defined by network alternatives, service portfolio, market segments and external factors such as regulatory issues, competition and demand evolution.

The scenarios for each investment project define a set of parameters and variables that are related to costs, market and risk. The overall input and output requirements of the generic models are discussed in section 1.4.
In the following, we will use the term “module” for a group of generic models that cover a specific area for example cost methodologies. At this stage we will not discuss the granularity of these models, nor the ways of implementation (Excel, high level language etc.); this work will be performed later on in the project. As an example, the costing module contain all the costing models are gathered in a well-structured way. As can be seen in Figure 5, each module will most often have inputs and outputs. The inputs to the cost, market, and risk models are defined by the scenarios. Even though the investment projects under study and their respective scenarios may be very significant, the following model elements must be presented in a general way:

- Services. Penetration, number of customers and tariffs are presented as time series.
- Network architecture. Cost evolution and volume of each network element (time series)
- Market segments. Number of customers in each market segment as a function of time (for each service). A moderate number of segments is recommended.
- Usage of services. For each market segment, the usage for each service is most often modelled as busy hour traffic in Mb per day/month (data) or minutes per day/month (voice)
- Area types. Different areas are described by the same attributes: Customer density, customer mix, average loop lengths, duct availability, surface conditions (necessary for civil works cost estimates) and housing (single house dwellings or apartments).

![Figure 5. Model input and output definition](image)

In Figure 5, the scenario description is defined in terms of regulation, services, competition and technology. The scenario attributes of central importance for each investment project such as regulatory regime, competitive environment and choice of technology is described by switches. The layered network architecture described earlier is used to indicate the drivers of each network and service layer.
The investment project definition/selection feeds the three indicated groups of models with the necessary information on market, strategy and technology.

**Input/output requirements**

Still by looking at Figure 5, we now go through the model requirements in terms of input and output.

**Cost models: input requirements**

The cost module must receive inputs of the following categories (as seen in Figure 5):

- Technology types
- Technology strategy
- Project lifetime
- SWOT results

When building a new network or upgrading an existing one, an operator has a set of technologies to choose. The cost structure may vary significantly from one technology to the other in terms of up-front costs, variable cost and maintenance costs. Each technology type has elements that are dedicated as for example modems and shared elements (shared by many users) such as cabinets, optical network units, base stations and cables.

The technology strategy of an operator is defined by the target network architecture and a set of evolutionary paths (ways to get from the present network architecture to the target architecture). The terms *scenarios* and *evolutionary paths* are defined later in this chapter. Each evolutionary path is defined by a number of technology upgrades within a given period called the *study period* or project lifetime. For R&D related projects which are long term, the project lifetime is mostly 5-10 years.

Different technology solutions evaluated by the use of a so-called SWOT analysis which stands for *Strengths, Weaknesses, Opportunities* and *Threats*.

The SWOT analysis narrows down the number of technology solutions and thereby the number of relevant scenarios. The possibility to use the existing copper plant is a strength of xDSL solutions to give an example.

For each technology type, the following attributes are necessary input to the cost module:

- The equipment price in a given year
- Price trends
- Operation Maintenance cost parameters

The cost module need input from the market module, which are:

- Penetrations and thereby the number of customers for each service. This information is necessary for the network dimensioning and therefore costs
- Traffic for each service. Used for network dimensioning
- Administrative costs that are related to the customer base
Network dimensioning tools/planning tools might be necessary in this process. The service strategy defines which services to offer where and when. The service strategy has a great influence on costs as well as revenues.

**Cost models: output requirements**

The cost module gives a range of outputs necessary for the calculation of product indices such as IFC (installed first costs), LCC (life-cycle costs), NPV and IRR.

IFC is calculated as the sum of total discounted investment within the study period, whereas LCC is defined as sum of discounted investments and running costs.

These outputs are:
- Yearly investment for each network element
- Yearly maintenance cost for each network element
- Yearly amount for a each type of operation and administration cost

**Market models: input requirements**

As seen in Figure 5, the following inputs are necessary for the market module:
- Service types
- Service and price strategy
- Project lifetime
- SWOT analysis

The service types define the range of services to be offered. These services can be bearer services or teleservices.

The service and price strategy defines which services to offer when and where together with the proposed tariff for each service. A price strategy can for example be flat rate or volume-based. Different price strategies for business customers and consumers are generally expected.

Project lifetime or study period, which is a central parameter for all modules is defined earlier.

The opportunities and threats parts of the SWOT analysis is helpful when defining the service strategy. Where (geography and segments) are the opportunities in terms of launching a new and better product than the competitors? In which areas and in which markets is heavy competition expected?

**Market models: output requirements**

The market module must generate the following set of outputs:

Penetration and market share per service for each year within the project lifetime (study period). The time services together with the total number of customers give the number of customers per year for each service. The outputs are used in the cost module to calculate network costs and administrative costs.
Yearly generated traffic for each service. Used in network dimensioning and thereby in the evaluation of costs. The generated traffic is also used for revenue calculation if tariffs are not pure flat rate.

Revenues per service is calculated from the number of customers and the average generated traffic per service per segment.

**Risk module**

The description of the risk module has a different structure than the description of the cost and market modules. For this reason, dedicated paragraphs for input and output are not used. The risk module is an “overlay module” and therefore it makes less sense to talk about input and outputs in the same meaning as for the other modules.

The risk module is a set of models or methodologies which are shortly described in section 2.5 and in more detail in the Annex B of this Deliverable and Deliverable 2, [4]. Before one is able to perform a risk assessment, the uncertain parameters in the investment project must be identified and quantified. Uncertain parameters can be overall parameters such as regulatory factors competition, market related parameters such as growth rates for new services and cost related parameters such as equipment costs. Uncertainties can be quantified in terms of probability density functions. The results from the risk module are:

- Probability distributions of project indexes such as NPV and IRR
- Metrics related to profit indexes and cashflows. In general, different metrics are used for different risk methodologies

The decision variables such as the time where services are launched, networks are build etc. are defined by the chosen strategy.

**The need for new models**

The framework of P901 and the corresponding flows of information and models has been described. The models can be based on established models from earlier projects within EURESCOM and ACTS (but put in a new setting) as well as new models based on more advanced methodologies that are not widely used in horizontal techno-economic assessments.

Interconnect pricing is a necessary ingredient of strategic planning in competitive markets. At the cost side, models based on methodologies such as ABC and LRAIC are therefore of great interest.

EURESCOM P901 Project deals with investment analyses under uncertainty. In the area of uncertainty and risk. A number of methodologies have been given thorough treatment in the literature:

- Monte Carlo simulation
- Real options
- Game theory
- System Dynamics

However, clear understanding of the strengths and weaknesses of the methodologies, how they can be combined if relevant and how the models and their interfaces should
be defined. Therefore, P901 will provide new models based on these methodologies with clear interfaces and in a clear and userfriendly setting to add new value to the EURESCOM shareholders, see Deliverable 2, [4].
Methodology requirements – framework definition

Thus, having established the overall framework for the investment analysis, as depicted in Figure 4 and given the overall requirements to the modules or groups of models, the corresponding methodology requirements must be examined.

In the following the term module should be understood very generally as a set of related models for example a cost module including the various cost models (ABC, LRIC, OA&M etc.). The modules can be realised as sheets in an Excel workbook, coupled Excel workbooks or object-oriented code such as C++ just to give some examples of structures and formats. There are no restrictions at this point as far as implementation is concerned. A modular structure makes it easier to debug, revise and refine the methodologies when needed. The methodology requirements described herein are linked to the features and the requirements of each of the modules shown in Figure 4 are described. The main modules are:

- Scenario definition and description
- Market models
- Network infrastructure dimensioning
- Cost models
- Risk models

Some modules in the figure are more related with the performance of the actual project calculation and analysis, and as such may not directly imply specific methodology requirements, but rather indirectly through the methodology and modelling modules on which they are dependant. These modules are Investment project definition/selection, Investment and OAM (operation, administration and maintenance) costs, Cash flow and Project indexes + analysis.

In addition to the above we need to consider methodology requirements for modules handling the following aspects:

- Results and presentation
- Interfaces for external data (e.g. traffic data generated by planning tools).

Scenario definition and description

A scenario is the description of the environment in which the network business is run, including one or several operators, in which there a set of services to be provided to predefined user segments [5].

The identification of major influences and drivers are usefully built into the construction of scenarios. Scenario planning is especially useful in circumstances where it is important to take a long-term view of strategy (typically between five to ten years). Other criteria are a limited number of key factors influencing the success or failure of that strategy and a high level of uncertainty about such influences.

Scenario building is not just based on a hunch, but rather on plausible views of different possible futures for the operator based on groupings of key environmental influences and drivers. The result of this exercise is limited number of logically consistent, but different scenarios that can be considered alongside each other.
The definition of the scenarios to be assessed in each study case must be clearly isolated from model data etc. The scenario attributes constitute the overall parameters compared to low-level parameters such as for example network component costs and duct availability. A set of scenario attributes which are most often used in definition of an investment project are listed below:

- Service scenarios: optimistic, nominal, pessimistic
- Parameters describing technology evolution and obsolescence
- Number of competitors
- Regulatory issues e.g. licence costs and USO impacts

It is important to distinguish between the uncertain key factors and decision variables (over which the operator has control). Pricing strategies, and roll-out strategies are described by such parameters. In the framework the module Investment project definition/selection comprise the specification of the operator’s market and technology strategy. In general, in techno-economic assessments the basic terms are scenario, evolutionary path, target and strategy.

The target represents the objectives of the telecommunication operator both with respect to economic and technological aspects.

A strategy represents the means by which the objectives of the operator are reached, starting from the present situation. A strategy is based on a set of actions and initiatives that the telecommunication operator plans to take in order to reach a predefined target (e.g. integration of narrowband and broadband services over a PON network). The definition of a strategy implies a choice among different evolutionary paths. Often the term migration strategy is used to emphasise that the operator migrates from the present network and service portfolio to a future (target) network with new advanced services including multimedia.

An evolutionary path is a time-ordered sequence of network architectures and the set of transitions between consecutive architectures. In general there can be several alternative evolutionary paths spanning from cautious to aggressive.

**Market modelling**

In each investment project assessed in P901, a definition of the services offered is needed together with a segmentation of the market. The attributes of the market are

- Market segmentation (macro or micro- segmentation)
- Service types (bearer services, teleservices, applications)
- Penetration of services
- Willingness to pay (per service per segment)
- Tariffs (annual fees, usage fees, connection fees)
- Operator market shares
- Churn rates

After having defined the attributes of the market model, it is necessary to define the drivers and inhibitors of the attributes as well as the correlation/interdependencies between attributes. A tool named Wirkungsmatrix, from Swisscom, is described in
more detail in the Annex B of this Deliverable is used to quantify the interdependencies in a matrix structure.

In summary, the following attributes are needed in the market framework:

**Segmentation**

The customer segments and the service penetrations within each segment. The size of each segment is generally time-dependent throughout the study-period. One example of segmentation can be corporate, SME and residential users.

**Services**

For each segment, a number of services are offered. Each service is described by:

- Total number of potential customers belonging to segment $i$, $T_i(t)$
- Penetration $S_i^j(t)$, which is time-dependent share of the total number of potential customers belonging to segment $i$ segment that subscribes to service $j$
- Operator market share $Q_i^j(t)$, which is the time-dependent market share of service $j$ in segment $i$.
- $PC_i^j(t)$, which is the time-dependent connection tariff of service $j$ in segment $i$
- $PA_i^j(t)$, which is the time-dependent annual traffic of service $j$ in segment $i$. The annual tariff can be either flat rate or include traffic usage.

The number of customers at time $t$ in segment $i$ belonging to the customer base of the operator, subscribing to service $j$ is calculated as:

$$C_i^j(t) = T_i(t)S_i^j(t)Q_i^j(t)$$

We have for the total revenue at the end of year $t_n$ for service $j$ in segment $i$:

$$R_i^j(t) = T_i(t_n)S_i^j(t_n)Q_i^j(t_n)PA_i^j(t_n) + \left[ T_i(t_{n-1})S_i^j(t_{n-1})Q_i^j(t_{n-1}) - T_i(t_n)S_i^j(t_n)Q_i^j(t_n) \right]PC_i^j(t_n)$$

- Mobility
- Capacity
- Interactivity (real-time features)
- Connectivity

We would like to know how customers trade these characteristics against each other in terms of money. The ultimate output of the market model should be how the price and demand for a service, in terms of the above characteristics, evolves as a function of time. The main criteria for market segmentation are the different customer categories like residential, SMEs and larger enterprise customers. The figure below illustrates the market modelling framework under development in the project.
Significant factors

Figure 6 The market modelling framework under development in the project
In Figure 6, the inter-working of the methodologies is shown. The benefit of a modular framework is clearly seen when defining scenario analyses.

Figure 7 indicates the inter-working between the market module and the other modules, highlighting the input and output from the market model module.

Network dimensioning
The network dimensioning is done partly by planning/dimensioning tool or directly inside the techno-economic tool dependent on the complexity. The inputs needed to the network dimensioning are:

- The number of customers in each segment subscribing to a given service
- The usage pattern of each service type and thereby the traffic matrix
• Traffic type (IP (internet protocol), ATM (asynchronous transfer mode) etc.) and their attributes namely bitrate, Qos (quality of service) class and level of symmetry
• Dimensioning rules for network equipment e.g. ATM switches, SDH (synchronous digital hierarchy) ADMs (add and drop multiplexers), LMDS (local multipoint distribution service) base stations
• Location and density of customers
• Location of exchanges, RSUs (remote subscriber units)
• Level of ducting
• LOS (line of sight) for wireless systems

A set of planning and dimensioning tools (for example INPLAN) are described and evaluated the Annex B of this Deliverable.

The outputs of the network dimensioning module are typically:
• A list, the so-called shopping list, which contains the number of each network element needed in order to satisfy the capacity and quality of service demands related to the services and their attributes.
• Grouping of cost elements into various classes e.g. to network level, functionality or type of technology.

Cost modelling

The cost modelling module should contain the following basic ingredients:
• Cost evolution of network components (as a function of time) e.g. specified by the extended learning curve of the TITAN/OPTIMUM methodology [6,7,8]
• Maintenance costs
• Installation costs
• Operating and administrative costs (of which some are service specific)

As a result of deregulation of the telecommunication market, incremental methodologies such as LRAIC (long run adjusted incremental cost) and TELRIC (total element long run incremental cost) have gained increasing interest. The incremental cost methodologies are described in more detail in the Annex B of this Deliverable and treated thoroughly in Deliverable 2, [4].

Figure 8 indicates the inter-working between the cost module and the other modules, highlighting the input and output from the cost model module.
Risk modelling

The business risks associated with new technology investments will be defined in the project and modelled, including factoring technology risk, market risk and revenue risk into the project investment analysis [9]. In the real world, variables are both very uncertain and often correlated to some extent. Future service demand is uncertain and so is the willingness to pay. In addition, the regulatory environment, technology evolution and levels of competition are highly uncertain. Changing one variable at a time and looking at the impact is a cumbersome and incorrect method. This single-variable sensitivity analysis approach only tells you what is possible and not what is probable. Various risk methodologies such as Monte Carlo simulation and the theory of real options are described in the Annex B of this Deliverable and are dealt with in more detail in Deliverable 2, [4].

When using Monte Carlo simulation, uncertain variables (market or technology specific variables) are assigned probability distributions and the output forecasts such as NPV are calculated in the economics module a predefined number of times. After the simulation has ended the statistical information of the outputs are interpreted using the decision criteria of the project.

A very important issue when carrying out risk analyses is the complexity of the scenarios including the number of uncertainty variables in the model. Only the most important factors should be included. Methodologies for narrowing down the number of variables and reducing the complexity of structural scenarios as described in [10] should be an integrated part of the risk analysis methodology.

The inputs needed for the Monte Carlo simulation approach and typical outputs are summarised below:

- The uncertain assumptions together with their probability functions. The assumptions are typically selected from a brainstorming process, Delphi Survey, factor analysis and related methods.
• The amount of correlation between assumptions. Ranking correlation is used in order to correlate assumptions with non-identical probability distributions as described in [11, 12].

• The forecast variables as for example NPV, IRR or payback period.

• The selection criteria for each investment project e.g. discard project if the probability of getting a negative NPV is more than 10%.

Outputs from the Monte Carlo simulation:

• Risk profiles for the selected forecasts including detailed report containing statistical information such as variance, percentiles, skewness etc.

• Sensitivity ranking of assumptions. This ranking helps the user in identifying assumptions that have a major impact on the overall uncertainty and risk.

The theory of options described in [13], [14] and [15]. Traditional discounted cash flow approaches (NPV > 0 rule) cannot properly capture management’s flexibility to adapt and revise later decisions in response to unexpected market developments. Traditional approaches assume an expected scenario of cash flows and presume management’s passive commitment to a certain static operating strategy. The strength of the options approach is the fact that is an overlay to the traditional cash flow set-up; the necessary information is already hidden in the DCF spreadsheets.

A simple and concise step-by-step framework for mapping an investment project into a call option is given in [16] and summarised in the Annex B of this Deliverable. The elaboration and implementation of the methodology is presented in the Deliverable 2, [4].

Figure 9 indicates the inter-working between the risk model and the other modules, highlighting the input and output from the risk model module.
Figure 9 The input and output of the risk module
Selection of the investment projects

Before a project is able to generate useful results it is important to set up a clear framework on what it actually going to be analysed and why. It was agreed within P901 to design a template for the investment projects. The template is completed (one document for each investment projects) and gives information on the objectives, key questions to be answered, expected results, technology description etc. In the following, the investment project template is presented.

Investment project template

The Investment projects are identified by:

1. Title
2. Objectives
3. Strategic importance of the investment projects.
4. Technical alternatives (e.g. HFC (hybrid fibre coaxial) network compared to twisted-pair copper and DSL (digital subscriber line))
5. Description of the technical alternatives in terms of architecture characteristics and network dimensioning rules. A coarse granularity would be preferred wherever possible.
6. Services offered by alternative technical solutions. If for example the business case selected has the broad title Wireless Internet Access, the services offered by UMTS and LMDS it is interesting to know which services are available in the two different technical solutions and which services are common.
7. SWOT (strengths, weaknesses, opportunities and threats) analysis. Opportunities and threats are related to external factors such as competition and regulatory issues such as cost of spectrum and USO (universal service obligation).

Candidate investment projects

The candidate investment projects are described using the template. The investment projects that are actually going to be analysed in the P901 project will be selected based on a number of criteria listed in section 3.4.

UMTS (universal mobile telephony system)

The proposed investment projects will study the economic viability of UMTS (universal mobile telecommunication system) services and networks across the European Telecommunication Operators.

Objectives

- The goal might be to clarify in which circumstances it will be profitable for an operator to offer UMTS services and to gain more understanding of the associated risks. The possibility that the introduction of UMTS onto the world scene could require large number of present users to abandon their existing systems to take up an entirely new services should investigate with caution. That seems quite unlike, especially since the incremental cost of adding additional
features to an existing system has almost been lower than the life cycle cost of introducing an entirely new system.

- The identification of the service basket that could be offered to customers and how should an operator prioritise which ones to provide first.

- The identification of different technological scenarios (solutions) should be done since the UMTS technology isn’t mature enough. So the alternatives must be recorded before the final selection of an optimum compatible architecture as well as what new technologies are likely to be introduced over the next five years that an operator could invest on.

- Several issues, such as spectrum availability and capacity should be studied.

**Strategic importance of the investment project**

The strategic importance of this business case arises from the evolution of the mobile market. The mobile market is grown very fast and the technology evolution must be investigated. A recent forecast by Allied Business Intelligence (ABI) suggests that there could be more than 670 millions wireless subscribers around the world by 2002.

Nowadays an open issue, both from the technical and economic points of view, is to identify the requirements and the necessary steps to migrate from GSM to UMTS. The main issue for the incumbent operator is to identify economical viable technological solutions to migrate his existing GSM (global system for mobile communication) customers and the new “mobile broadband customers” towards UMTS. The reuse of network elements is a crucial part of this investment. The definition of a profitable path, which allows his existing system to migrate towards UMTS, but at the same time demonstrating lower maintenance cost and improved services could be the aim of the case study. In addition to that the provision of guidelines for the investment policy during the next five years is the most important issue into the competitive environment.

Following the relaxation of regulatory constraints, a number of PNO’s will be offering both fixed and mobile services to their customers. Mobile services will be offered through a variety of technologies including GPRS, EDGE, HSCSD, BRAN, TIPHON and UMTS.

**Fixed Mobile Convergence**

**Objectives**

The goal of the investment project is to offer new services based on mobile and fixed convergence. The convergence is both service-wise and network-wise, and will be based on the Intelligent Network (IN) features.

The first step of the project is to achieve “convergence” using two separate intelligent networks. One of these is the master where are implemented Fixed and Mobile convergence logical services. The second step will be to verify the convenience of the introduction of a unique intelligent network for Fixed and Mobile networks.

An economic evaluation of the impact on networks of fixed-mobile convergence based services is necessary to understand revenues, costs and risks. Some of the variables concerning the project (i.e. the starting date for the convergence) could also deal with risk analysis.
Strategic importance of the investment project

Interest and demand for convergent solution affecting fixed and mobile services has grown recently due to the liberalisation regime and the levels of competition among operators. Symptoms of the convergent approach are evident in fact fixed network operators are already now implementing wireless access solutions, in order to expand (or maintain) their penetration into market segments. Mobile operators, on the other hand, are extensively adopting fixed network-like tariffs for the local mobility and Intelligent network in order to increase their capability in creating new services. In this scenario a generic telecommunication operator who owns both Fixed and Mobile networks will achieve a strategic position only if it is able to offer a complete set of services, including fixed-mobile ones. Only the fixed-mobile services will allow the Operator to gain from his competitive advantage of owning both the networks.

IP with or without ATM

This investment project will analyse the role of IP and ATM in the future competitive telecommunications market place.

Objectives

TelCos are facing an evolution where the existing service-specific networks like X25, FR, ISDN and GSM gradually are being replaced by a unified Full-Service Network (FSN). The key issue is the role played by IP and ATM in such a FSN. It is anticipated that IP, including both best-effort and prioritised services, will be of most importance for the end-users. For the network operator ATM is an attractive option to provide transport due to its flexibility and QoS support. The question is if there are any economical impacts of building a FSN with or without ATM. The objective of the proposed investment project is to give insight into this issue. Two alternative scenarios corresponding to an IP-oriented operator and an ATM-oriented operator are considered.

Strategic importance of the investment project

Provisioning of high-quality IP-services is essential for TelCos to generate revenue in the new world. Further, the deployment of a FSN represents a huge investments for a telco having large economical impacts. Hence, it is important to decide from an economical perspective if ATM should be used for provisioning of IP-services in a FSN.

IP over WDM

Objectives

Several choices have been thought for simplifying the whole protocol stack (IP/ATM/SDH/WDM) that may be found in the transport network when carrying IP traffic. The need for the intermediate levels (ATM and SDH) is being questioned; then, simpler solutions, such as MPLS, Diff-Serv or DPT, are proposed. The drop of such levels reduces the complexity, and hence the cost, of the equipment.

In this investment project, the different alternatives for offering IP services over the transport network by using WDM techniques will be analysed.
Strategic importance of the investment project

Data traffic (mainly IP / Internet) is growing exponentially and becoming one of the more important source of revenues for the PNOs. It is expected for the data traffic to be bigger that the voice one in few years from now. At this moment, most of the transport networks are designed for carrying voice traffic (PDH and SDH based) and WDM is being installed as a way for reducing the cost per transmitted bit by using in a more efficient way the installed infrastructure. The protocol stack in the transport network is becoming quite complicated and not adapted to the IP traffic.

In the present liberalised market, PNOs need to be as much efficient as possible; then, the search for simple, but enough versatile, solutions for carrying IP traffic in the transport network becomes crucial for the PNOs.

Advanced access networks

Objectives

To offer broadband services to business as well as residential customers. Due to the high costs of the civil works, the current infrastructure is a serious constraint for the telecom operator. The incumbent operators are faced with increased competition and a resulting decrease in market share of existing services. In order to be able to offer new broadband services, an upgrade of the existing network is necessary.

Three different groups of advanced access networks are treated:

- xDSL upgrade by the incumbent operator
- HFC network upgrade by the cable operator
- Wireless Local Loop by new operators.

ATM services over transit networks

ATM services with multiple QoS classes are expected to gain increasing interest in over the next few years for the business segment.

1 In fact, BT has announced that at the end of 1998 transports more data traffic than voice one.
Objectives

Market issues show strong development of data transmission demand.
We prepare a detailed analysis for examination the adequate investment.
New service providers are to enter the market very soon.

Strategic importance of the investment project

Development of modern transit networks and service packages are needed to satisfy future customer requirements.
Market surveys show that transmission in speed range of 2-155 Mbit/s is highly spoken for.

Mapping the proposed investment projects on the layered architecture

Figure 10 shows a mapping of the proposed investment projects on the layered architecture. The figure shows clearly the different focus of the proposed investment projects. Below four main factors are listed which should characterise the selected business cases for further study in the P901 Project.

The selected investment projects in P901 should:

- focus on an important strategic issue for a typical European PNO (public network operator)
- have large economical impact for a PNO.
- demonstrate the new methodology developed in the project.
- be easy to implement through a top-down approach.
Selection criteria

After the first round, where the project partners have given their proposals to the investment projects to be analysed, a second round will deal with the selection.

The selection is based on the following criteria:

- Consensus between partners: If a majority of partners agree on a certain investment project; a so-called “hot topic”

- Existence of relevant projects, that can deliver results as inputs to the business cases within the timeframe of the P901 Project (important milestones such as deliverables)

- The necessary planning and dimensioning tools are available for the analyses. IP traffic has a far more complex (read fractal or chaotic) behaviour than traditional circuit-switched traffic.
Collaboration with other projects

Specific network dimensioning issues, mobility, fixed-mobile convergence, IP over optical networks and other “hot issues” are covered in detail in other projects within EURESCOM, ACTS (advanced communication technologies and services) and The Fifth Framework Program. The P901 Project will make use of the results from other projects where appropriate. The collaboration projects will of course depend on the investment projects that are selected in P901 as well as the time frame of these projects – when will there be results available that we can use as inputs to the business case analyses?

A first selection of collaboration projects is based on the topics covered in the business cases to be analysed in P901. The second step in the selection process is based on the match between the time schedule of P901 and the milestones (of collaboration projects). There could be many different levels of collaboration ranging from reading deliverables only, to a more formal contact between the projects. In case of formal collaboration, the collaboration project is likely to expect results and guidelines from P901. In the following, a number of relevant collaboration projects will be listed. The scope and relevance for P901 is described.

ACTS 364 TERA

The project TERA (Techno-economic Results from ACTS) [17] is a horizontal project within ACTS. The main objective of this project is to support consolidation, condensing and rationalising of deployment guidelines for introduction of advanced services and networks. This horizontal action will be achieved by performing techno-economic evaluations of the outputs from ACTS projects and field trials. The project applies the techno-economic methodology and tool developed in the previous project ACTS 226 OPTIMUM (Optimised Network Architectures for Multimedia Services), which is now widely accepted within the ACTS community and EURESCOM as the state-of-the-art approach for techno-economic evaluations of multimedia communication services and networks. In OPTIMUM project, a methodology and framework on risk assessment was developed. The risk methodology is being extended and further developed within the TERA project. The risk assessment methodology handles the uncertainty of cost evolution, market share, service demand and tariffs.

TERA has collaborate with EURESCOM P614 in risk assessment the economics of broadband access network evolutionary paths.

The following issues of TERA is of relevance to P901:

- Cost evolution of network components
- OA&M modelling
- TERA cost database (collaboration/co-ordination between TERA and EURESCOM P816)
- Lost market share model
- Monte Carlo simulation approach and TERA risk framework
- Business cases: UMTS and Fibre Access Evolution. These business cases are expected to deliver inputs to the P901 Investment Projects “UMTS” and
“Advanced Access Networks”. These inputs include dimensioning rules of networks, demand modelling and costs of network components.

The various inputs from TERA on cost modelling, risk and network dimensioning will be incorporated in the P901 framework where appropriate and put together in a new context to in order fit with the new methodologies being developed in P901.


An important milestone within TERA is the Deliverable 7 (November 1999) which contains the results of the business case evaluations.

**Summary of relevant workpackages/Tasks/PIRs**

TERA will be able to deliver input to the following investment projects given in section 3.2: UMTS and Advanced Access Networks.

These to areas are covered in Deliverable 7 of TERA titled “Techno-economic results of ACTS field trials” due 30th November, 1999.

The business cases evaluations are done by Work Package 1

In the UMTS case study (business case is the term used in TERA), the services, network migration paths, and architectures are defined. Techno-economic assessment including risk and externality effects are carried out. This business case will therefore provide a good starting point for the UMTS investment project in P901.

Another case study being assessed in TERA is “Fibre Access Evolution” Three different solutions are investigated and compared:

- FSAN (Full Service Access Networks)
- ACTS 038 BBL “BroadbandLoop” [18]
- ACTS 349 PRISMA “Photonic Routing of Interactive Services for Mobile applications” [19]

Also in this case, a lot of work on service definitions, area and customer framework and network dimensioning has been conducted.

Due to the fact that the TERA business case evaluations are complete by Nov. 1999, the timing is well-matched to the investment project analyses of P901. In addition, a formal collaboration with TERA exists.

Work Package 3 have the following subtasks:

3.1 Market watch
3.2 Externality effects
3.3 Risk analysis

An exchange of ideas between WP 3 in TERA and P901 is highly relevant. The externality effect models developed by TERA could be implemented at a later stage in the investment project defined by P901 and using the new P901 methodologies.
EURESCOM P918

EURESCOM P918 “Integration of IP over Optical Networks: Networking and Management” is a relevant collaboration project for the assessments in Task 4 dealing with IP/ATM and backbone network issues.

P918 aims to make progress in the definition of the transport network scenarios with particular reference to the distribution of the network functionality across the different layers (ATM, PDH, SDH, IP and WDM) composing a transport network.

Summarising the objectives from P918, the following activities and sources of input relevant to the investment project assessments of P901:

- An overview on IP protocols and routers, technologies, products maturity and costs
- Definition of transport network alternative approaches assessing IP, ATM, SDH and WDM inter-networking
- The architectures/protocol stacks defined within P918: IP over WDM via:
  1. ATM/SDH (reference)
  2. DTP (Dynamic Transfer Protocol; proposal from Cisco)
  3. MPLS (Multi Protocol Label Switching)

Deliverables 1 (“IP over WDM, transport and routing”) and 2 (Network scenarios for IP over optical networks”) are considered relevant and valuable sources of information concerning topology description and network dimensioning of future transport networks. The project ends in March 2000. The timing of the milestones within P918 are matched to the work-plan of P901, i.e. necessary inputs can be expected in time.

Summary of relevant workpackages/Tasks/PIRs

The work of technical Tasks 2, 3 and 4 (with PIR 4.3 as the only exception) are to be completed by December 1999. This means, that the necessary background information would be available for the IP over WDM investment project in P901. Below, a summary of the relevant P918 Tasks and their PIRs are listed together with planned start and end dates.

Summary of relevant workpackages/tasks/PIRs

<table>
<thead>
<tr>
<th>Task 2</th>
<th>“WDM bearer services for IP”</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIR 2.1</td>
<td>“IP protocols and high capacity routers”</td>
</tr>
<tr>
<td>Start date: 1/1/1999</td>
<td>End date: 7/5/1999</td>
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</tbody>
</table>

The PIR will give an overview of the state-of-the-art of IP related protocols, software, high-speed routers and high-speed physical interfaces.

<table>
<thead>
<tr>
<th>PIR 2.2</th>
<th>“IP routing and WDM high pipe cross-connection”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start date: 1/1/1999</td>
<td>End date: 7/5/1999</td>
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</table>
A survey of methods for IP over WDM end-to-end communication is carried out covering aspects such as QoS, optical cross-connection and routing as well as requirements to restoration and protection in optical networks, will be carried out.

**Task 3**  
"IP and transport network scenarios"

<table>
<thead>
<tr>
<th>PIR 3.1</th>
<th>“IP and transport network scenarios”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start date: 1/3/1999</td>
<td>End date: 31/8/1999</td>
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</table>

The PIR deals with the analysis of the requirements for future IP-based architectures and technologies with special focus on the functional and performance requirements from the user end-to-end perspective. Particular attention should be given to the provision of IP services with the appropriate level of interworking over different network domains. The IP client layer poses different constraints on the optical network architectures than more conventional technologies.

<table>
<thead>
<tr>
<th>PIR 3.2</th>
<th>“Assessment of IP network scenarios”</th>
</tr>
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<tbody>
<tr>
<td>Start date: 1/6/1999</td>
<td>End date: 30/11/1999</td>
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</tbody>
</table>

**PIR 3.2** will address topics related to network topologies, network hierarchy, migration from present networks to an IP backbone and business risks and opportunities with the introduction of the new alternatives to carry IP traffic.

**Task 4**  
“Optical network management"

<table>
<thead>
<tr>
<th>PIR 4.1</th>
<th>“Optical transport network management requirements”</th>
</tr>
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<tbody>
<tr>
<td>Start date: 15/2/1999</td>
<td>End date: 30/7/1999</td>
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The main objective of this PIR is to define the requirements for the management of an optical network.

<table>
<thead>
<tr>
<th>PIR 4.2</th>
<th>“Definition and overhead of overhead information”</th>
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<tbody>
<tr>
<td>Start date: 1/5/1999</td>
<td>End date: 30/9/1999</td>
</tr>
</tbody>
</table>

The objectives of this PIR are to define the overhead (OA&M signals) and its relationship to the management of an optical transport network

P901 will use the selected architectures and topologies from P918, Task 2 and PIR 3.1. Extended investment analyses of the scenarios defined in P918, PIR 3.2 will be carried out in P901, PIR 4.1 using the new methodologies in P901, Task 3. A true collaboration on the cost issues and business risks would be beneficial for both projects.

**EURESCOM P919**

EURESCOM P919 “Evaluation of Integrated Fixed and Mobile Networks” is a relevant collaboration project for the assessments in Task 4 of P901 dealing with Fixed-Mobile Convergence. The main objectives of P919 which are of relevance to P901 are:
• Identify converged services (not already covered by P809)
• Identify the infrastructure requirements for converged services
• Identify the commonalities of various fixed and mobile networks
• Propose potential architectures and topologies for integrated networks
• Devise a framework to assess each architecture and topology in terms of desirability from the network operator perspective
• Identify the preferred architecture(s) and topologies from the network operator perspective
• Propose an evolution path towards the identified architectures and topologies

The planned deliverables are:
• Deliverable 1 “Recommended Strategies for FMI” (March 2000)
• Deliverable 2 “Framework for Fixed and Mobile Networks Integration Testing” (March 2000)

of which Deliverable 1 is of relevance to P901. However, the date is quite late in time, therefore it is recommended to follow more closely the work being done in P919 and establish a more formal contact by partners participating in both P901 and P919.

Summary of relevant workpackages/Tasks/PIRs

The following PIRs inside P919 are relevant for the FMI investment project in P901 and fit the timeframe of Task 4 of P901, as they are planned to end no later than January 31st, 1999:

**Task 2 “Evaluation of Integrated Fixed / Mobile Networks”**

<table>
<thead>
<tr>
<th>PIR 2.1</th>
<th>“Identification of integrated fixed/mobile services”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start date: 1/4/1999</td>
<td>End date: 30/6/1999</td>
</tr>
</tbody>
</table>

This PIR will identify services and applications for fixed/mobile convergence/integration and will develop the service requirements identified by P809 more thoroughly.

<table>
<thead>
<tr>
<th>PIR 2.2</th>
<th>“Identification of integrated network architectures and topologies”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start date: 1/4/1999</td>
<td>End date: 31/7/1999</td>
</tr>
</tbody>
</table>

This PIR will develop a family of architectures and topologies for integrated fixed/mobile networks. These will form the basis for the evaluation of evolution scenarios towards a target system. Topologies will include cellular, cordless and wired access to integrated networks.

<table>
<thead>
<tr>
<th>PIR 2.3</th>
<th>“Evaluation criteria”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start date: 1/5/1999</td>
<td>End date: 15/9/1999</td>
</tr>
</tbody>
</table>
This PIR will describe the methodology and criteria to be used in the evaluation of network architectures described in PIR 2.2.

<table>
<thead>
<tr>
<th>PIR 2.4</th>
<th>“Evaluation of evolution to target architectures”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start date: 1/9/1999</td>
<td>End date: 31/1/2000</td>
</tr>
</tbody>
</table>

This PIR will perform evaluation of the integrated fixed/mobile architectural scenarios identified in PIR 2.2 against the criteria identified in PIR 2.3 and document the results.

The match between the calendars of P901 and P919 should therefore make it possible to provide the necessary input for assessment of an FMI investment project in P901.
References


17. ACTS project AC364 TERA, “Techno-economic Results from ACTS” http://www.uk.infowin.org/ACTS/RUS/PROJECTS/ac364.htm

18. ACTS project AC038 BBL, “BroadbandLoop” http://www.uk.infowin.org/ACTS/RUS/PROJECTS/ac038.htm

19. ACTS project AC349 PRISMA, “Photonic Routing of Interactive Services for mobile Applications” http://www.uk.infowin.org/ACTS/RUS/PROJECTS/ac349.htm
Annex B: Methodologies and Tools Review

1 Methodologies Survey

Introduction - Framework for the provision of this work

The purpose of this chapter is to provide guidelines for the Methodology approaches that will be further presented in detail in Deliverable 2. A literature survey has been done in order to provide the most important issues that influence the Investment Strategy of a Telecommunication Operator. For the provision of this work a large list of references has been created and specific topics have been assigned among the EURESCOM participants in the P901 Project.

The aim of this part is to examine all the possible issues and approaches of an investment project and to present the alternatives methodologies found in the literature. The provision of guidelines and recommendations for the future uses of the methods is one of the main objectives of the literature study and specific. This chapter presents the investment criteria and the objectives for an investments analysis, dimensioning methods for telecommunication networks, market-modelling approaches for the service demand prolepsis, incremental basis costing methods and the concept of Real Options Theory.

Investment Analysis The Economist View

Introduction

This section presents general investment analysis concepts from an economist point of view.

The investment criteria and the objectives in investments analysis will be analysed with the following order:

1. Investments Decisions Criteria
2. Capital Rationing
3. Cash Flows on an Incremental Basis
4. Closure on Cash Flows
5. Value and the Risk – Return Trade – Off
6. Capital Asset Pricing Model
7. The Cost of Capital
8. Techniques to measure Project Risk

Investment Decisions Criteria

- Accounting rate of return
- Economic Value Added (EVA)
- Payback
• Net Present Value (NPV)
• Internal Rate of Return (IRR)
• Profitability Index (PI)

**Accounting Rate Of Return**

Accounting rate of return or book rate of return is the Average forecasted earnings before interest and after taxes over the life of the project divided by Avg. book value of total investment in the project.

Decision criteria:
If the accounting rate of return > Cost of Capital then we accept the project
If the accounting rate of return < Cost of Capital then we reject the project

It is compared with the book rate of return for the firm as a whole or against some external yardstick (such as the industry)

Advantages:
• It is a simple and intuitive measure of the profitability of a project.

Disadvantages:
• It is based on accounting income not the Cash Flows of the project. Operating income can either lag or be very different from the cash flows generated by the project. Furthermore, changing depreciation methods and inventory costing may lead to changes in operating income and the return to capital, even though the underlying cash flows might be unaffected.
• There are some expenses, such as R&D, that accountants treat as operating expenses. Reducing operating income due to these expenses is in a sense unfair to the assets in place, since they do not benefit from these expenses. It is more appropriate to consider these expenses as capital expenditure, capitalising them instead.
• The book value may not be a very good measure of the investment in the project, especially over time when accounting depreciation advances faster from economic depreciation (the true reduction in the value of a physical asset), since accounting depreciation reduces the book value of the investment and increases the accounting rate of return.
• Finally, there is no allowance for the fact that profits made in the early years of the project are more valuable than those made in later years.

**Economic Value Added (EVA)**

EVA is a measure of dollar surplus value (excess return), not the percentage difference in returns. It is closest in both theory and construct to the net present value of a project in capital budgeting, as opposed to the IRR.

\[ \text{EVA} = (\text{Return on Capital} - \text{Cost of Capital}) \cdot (\text{Capital Invested in Project}) \]

The return on capital is measured using “adjusted” operating income, where the adjustments eliminate items that are unrelated to existing investments, and where the
capital investment is based upon the book value of capital but is designed to measure the capital invested in existing assets.

Decision criteria:
A project is accepted when its EVA is greater than zero.
Firms which have positive EVA are firms which are creating surplus value, and firms with negative EVA are destroying value.

Firm Value = Capital Invested in Assets in Place + PV of EVA from Assets in Place + Sum of PV of EVA from new projects

Advantages:
• EVA is closely related to NPV. It is closest in spirit to corporate finance theory that argues that the value of the firm will increase if you take positive NPV projects.
• It avoids the problems associated with approaches that focus on percentage spreads - between ROE and Cost of Equity and ROC and Cost of Capital. These approaches may lead firms with high ROE and ROC to turn away good projects to avoid lowering their percentage spreads.
• It makes top managers responsible for a measure that they have more control over - the return on capital and the cost of capital are affected by their decisions - rather than one that they feel they cannot control as well - the market price per share.
• It is influenced by all of the decisions that managers have to make within a firm - the investment decisions and dividend decisions affect the return on capital (the dividend decisions affect it indirectly through the cash balance) and the financing decision affects the cost of capital.
• It is a method of measuring value that is simple to be used.

Disadvantages:
• It shares the same disadvantage as the accounting rate of return.

**Payback Method**

The payback period, also called pay off period, is defined as the length of time required to cover the initial investment outlay through the accumulated net cash flows earned by the project.

A maximum acceptable payback period is typically set as the assessment criterion. Projects that pay back their initial investment sooner than this maximum are accepted, while projects that do not are rejected.

Payback period is much more likely to be used as a secondary investment decision rule.

Advantages:
• Easy and inexpensive to calculate & apply.
• Provides a measure of project liquidity (how fast the cash outlays will be returned).
• An indicator of the relative risk of projects since the later CFs are riskier to forecast.
Disadvantages:

- Ignores CFs beyond the payback point.
- Ignores the time value of money.
- When the investment is spread out over time or when there is no initial investment the rule breaks down.

An alternative version of the payback method is the breakeven time. It is defined as the period required for the cumulative cash inflows on a project to equal the cumulative cash outflows (usually the initial cost). It is the time necessary for the present value of the cash flows to equal zero.

**Discounted Cash Flow Measures Of Return**

**Net Present Value (NPV)**

The Net Present Value of a project is defined as the value obtained by discounting at a constant interest rate and separately for each year, the difference of all annual cash outflows and inflows accruing throughout the life of a project.

Decision rule:

- Accept if NPV > 0
- Reject if NPV < 0

Advantages:

- The NPVs are additive. The NPVs of individual projects can be aggregated to arrive at a cumulative net present value for a business or a division. No other investment decision rule has this property.
- Intermediate cash flows are invested at the hurdle rate, which is the cost of capital. The hurdle rate is the minimum acceptable rate of return that a firm will accept for taking on a given project.
- The NPV can be computed using time-varying discount rates.

Disadvantages:

- You have first to calculate the opportunity cost of capital (discount rate) that may be a difficult and time-consuming process.
- NPV favours larger projects whereas smaller ones inherently have less risk.
- When evaluating a project within different organisations there will be different opportunity cost of capital.

**Internal Rate Of Return (IRR)**

It is that discount rate that makes the net present value of a project equal to zero.

Decision rule:

- If the IRR is greater than the discount rate (required return) then the project is accepted.
- If the IRR is lower than the discount rate then the project is rejected.

Advantages:

- It is easy to understand and implement.
• It may be used in cases when the discount rate is not known.
• It is a rate of ratio, not an absolute amount, and thus more useful for comparing unlike investments.

Disadvantages:
• If there is more than one change in the sign of the CFs there may be multiple IRRs or no IRR at all.
• The IRR rule requires to compare the project’s IRR with the opportunity cost of capital. When the opportunity cost of capital is not the same for different periods then there is not a simple yardstick for evaluating the IRR of a project.
• Since the IRR is a percent return measure, it tends to bias decision makers toward smaller projects, which are much more likely to yield high percentage returns, over larger ones. Additionally, when the examined projects are mutually exclusive then the NPV is a better decision criteria.
• The IRR rule assumes that intermediate CFs on the project get reinvested at the IRR. When the IRR is high and the project’s life is long, then the IRR will overstate the true return on the project.

Profitability Index (PI)

The profitability index is the present value of the project's cash flows divided by the initial investment in the project.

When funds are limited, this rule offers the highest net present value per dollar of initial outlay and facilitates comparison of investments of different size.

While NPV measures success in absolute terms PI is a relative measure.

Decision rule:
Accept project when IP > 1
Reject project when IP < 1

Capital Rationing

• If a business has limited access to capital, has a stream of surplus value projects and faces more uncertainty in its projects cash flows, it is more likely to use IRR or PI as its decision rule.
• If a business has substantial funds on hand, access to capital, limited surplus value projects and more certainty on its project cash flows, it is more likely to use NPV.

One source of capital rationing arises from the fact that firms cannot always raise funds for investments from capital markets due to the imperfections of those markets.

While capital market imperfections are one source of capital rationing it is more common for the firm to face a capital rationing situation because the firm itself choose to limit the amount of investment which it will undertake. When funds are limited we must pick projects that offer the highest NPV per dollar of initial outlay.
Cash Flows On An Incremental Basis

The objective in investment analysis is to maximise the value of the firm taking the investment. Consequently, it is the cash flows that an investment will add on in the future to the firm that we should focus on.

Incremental costs are the change in the firm’s total cash flows that occur as a direct result of accepting or rejecting the project.

Some of the reasons that may make the incremental cash flows on a project to be different from total costs are the following:

- Incidental effects on the remainder of the business.
- Opportunity costs.
- Allocated overhead costs.
- Sunk costs
- Working Capital requirements

Incidental effects on the remainder of the business

Product cannibalisation

It refers to the phenomenon whereby a new product introduced competes with and reduces sales of the firm’s existing products. If the business in which the firm is going to operate under the new project is extremely competitive, it can be assumed that product cannibalisation will occur anyway, and the costs associated with it have no place in an incremental cash flow analysis.

If a competitor cannot introduce a substitute, because of legal restrictions, the cash flows lost as a consequence of product cannibalisation belong in the investment analysis at least for the period of the legal protection.

Project synergy

It is the increase in cash flows that occurs to other projects, as a consequence of the project into consideration.

Opportunity costs

They are the CFs that could be generated from assets the firm already owns if they are not used for the project in question.

For example a specific asset could be rented, sold or used elsewhere in the firm. The lost rental revenue, the forgone net sales price or the cost of replacing the asset could be the opportunity cost. This type of cost should be taken into account in the incremental cash flow methodology.

Allocated costs

They are those costs that are not directly traceable to revenues generated by individual projects but are allocated across these projects, based upon revenues, profits or assets. Such costs could be administration, rent, heat, light etc.
These costs may not be related to any particular project, but need to be paid. According to the incremental cost principle, only the extra expenses that result from the project should be included.

**Sunk costs**

Any expenditure that has already been incurred, and cannot be recovered (even if a project is rejected) is called a sunk cost.

When analysing a project, sunk costs should not be considered since they are not incremental.

Market testing expenses and R&D expenses are both likely to be sunk costs before the projects that are based upon them are analysed.

**Net Working Capital**

It is defined as current assets (cash, marketable securities, accounts receivable, inventories) minus current liabilities (accounts payable)

Funds that cannot be used elsewhere in the firm

Any increase of working capital corresponds to a cash outflow to be financed and any decrease to a cash inflow that sets free financial resources

In working capital is included the cash that is necessary for the day-to-day operations of the firm. Any cash beyond this should not be considered since it is not a cash outflow.

When calculating the working capital requirements, the minimum coverage of days for current assets and liabilities has to be determined first.

\[
\text{Accounts receivable} = \text{credit sales per day} \times \text{length of collection period} \\
\text{Accounts payable} = \text{cost of goods sold} \times \text{days in accounts payable}
\]

**Closure On Cash Flows**

- In a project with a finite and short life, you would need to compute a **salvage value**, which is the expected proceeds from selling all of the investment in the project at the end of the project life. It is usually set equal to book value of fixed assets and working capital.

- In a project with an infinite or very long life, we compute cash flows for a reasonable period, and then compute a **terminal value** for this project, which is the present value of all cash flows that occur after the estimation period ends.

**Terminal Value**

It should be estimated in a period not far away in the future and in a time that we estimate that the growth rate will be constant.

In such case:

\[
\text{terminal value} = \frac{\text{FCFF}_n + 1}{\text{WACC}_n + 1 - \text{gn}}
\]
FCFF = free cash flow before financing activities

If in that time the expected RoC is equal to the WACC then the terminal value is equal to

$$\text{terminal value} = \frac{\text{EBIT}_n + 1(1-T)}{\text{WACC}_n + 1}$$

$$g = \text{growth rate of cash flows} = \text{reinvestment rate} \times \text{ROC}$$

Reinvestment rate = \frac{\text{Capex - Depreciation} + \Delta \text{WorkingCapital}}{\text{EBIT}(1-T)}

FCFF = EBIT(1-T) - (\text{Capex - Depr + } \Delta \text{WC})

Another way for estimating the project’s terminal value at the end of the forecast period is by reference to the multiple of earnings before interest, tax, depreciation and amortisation (EBITDA). For matured telecommunications companies the ratio Enterprise value divided by EBITDA is estimated today at 7.

**Value And The Risk - Return Trade-Off**

- The value of a project depends on:
  - the expected future cash flows
  - the cost of capital
- An increase in the expected future cash flows will increase value only if there is not an offsetting increase in risk. The increase in risk will increase the project’s cost of capital. A sufficiently large increase in the cost of capital, can offset the positive effect of the increase in expected future cash flows.

**Risk**

- The risk is defined as the variance in actual returns around an expected return.
- Risk has to be measured from the perspective of the marginal investor in an asset who is well-diversified.
- Only the risk that an investment adds on to a diversified portfolio should be measured and compensated.
- There is a firm specific component of risk that relates only to that investment or to a few investments like this and a market component that contains risk that affects a large subset or all investments.
- It is the latter risk that it is not diversifiable and should be considered.

**Risk Types**

- The risk -variance on any individual investment can be broken down into two sources. Some is specific to the firm and is called firm-specific, whereas the rest is market wide and affects all investments.
- The categories of risks a firm is faced are: Project-specific, Competitive, Industry-specific, International, Market.
Project-specific: This is the risk that affects only the project under consideration and may arise from factors specific to the project or estimation error. When firms take on a large number of similar projects, it can be argued that much of this risk could be diversified away.

Competitive: The earnings and CFs on a project can be affected by the actions of competitors. Although in project analysis this factor is taken into consideration, the actual actions taken by competitors may differ from the expectations.

Industry-specific: Factors that primarily impact the earnings and CFs of a specific industry. There are three categories: 1) Technology risk, which reflects the effects of technologies changes different than those expected. 2) Legal risk, which reflects the effects of changing laws and regulations. 3) Commodity risk, which reflects the effects of price changes in commodities and services.

International: The additional uncertainty created in cash flows of projects by unanticipated changes in exchange rates and by political risk in foreign markets.

Market: The effect on earnings and CFs of macroeconomic factors that essentially affect all companies and all projects, such as changes in interest rates, inflation rates, and economic growth.

The Effects Of Diversification

- Firm-specific risk can be reduced, if not eliminated, by increasing the number of investments in your portfolio. This can be justified on either economic or statistical grounds.

- On economic grounds diversifying and holding a larger portfolio eliminates firm-specific risk for two reasons:
  1. Each investment is a much smaller percentage of the portfolio, muting the effect on it.
  2. Firm-specific actions can be either positive or negative. In a large portfolio these effects will average zero.

Capital Asset Pricing Model (CAPM)

- The risk of any investment is the risk added on by this investment to the investor’s overall portfolio that is the ‘market portfolio’

- The expected return from the model is:
  \[ r_j = r_f + \beta_j \cdot (r_m - r_f) \]
  where
  \[ r_j = \text{cost of capital for project } j \]
  \[ r_f = \text{riskless rate of return} \]
  \[ r_m = \text{required return on the market portfolio} \]
  \[ \beta_j = \text{beta of project } j \]

Assumptions:
The marginal investor holds a well diversified portfolio (it includes every traded asset).
Investors adjust their risk preferences in their allocation decisions, by deciding how much to invest in a risk free asset and how much in the market portfolio.

There are no transaction costs.

There is no inside information.

All assets are traded, and investments are infinitely divisible.

In this model two types of risk are identified:

Systematic or undiversifiable or market risk and unsystematic or diversifiable risk

The reason why the distinction between the two types of risk is important is that one of the types of risk, unsystematic risk, can be avoided fairly easy and at little almost zero cost, while the other type, systematic risk, cannot be avoided.

A factor which is of central importance to the application of CAPM is the beta coefficient of an asset.

The risk of any asset is the risk that adds to the market portfolio.

The risk can be measured by how much an asset moves with the market (called the covariance).

Beta is a measure of the non-diversifiable risk for any asset that can be measured by the covariance of its returns with returns on a market index

Limitations:

The model makes unrealistic assumptions

The parameters of the model cannot be estimated precisely.

The relationship between betas and returns is weak. Other variables (like size and price/book value) seem to explain differences in returns better.

Adjustment of beta to reflect total rather than market risk.

\[
\text{Total beta} = \frac{\text{Market beta}}{\frac{R^2}{\sqrt{1-R^2}}}
\]

\(R^2\) is the proportion of the risk that is market risk.

A new approach, the TFM theory (Three Factor Model) includes two more factors except than market premium for cost of equity calculation:

Size = market value of equity relative to the average

Distress = ratio of market value to book value of equity

The explanation why the above model captures abnormal returns in excess of market risk premium is the existence of real options possessed by small and/or distressed companies.

CAPM, regardless its previous reported limitations and alternations, still remains the most effective way of dealing with risk in modern corporate finance.

**Capital Budgeting & Risk**

- If the project has the same market risk (beta) as the co’s (companies) existing assets then the required return is equal to the co’s cost of capital.
• For projects that are riskier or safer than the co’s existing assets then the required project return on equity is equal to:

$$r_f + \beta_j \cdot (r_m - r_f)$$

and the project’s cost of capital equal to:

$$\text{re(project)} \cdot \frac{E}{E+D} + \text{rd} \cdot (1 - T) \cdot \frac{D}{E+D}$$

where:
E= Equity
D= Debt
T= Marginal tax rate
re= cost of equity
rd= cost of debt

**Measuring Beta**

• If the asset is publicly traded the **beta** is estimated by:
  • Regression using historical price data.

• If the asset is not traded the **beta** is estimated by using:
  • Comparable firms To estimate the betas of comparable firms you must adjust them for the differences in capital structure by using the following formula:

$$\beta_{unlevered} = \frac{\beta_{levered}}{1 + (1 - T) \cdot \frac{D}{E}}$$

  • Accounting earnings. Accounting beta is estimated by regressing the company’s changes in profits against the market’s changes in profits.
  • By examining the determinants of assets beta (cyclicity and type of business, operating and financial leverage, relative volatility)

$$\text{Operating leverage} = \frac{\Delta \text{EBIT} / \text{EBIT} / \Delta Q/Q}{Q \cdot (P - V) / (P - V - F)}$$

Cyclical firms are those whose revenues and earnings are strongly dependent on the state of the business cycle (performance of the economy), and tend to have higher betas.

The beta increases as the firm’s financial leverage (proportion of debt in total capital) increases.

**The Cost of Capital**

• The **Cost of Capital** is the required return for a capital project.

• It is the opportunity cost of funds committed to the project.
• It is the rate of return at which investors are willing to provide financing for the project today.
• It reflects the risk of the project.

**The Weighted Average Cost of Capital**

• The Weighted Average Cost of Capital, WACC, is the weighted average rate of return required by the suppliers of capital for the firm’s investment project.
• The suppliers of capital will demand a rate of return that compensates them for the proportional risk they bear by investing in the project.

We assume that the debt-equity structure of the project will be similar to the optimal capital structure of the telecommunications operator that makes the project, or, if the project is independent, to the optimal capital structure of the project itself.

The WACC of the project should be adjusted for its riskiness if different from that (measured by Beta) of the existing business.

**WACC Calculation**

The WACC (Weighted Average Cost of Capital) provides an appropriate means by which to calculate the discount rate.

In general the WACC is given by the following formula:

\[
WACC = \frac{D}{V} \cdot rd + \frac{E}{V} \cdot re
\]

V: Value of company
D: Market value of debt capital
E: Market value of equity

There are three conditions if WACC is to be used:

1. The project under consideration must be marginal in the sense that it is of small size relative to the company as a whole.
2. The project should have the same level of risk.
3. The financing of the new project should not lead to a significant change in the capital structure of the firm. This is because it is possible that changing the capital structure will lead to a change in the WACC. For example as the capital structure changes, so do the weights attached to rd and re. As the level of debt in the company increases, equity holders face increased financial risk which will lead to demand a higher rate of return leading to a change in the WACC.

The weightings should be estimated in market values (if we use book values then the WACC will be underestimated). The cost of capital measures the cost of issuing securities, stocks, as well as bonds, to finance projects and these securities are issued at market not book value.

**Techniques to Measure Project Risk**

*Project or total risk* is the project’s risk viewed without consideration for the effects of the investors’ personal diversification.
It is the probability that the project will incur losses and may be destabilised.
Although, only beta risk affect the project’s cost of capital and value, the total risk matters and has to be taken into account for the following reasons:

1. Concerns undiversified investors
2. Even for diversified investors total risk may be as well as important in setting required returns.
3. Stability is important to customers, managers, workers, suppliers, creditors and also to the community. High corporate risk may increase the cost of financial distress.

There may be cases when increases in total risk make likely that a firm will end in a situation where it cannot take advantage of valuable projects.

The traditional approaches to dealing with uncertainty are:

**Sensitivity Analysis**

Sensitivity analysis can be used to determine how sensitive the profitability of the project is when a single factor, or specific group of factors, changes by a given amount. With sensitivity analysis each of the figures used in the NPV calculation is examined in turn to determine how variations from the estimated figures impact on the NPV.

It is useful in identifying what are the key drivers in a project.

Indicates how large the forecast error on a key driver can be tolerated, before the project becomes unacceptable. As a minimum requirement, each project evaluation should describe the effect of a wrong forecast in the factor judged most uncertain.

Advantages:

- Easy to implement and understand

Disadvantages:

- Ignores interdependencies among variables at a point in time, and over time.

**Scenario Analysis**

The manager takes a pessimistic and an optimistic view of the variables.

Disadvantages:

- There is not a clear way to reconcile, aggregate, or choose between scenarios.

**Break-Even Analysis**

How much sales the project must have to begin making money (NPV>=0). It helps to appreciate operating leverage (exposure to fixed assets).

**Monte-Carlo Simulation**

A tool for considering all possible combinations of all variables, after you specify the probability distributions of each of the determinants of the cash flows. The program will also incorporate details of how the variables are interrelated and when the cash
flows are likely to arise. The computer will reveal the expected cash flows in each year and the spread of them.

The required steps are:
1. Identify equations that specify relationships among variables.
2. Specify probability distributions of underlying variables.
3. Random draws from distributions; compute NPV.
4. Repeat steps 1, 2 and 3 many times. After a large number of simulations, accurate estimates of the probability distributions of the project's cash flows are obtained.

Advantages:
- Takes into account interdependencies among variables.

Disadvantages:
- Difficult to interpret a distribution of NPVs. A solution could be to assess the distribution of the net cash flows.
- Problems in specifying interdependencies in step 1.
- Cannot manage well asymmetries in the distributions introduced by management’s flexibility to revise its prior operating strategy as more information about project cash flows becomes available over time.

Decision Trees

Some large projects present a wide variety of alternatives with varying degrees of uncertainty. Under the decision trees analysis you consider not only the first accept-reject decision, but all the subsequent investment decisions by mapping out all the feasible managerial alternatives in response to future events that may be tied to them.

Advantages:
- Forces management to recognise its implied operating strategy and the interdependencies between the initial and subsequent decisions.

Disadvantages:
- The number of different paths on the tree increases geometrically.
- It relies on subjective assessments of probabilities, subjective discount rates, and preferences about the objective.
- The real options based approach circumvents the discount rate problem by constructing a risk free hedge.

Conclusions

- Cash flow based investment decision criteria produce better results than accounting earnings based ones. In capital budgeting the Net Working Capital requirements and the terminal value (when it exists) should be included in the cash flows estimations.
- NPV, IRR and PI are complementary ways of looking at a project.
The payback period can be used as a supplementary decision rule since it is a
good indicator of the riskiness of the project and the value of the option to defer.
For projects with short payback period the foregone revenues are high while the
benefits of delay are low. Consequently the value of a project’s option to delay is
an increasing function of the project’s payback period.

- The discount rate used in the analysis should be adjusted for the riskiness of the
project as measured by the beta coefficient (average of similar businesses).
For the WACC calculation the optimal capital structure of the industry (average)
should be used.
- Although in theory only the non-diversifiable risk is relevant, the project's total
risk should be considered as well.

Ways to dealing with uncertainty:
- Adjust the discount rate for the project’s beta.
- Modifying a DCF analysis with scenario analysis.
- But, each scenario remains fixed on a fixed future outcome & investment plan.
- There is no clear way to reconcile, aggregate, or choose between scenarios.
- Sensitivity analysis by using ranges to capture the values of the cash flows
helps to bound the uncertainty, but it does not help to incorporate into the
valuation the variance. Additionally it does not capture the flexibility
inherent in a situation.
- Simulation analysis lays out thousands of possible paths for the uncertain
variables. It is very difficult to handle decision opportunities that arise
before the final decision date, though.
- It is often hard to interpret the results of a simulation analysis because
simulation models use a subjective discount rate and do not incorporate
financial market information.
- When expenditures are at least partially irreversible, and managerial
decision flexibility is present, a traditional DCF analysis alone is not
adequate. The decision problem could be analysed using decision trees or
real options, with the later technique being superior.
- A firm should delay investing in a project until the NPV of the project is
sufficiently positive, with the determinants of this NPV being the volatility of the
project’s cash flows and the cash flows foregone by deferring investment.
- Investment opportunities usually have finite lives because of the threat of entry
by competitors, or the development of a new product.

Dimensioning methodologies

Introduction
This section includes information about the network dimensioning problems typically
present when a network is designed. These problems are not deeply treated in this
contribution so the dimensioning part is not the core part of the strategic evaluation of
the investment projects; then, it is nor in the main focus of the P901 Project. However, the dimensioning activity may not be absolutely dropped in the investment evaluation so the number of network elements to be costed should be calculated in some way, typically by using some simplistic dimensioning rules. According to that, this contribution mainly identify the typical problems and finally it presents a table linking the possible investment projects and the dimensioning problems to be taken into account in each one.

The dimensioning process is performed previously to the scenario costing and in an independent way; in this case, the dimensioning procedures should minimise the number of equipment and transmission infrastructure needed in the considered scenario. However, in some cases, the costing and dimensioning are linked together; in this case, the dimensioning algorithms use as target function the scenario costs.

The following figure presents the case where the dimensioning and costing activities are not performed together.

**Figure 11** The dimensioning step in the investment modelling process.

Typically, the inputs of the dimensioning activity are:

- **Demands to be served by the own network**: taken from the market modelling step and calculated according the competition conditions (own tariffs, other tariffs, externalities, …)

- **Location of customers, switching premises, existing infrastructure**: taken from the scenario definition.

- **Technology and implementation strategy**: taken from the scenario definition. The technology and the implementation strategy makes to appear some dimensioning rules to be fulfilled in the dimensioning process.

According to these inputs, the number and location of network elements (switching equipment and transmission infrastructure) in each period of the investment project life are calculated. By using these values and the corresponding cost database, the network to be installed may be costed separately. As previously stated, the costing
and dimensioning activities may be linked; typically for using the whole scenario cost as an harmonisation variable for taking into account with different weights the number of each type of elements.

### Dimensioning framework

The basic purpose of mobile and fixed telephone networks is to provide voice communication between their own customers and between these and the customers of other networks, in optimum conditions of quality and price. In other words, they must provide a system of communication that the customer perceives to be as efficient, simple, fast, reliable and cheap as possible.

Either type of network can be subdivided into the following subsystems: access network, switching and control subsystems, transmission network and operation

To achieve the objectives mentioned previously- simplicity, efficiency, quality and economy in a mobile network- work is required on each of the subsystems, as follows:

- **Access network**: adequate, properly planned coverage which makes allowance for the problems inherent in radio communication.

- **Transport network**: the reliability and economy of the service depends largely on how this subsystem is structured. Several network level may be found in this subsystem: purely transmission (PDH / SDH / WDM layer) and a service layer (ATM, circuit and packet switching level). Typically some kind of transmission layer should be present in each network, and one or several service layer may be present).

- **Switching and signalling network**: this must be endowed with a network structure that provides for adaptation to unforeseen changes and developments. The network design must be flexible, modular and above all reliable. A new aspect that it is becoming more important due to the liberalisation is the planning of the interconnection points with other network.

- **Other subsystems**: apart from the more operational-related network segments, other subsystems are present in the network: management, synchronisation, … The dimensioning aspects of this subsystem are not included so none of the potential investment projects to be studied in P901 are related with this part of the network.

The purpose of network planning is to determine which and how many elements of each subsystem should be used, how and where they should be deployed, and how they should be connected to achieve sufficient network quality and reliability at the lowest possible cost.

Typically, the network planning of each subsystem is performed separately due to the high complexity of the whole optimisation problem. This fact derives into non-optimal solutions but, acceptable in any case.

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2 The dimensioning algorithms need a target variable to be minimised; if a significant types of equipment are present in the scenario, the cost may be used for taken into account jointly the number of all the present equipment. Another alternative is just to minimise the predominant element or use multi-target algorithms.

3 Interconnection planning is not covered in this contribution so none of the potential investment projects to be studied in P901 are related with it
The planning activity requires on two types of data (see Figure 12). Internal (generated by the own department) and external (supplied by other company department, manufacturers and authorities through regulatory framework).

**Characterisation of switching traffic**

The purpose is to determine the characteristics of switching demand from and/or to terminals. Traffic measurements are analysed in order to characterise current user traffic and forecast future demands. The parameters measured are the number and duration of calls per subscriber at the busy period, the number of tries, the proportion of different types of call, the bandwidth for each call, ...

**Characterisation of signalling traffic**

The purpose is to determine the flow of signalling messages between the different network elements. This traffic mainly arises from the establishment and routing of calls. In the case of intelligent network systems, the signalling traffic is more important (data of subscriber, value-added services, ...). Finally, in the case of mobile systems, location, roaming, hand-off traffic is added to the previously mentioned signalling traffic. Other types of signalling traffic are of minor importance for the structure.

In order to forecast the volume of signalling traffic that will be generated in each case, it is necessary to identify the required system procedures, to evaluate the traffic that each of these procedures generate. Additionally, in the case of mobile systems, it is necessary to establish an user mobility model and the load that this will generate.

**Economic analysis**

A third aspect to be addressed is an economic analysis of the investments in current infrastructure, based on comparative studies about suppliers for guidance in selecting plant equipment.
External sources

**Forecast demand**

The main input is the required network capacity -that is, the number of users to be considered. Profiling of the traffic generated by each customer and its estimated geographic distribution will provide an approximate idea of the size of network required.

**New services**

Given the strategic importance of new services, information about them is not normally available much in advance. Once they have been designed, implementation is normally a race against time. In fact modern networks have powerful tools for the creation of services to facilitate design and development. It is therefore important to know of new services from the outset in order to anticipate the implications that these may have for the rest of the network.

**Budgeting**

It is important to take into account the budget constraints that the planning department may have, this aspect is becoming more important now that the competition is in a fierce stage. These constraints come from external departments to the planning one. It is not an easy task to juggle investment requirements in such a way to meet given objectives with the budget initially allocated.

**Radio planning**

This aspect, of course, should be taken into account only when wireless solutions are considered. On the basis of known network capacity and established coverage targets, the radio planning area estimates plant requirements -base stations- which will require corresponding control and switching centres for its operation. In the case of considering wireless solutions this aspect becomes crucial so the number of base stations is an important driver for the network costs. The number of base stations should be calculated as a function of the coverage and it should take into account the used frequencies, topographical data of the area, …

**Technological evolution**

Given the constant evolution of telecommunications equipment technology, it is essential to maintain close contacts with the manufacturing sector to be able to choose the right supplier and identify the best elements and technologies for finding the optimum investment strategy and network performance.

**Quality parameters**

The criteria applied to the planning of the different subsystems determines the quality of service. The main criteria are grade of service and availability.

The grade of service or probability of congestion is fixed for each network by the operator, and it directly affects the dimensioning of all network elements. Availability is determined partly by the reliability of the component elements of the plant (determined in turn by the mean time between failures and the mean time to repair), and partly by the structure of the network. This aspect is directly affected by such factors as diversity, duplication and contingency plans for rapid, effective response to failures.

**Regulatory framework**
The sector is increasingly subject to a mass of regulations governing numbering, interconnection and so on (imposed not only by local and international authorities but by industry bodies as well), which greatly influence planning.

This aspect is specially important for incumbent operator so they are normally designed as the dominant one and they have stronger regulatory constraints: universal service obligation, fixed interconnection costs, …

**Specific network dimensioning problems**

**Access network dimensioning**

In access networks, the main goal of the network planning activities is the finding of the optimum path for the transmission infrastructure (fibre, copper, coaxial); so, typically, civil work and the installation of the buried infrastructure is the more expensive component of the upgrading of an access network, [2].

According to that, the transmission equipment (modems, multiplexer, splitters,…..) is not normally used as the objective of the optimisation algorithms. Of course, if most of the plant is available or radio technologies are used, the equipment cost turns to be the main component and, hence, the parameter to be optimised.

The access network dimensioning algorithms take as an input the customer location and demands, the installed plant and the candidate node locations (both for central office equipment or, only, small transmission or multiplexing equipment). The process calculates the needed transmission infrastructure and switching equipment for fulfilling the customer demands. The process is normally divided into several steps, as indicated in the following figure:

![Access network dimensioning process](image)

**Figure 13: Access network dimensioning process**

**Customer clustering**

The first step consists in the calculation of the optimal assignment of the different customers to the area. Each area is characterised for having one switching location where the traffic generated by the different customers is sent to the transport network.
Typically, simplified cost models for the transmission plant are used in this step for having an estimation of the overall customer cluster costs.

**Service grouping**

The services requested by each customer are added and the equivalent bandwidth is calculated by taking into account the different parameters of each service: peak bandwidth, traffic generated by each service, and QoS parameters.

It is very typical to use the Kauffmann-Roberts formula for the calculation of the equivalent bandwidth of several number of traffic sources with different bitrates, typical dimensioning problem of ATM networks, [3, 4, 5]. This formula takes as an input parameter the traffic generated for each service, and the LQP (low QoS probability), and it calculates directly the equivalent bandwidth:

\[ n \cdot P(n) = \sum_{i} a_i \cdot l_i \cdot P(n - l_i) \]

where \( i \) are the different services, \( l_i \) is the bitrate requested by service \( i \), \( a_i \) is the traffic of service \( i \) (in Erlang), \( n \) is the total bitrate and \( P(n) \) is the probability of having the bitrate \( n \).

**Transmission Infrastructure Paths Allocation**

In this subproblem, the path where the transmission infrastructure should be laid is calculated. This is the more difficult and critical subproblem of the access network planning.

The optimal location of the flexibility points and switching equipment should be calculated with the objective of minimising the overall transmission infrastructure (fibre,…) costs. In this case, typically linear programming and/or methods based on simulated-annealing techniques are used for performing the calculations.

**Transmission Equipment Allocation**

The needed equipment in each node is calculated in this subproblem.

In the case of the flexibility points, it is not a difficult problem to perform the calculation so there is few equipment configurations that should be analysed. However, the calculation of the number of equipment that are needed in the hub of the access cluster is more complicated. In this case, as in the service grouping subproblem the Kaufmann-Roberts formula may be needed. Only in the case where all the customers are similar, the Kaufmann-Roberts formula may be simplified to the Erlang-B one.

**Transport network dimensioning**

In transport networks, the information is carried out in virtual pipes of a defined bandwidth. The pipes should be understood as virtual containers in SDH/PDH-based networks or as wavelengths in WDM-based ones. The virtual pipes are carried through the transmission infrastructure (fibre installed plant) and need switching equipment at their edges (DXC, ADM, OADM, OXC, DMUX, OMUX, …). The dimensioning process should calculate the minimum-cost set of virtual pipes (location and bandwidth) that fulfil the demand constraints.

As stated, this problem is not a simple one due to the significant number of constraints; but becomes significantly more complicated when several levels are considered. Normally, transport networks are composed of several levels: SDH and
WDM one, for example. In this case, one alternative is to plan each level separately, but better result may be obtained if both levels are jointly planned.

For making possible to solve this problem, typically it is subdivided into several subproblems that are solved separately, [6, 7], as indicated in the following figure. When some interrelation between the different subproblems is needed, simplistic solutions or cost models are used. The different optimisation problems associated with the different subproblems are solved by using linear programming techniques [8, 9] or methods based on simulated-annealing techniques.

![Transport network dimensioning process](image)

**Figure 14: Transport network dimensioning process**

**Network clustering**

Transport networks are divided in clusters; typically ring and meshes. The number, type and location of each cluster should be identified. Additionally, the interconnection nodes between clusters should be identified as well.

Typically, simplified cost functions for the transmission systems are used in this subproblem, so it needs the transmission infrastructure allocation for their solving, [10].

**Demand routing**

One or several routes for each demand are found. The number of routes depends on the diversification constraints of the considered demand.

The routes should include both the different clusters that are crossed through and the different nodes inside each cluster.

**Demand-level stand-by network**

Protection to the active routes may be provided in a demand or a circuit level. In the first one, the protection resources are located prior to the demand grooming, while the
second one, the protection is performed to the virtual circuits (carrying several demands). It is not usual at all to have protection at both levels.

In the demand-level case, alternative routes that protect the active ones should be located in this subproblem. The alternative routes are searched only for the demands that need this level of protection. The stand-by routes should be link and/or node disjoint with the active ones.
Demand grooming
The different routes are grouped into different virtual circuits. Both the active and the stand-by routes are grouped with the objective of getting the maximum filling rate of the virtual circuits. The final consequence of filling up the virtual circuits is the reduction in the total number of needed transmission systems, and hence, the overall cost of the solution.

Circuit-level stand-by network
If needed, additional virtual circuits are located for protecting the active ones. As in the demand-level one, the stand-by routes should be link and/or node disjoint with the active ones.

Transmission Systems Allocation
The different needed transmission systems for carrying the defined active and stand-by virtual circuits are found.

Equipment Allocation
The equipment that it is needed in each node is calculated. Both the equipment related to the source or destination of the transmission systems and the external demands is considered.

ATM network dimensioning
In ATM networks [1,2] the information is organised in cells, transported to destination according to the content of the relevant cell header. Two transport mechanisms can be used, respectively based on the VPI and VCI fields of the header. Cells belonging to different calls can be routed in the network along chains of predefined virtual paths logically connecting pairs of switches: only VPI are processed at the intermediate transit nodes of a virtual path, while VCI are processed only at the endpoints of the path.

The ATM network dimensioning implies a complex optimisation problem that cannot be carried out in a rigorous way taking into account realistic dimension networks. Therefore in [3] a heuristic procedure for the cost optimisation is used. The procedure is composed of three modules:

- VP selection
- Routing Plan generation
- VP switching optimisation

Although presented independent, the previous issues are interrelated thus some iteration is needed between them.
**Cost model**

In order to investigate about the conditions in which VP concept is economically convenient, the following three components, due to transmission, switching and set-up cost, are included in the total cost $C$ of the network:

- Transmission cost: it includes the cost of all the transmission sections used in the network
- Switching cost: it represents the traffic routing cost due to the VP/VC switching operated in all the nodes of the network
- Set-up cost

**Virtual Path selection**

The VP network optimisation is related to the network structure, hence it is a topologic problem. These problems are solved using technique based on algorithms able to optimise flow network [14]. In [13] is quoted an algorithm based on a heuristic consideration: a certain VP is the more suitable to be included in the optimal set as the traffic it can carry is greater and its cost is lower. So all the VPs are ranked according to a “merit” figure and the VPs with the best merit figure are chosen.

**Routing Plan generation**

This module determines the routing plan for each traffic relation in the network. The routing structure can be of two types: hierarchical and non-hierarchical. In hierarchical network, the routing plan follows some simple rules depending by a predefined node hierarchy. In the non-hierarchical routing structure any possible path between the origin and the destination can be chosen [13].

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**Figure 15. Dimensioning of ATM network procedure.**

[Diagram showing the process of dimensioning an ATM network, with nodes for Network Topology, End to end traffic demands, Services characteristic, Services integration, Cost factors, VP selection, Max VP Number, Routing Plan generation, VP Switching optimisation, VP Dimensioned Network, VP cost/efficiency ratio, Routing constraints, End to end blocking constraints, and VP cost/efficiency ratio.]
VP switching optimisation

The optimisation is performed on the basis of the chosen VPs and the routing structure obtained by the previous modules. A simple approach for switching optimisation in the case of hierarchical structure can be given by a modification of the classical Pratt’s method. The approaches, in the case of non-hierarchical structure, are quoted in.

In at the network level is assumed that all nodes are of the same type having both switching and crossconnecting functionality. All connections are bi-directional with the same bandwidth requirements in both directions. Regarding the VP optimisation procedure the problem is formulated as follow:

Given the structure of the physical network and the cost parameter find:

- The node pairs that should be connected with VPs
- The VP routes in the physical network
- The bandwidth for each VP
- The VC routing plan for each demand pair and traffic class.

Because of its complexity it is impossible to solve the problem by searching the optimal VP routes, the VP blocking and the VC routing plan simultaneously. As a consequence the adopted solution has been to decompose the problem into the three sub-problems and solve one sub-problem at time while keeping the others constant.

The paper deals with the problem of link dimensioning for an ATM network. The problem is first addressed for a single ATM link under two traffic assumptions: constant bitrate and variable one. The dimensioning problem is then extended to the full network.

The dimensioning methodologies regarding B-ISDN are also discussed in appropriate recommendation ITU-T.

Circuit switching network dimensioning

The network structure can be of two types: the hierarchical one and non-hierarchical one.

Hierarchical structure

In hierarchical networks, the routing plan follows some simple rules depending on a predefined node hierarchy. The links are classified as “final” or “high usage”. The high usage links are dimensioned to reach high traffic efficiency, the final links are engineered in order to meet the grade of service constraints.

The dimensioning of hierarchical network is discussed in the following terms:

Assigned:

- Network topology (transmission links and switching nodes)
- End to end traffic demands
- Routing plan
- Link costs and node costs

Minimise:
Network global cost

With the bond:

GoS (grade of service) offered, expressed as minimum end-to-end call blocking probability regarding the final links

The grade of service in the dimensioning of hierarchical network is expressed as minimum call blocking probability. PRATT’s method \[16\] bases itself on the previous hypothesis.

According to the Pratt’s method the final links are dimensioned in such a way as to satisfy the bond on the admitted call blocking probability whilst the high usage trunk are dimensioned so that the network cost is minimum.

The network costs are referable to the costs of the network components itself such as circuits and switching nodes. The function cost of the circuits is linear varying the circuits number. The network global cost can be obtained as follow:

\[
C = \sum_{i \in I} C_i N_i + \sum_{j \in J} C_j M_j
\]

where the final trunks are indicated by the index \( j \) whilst the high usage trunks by the index \( i \) and \( I \) and \( J \) are respectively the high usage and final links set.

As a consequence the variables that have to be determined during the dimensioning process are the links capacity \( N_i \) and \( M_j \). A more detailed discussion is in \[16\].

As previously stated the parameter used in the Pratt’s method to characterise the offered grade of service is the call blocking probability related to the final trunks. Berry \[21\] dealt with the network optimisation using as bond the point-to-point call blocking probability. He has tried to approach the problem using the non-linear programming technique. Because of the high number of variables to be optimised it takes a long time to obtain the result.

The decomposition technique by Pratt has been adopted in the optimisation procedure developed during the European research project COST 201 \[22\]. According to this procedure the high usage links are dimensioned using the Pratt’s method whilst the final links are dimensioned using non-linear programming techniques.

The previous methods are based on the assumption that the traffic peak hour is the same all over the network. Since this is not very likely to happen the problem is solved in a simplistic way using only one “fictitious” traffic matrix containing the data concerning the different peak hours.

Eisenberg \[23\] has proposed a particle method, which allows minimising the network cost when more than one traffic matrix is involved. Using this method the thrift on the network cost is 2-3% compared with the one obtained using only one “fictitious” traffic matrix. Nevertheless the dimensioning procedure is very onerous using many traffic matrixes.

Horn \[24\] has proposed a criteria which is less rigorous but easier to apply. It consists in sorting the matrixes related to the several peak hours ascending with respect to the total offered traffic. The network is dimensioned on the basis of the matrix corresponding to the lowest traffic. Then a new dimensioning is carried out on the basis of the next matrix and circuits extensions, with respect to the network previously obtained are accepted. The process goes on in such a way until the last matrix is left. The advantage of this method is that the dimensioning procedure are not
to be tuned, it is just necessary to utilise iteratively the one related to only one traffic matrix. With this method as well issues related to the evaluation time could arise when huge networks and a high number of peak hours are considered.

Non hierarchical structure

In the non-hierarchical network structure any possible path between origin and destination can be chosen. The links are not classified as “final” or “high usage” and for this reason the bond defined in the dimensioned network is the point to point loss probability for each node pair. Naturally this bond implies an increased number of independent variables to be optimised.

Katz’s \[25\] algorithm allows the dimensioning of the network trunks attempting to make equal the loss of each traffic relation. Since it is not possible to reach this goal easily, it is necessary to set a loss range and to investigate the network configuration with all the losses falling within this range. The algorithm requires the following input data:

- Traffic matrixes
- The routing plan
- The range \((B_{\text{min}}, B_{\text{max}})\) for the point to point losses

Unlike Katz’s algorithm \[25\], Garbin-Knepley \[26\] one sizes the trunks willing to minimise the overall cost of the network, guaranteeing determined point to point losses. The issue in this algorithm is how to determine the best routing plan. The problem can be solved by exploiting a technique based on the algorithm allowing to determine the shortest path in a graph whose arches are associated to lengths. The algorithm starting point is a fully meshed network whose topology is everytime updated getting the rid of not cost effective trunks.

Ash-Cardwell-Murray \[27\], unlike previous ones, uses traffic matrixes corresponding to the different time slots in which the traffic varies significantly. It relies on the following principles:

- Using time-sensitive dynamic routing
- Routing traffic along the least costly path
- Minimise incremental network cost

The basic idea of the algorithm is to determine for each relation and for each time slot, a set of paths and then to slit the traffic among them in the best way. The next step is to obtain the routing plan which best suits this split for each relation and each peak hour.

The three algorithms have been ordered according to the complexity, and perform quite well with the dimensioning of non-hierarchical networks. In particular the first two use routing plans not depending on the time whilst the latter is to be applied to networks whose traffic matrixes are time dependant.

Switching and signalling network dimensioning

Three basic structural areas have to be considered in the planning of this part of the network: the switching network, the signalling network and the interconnection with other networks. \[28,29\].
Switching network

The main objective of the switching network planning is to define a robust, flexible and economical network, adapting the new possibilities offered by the available technologies to the requirements of a market which is evolving rapidly. The switching network can be structured in several ways, depending on the philosophy adopted for the interconnection of elements - that is, a mesh, star or mixed format and one or more hierarchical levels. The routing criteria is so fixed and hence the dimensioning of each route.

The choice of a type of infrastructure is governed by a combination of three factors: reliability, economy and simplicity. The last one is specially important when networks grow to a large size. Additionally, the economic aspect is closely linked to the price of the transmission media (which constitute a major item of investment) and to the interconnection tariff policy. Both factors are decisive for network design.

The dimensioning of the switching network is normally divided into three subtasks:

- **Definition of the switching network structure.** It is devoted to determining the number and hierarchical levels of the different exchanges and the way they are interconnected in order to route switched traffic.

  The key aspects in evaluating different network structures are simplicity, flexibility, security, existing plant and cost. The security provided by any solution is particularly important since a failure can lead to major direct financial losses and, what is worse, deterioration of the quality perceived by the customer. Security is basically achieved by using duplicate network structures.

- **Dimensioning of routes and exchanges.** Given the great diversity of network structures available for consideration, there are a great many different types of route (single route, double route with load sharing, etc.), each can route traffic of various kinds (first-choice traffic, overflow traffic, shared-load traffic, etc.).

  To determine the required capacity or dimensioning of each of these types of route is no easy task, requiring complex traffic engineering algorithms (Erlang-B, Wilkinson and other formulas). As to dimensioning of switching centres, the basic aim is to determine the number of link ends needed at each centre to allow interconnection with other network switching centres. This figure will depend on the routes converging in each centre, and to calculate it, the dimensioning of the exchanges must be assessed globally.

- **Analysis of the different options.** The target network structure will be determined by the performance/cost ratio offered by each alternative proposal. The performance of a switching network is determined by the grade of service offered in each traffic link (between pairs of exchanges) in the network. This parameter is the quality of service indicator which the user can perceive. Since the network may be subject to irregularities such as unforeseen overload or failures in routes or exchanges, it is important to assess how the service level will be affected in such situations.

Signalling network

Signalling, first used in telephony to support voice communication, is particularly important in more advanced communication networks. In these cases, it is used not only for the original purpose of routing and establishing calls, but also to carry a large volume of information between the various network elements, particularly for the
purpose of subscriber location in mobile systems and in the provision of advanced services.

So the signalling network is important for the new service provision, the planning of such part of the network becomes more important. The objective signalling network should be reliable enough and should have sufficient non-used capacity to cope with unforeseen growth in demand due to, mainly, the incorporation of new services.

The dimensioning of the signalling network is normally divided into three subtasks:

- **Definition of the signalling network structure.** It is devoted to determine the number and location of the Signalling Transfer Points (STP) responsible for routing the signalling traffic between Signalling Points (SP) and establishing sets of signalling links to join them.

- **Dimensioning of Signalling Link Sets (STS).** The dimensioning of network elements is achieved by the evaluation of the traffic that they have to transport, either on the basis of measurements or on the basis of forecasts and estimations. Even where signalling traffic measurements are available, dimensioning based on these may not be sufficient, particularly in the case of fast-growing services and/or services whose protocols are highly dependent on situations external to the network. For example, in the GSM network, both the strong growth rate and the changes in the signalling traffic due to user behaviour (mobility) should be taken into account.

Where services have connection-oriented signalling, considerable simplification is possible in dimensioning, by using a more or less direct relationship between switching and signalling traffic, and even between the number of switching circuits and the number of signalling circuits required.

In these dimensioning it is important to take into account the alternative routes for dealing with possible network failures. The number of signalling links in a SLS must be such that the load on each one does not exceed a given value according to the failure level specified for the SLS.

- **Analysis of the different options.** The process of planning any network generally entails a comparison of various alternative solutions. It is important to set quality parameters to assess these options. In this case, the aim is to achieve a structure which guarantees, first, high availability with sufficiently low delays in the delivery of messages and, second, at the lowest possible cost.

**Interconnection structure**

A third aspect is the planning of the interconnection with other operators. The liberalisation of the telecommunications market has made to appear new operators, which means that any operator has to interconnect with increasing numbers of other operators.

Interconnection structures will depend on the agreement reached between operators. The factors that have to be considered for choosing these structured are: interconnection tariffs, transmission media tariffs, the volume of interchange traffic and the type of structure adopted by networks. This will determine the number and location of interconnection points.

Both the data and signalling network should be interconnected. Although the structure of this interconnection is mainly driven by the same factors as have been previously described, there are other factors specific to interconnection, for example:
• Connections have to be provided with a growing number of centres belonging to other operators. The strategy adopted may vary according to the agreements concluded with each operator at any time.

• The forecast of traffic demand to/from each operator is more uncertain.

• Greater precision is needed in cost assessment in order to define suitable tariff policies with respect to each operator.

• The network must be equipped with the requisite security mechanisms to protect it against a variety of errors which can arise in the other operators' networks.

**Mobile network dimensioning**

Planning of mobile and fixed network is performed in a similar way, but some differences arise due to the mobility functionality only present in the mobile networks, the extremely different rate of growth and the radio technology. Then, in this case the dimensioning should include: transport, switching, signalling, interconnection networks and, the access network planning should be substituted by a radio planning activity.

The main “marketing” and differentiating aspect of the mobile networks -geographic mobility- may be provided within the geographical area covered by the own network or in areas covered by other operators whom appropriate agreements has been signed with.

Mobility has the effect that the network load during the different hours of the day or seasons is not the same in all the network elements. Typically, the peak hour in downtown base stations does not occur at the same time as in suburban or rural ones. Additionally, massive population movements to tourist areas at certain times of the year originates also seasonal variations. Also, events such as workshops, trade fairs, sports events, etc., cause sporadic concentrations of traffic at certain places.

The second differentiating factor is the rate of growth of mobile telephone networks. Falling service prices, technological evolution (making terminals smaller, lighter and cheaper) and a comprehensive coverage are the three factors which have most helped to popularise what was initially an elitist service. Purchasing power is no longer a decisive factor for the customer. The result has been a spectacular growth on an entirely different scale from the typical growth curves of conventional telephony.

Given these mobility and growth characteristics, the network must have enough flexibility and capacity to adapt to the changing requirements. It is a serious network constraint to respond quickly to the unforeseen demand variations in a given area or throughout the network. In this case, the major threat is located in the switching and signalling network planning. This is caused due to the fact that while transmission infrastructure or radio elements can be installed in a matter of weeks or even days, several months are needed to bring switching and control elements into service. Therefore, given the long lead times required to install additional new elements in the network, network planning should take into consideration the flexibility of adaptation to unforeseen demands as one of the dimensioning objectives.

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4 Year after year, the most optimistic forecasts for growth of mobile telephony have invariably been outstripped by actual demand both locally and internationally.

5 This variations are specially significant in highly-touristic countries, like Spain.
A final difference is the radio planning task. In this case, coverage studies should be taken into account for calculating the number of base stations. These number should be calculated as a function of the coverage and it should take into account the used frequencies, topographical data of the area, …

Costing Approaches. Incremental approach to cost evaluation: Overview

The purpose of this section is to give a quick overview of the methodologies adopted in the literature for incremental cost modelling, and to describe the main steps that brought to the adoption of such approach for telecommunication services.

The introduction of the incremental approach in the telecommunication cost accounting systems has been strongly influenced by external factors to the telecommunication companies. The opening of the market to competition, in fact, has been driven by political choices, aimed to break the natural monopoly that characterised the first developing of the telecommunication services.

At the beginning of the 80’s, the increase in the use of telecommunication services and the development of both the technology and the market, started to put pressure on the Governments in order to allow the telecommunication market to grow in a competitive environment.

First the USA (where the market and the penetration of services were more developed) and later in Europe, the general orientation towards this topic was leading to let the former monopolists networks be accessible to new entrants. Such a process could not be left only to the market, because it could have lead to disproportion and inequalities, even possibly it could not have start at all due to the privileged position of the dominant operators. The introduction of a supervisor body to control the liberalisation process and allow it to be as fare as possible, appeared to be a fundamental requirement.

The supervisors started to generate a number of criteria and recommendations to clarify the terms for the “correct competition”. The most significant for the European market are quoted in the references, in which the principles are aimed to:

- protect competition on basic services and network infrastructures;
- improve competition on added value services;
- allow the creation of a common market for telecommunication service supply;

In the process of opening the European market, the supervisor body (European Commission DG XIII) and the national regulator authorities (NRAs), imposed the creation of an interconnection traffic tariffs. These tariffs should be traceable, transparent and cost-effective. That is, tariffs must be strictly related with the cost sustained for providing the facility or service, and the process for deriving the cost must be clearly stated and justified in every stage.

Within this framework, the incremental costing was developed. The methodology is founded on some basic assumptions, varying which different incremental approaches are derived. The fundamental factors to be assumed in defining the methodology are:

- Top-Down or Bottom-Up approach in looking at the provisioning of a service.
- Interaction with the previously installed network for new capacity to be added (scorched earth or scorched node).
• Time window in which the cost has to be sustained.

**Basic definitions**

**Top-Down & Bottom-Up**: these terms refer to the two approaches that can be followed to determine the cost of a service or network element.

The Top-Down approach consist of allocating the company costs on the network elements, starting from the general ledger and working down through appropriate drivers.

The Bottom-Up approach takes its start from the demand of the service or network elements. It implies a dimensioning process and an evaluation of the costs of the installed capacity for deriving the effective cost which has been originated from the demand. In the latter the inefficiencies of the company cannot be transferred on the service/element cost, whereas the first can be easier to perform if a well detailed accounting system has been set up for the firm.

**Short-Run & Long-Run**: they refer to the time window to be considered. The Short-Run is a period of time in which most costs can be considered fixed, particularly the cost of capacity. The Long-Run, instead, refers to a period of time in which all the costs are variable.

**Incremental Cost (IC)**: it measures the change in the total costs of the company that arises from an increase or decrease in the output by a substantial and discrete increment.

**Long Run Incremental Cost (LRIC)**: it measures the change in the total costs of the company that arises from an increase or decrease in the output by a substantial and discrete increment considering, in the long-run, all costs variable.

**Scorched Node & Scorched Earth**: they refer to two different ways to interact with the existing network. In the Scorched Node approach, network nodes are kept at the original position, according to Operator’s network topology. Components are dimensioned as if nothing was installed before. In the Scorched Earth approach, instead, network is redesigned, without any constrain from previous network structure.

In the following a brief description of the procedure which leads to the incremental cost is outlined, referring to TELRIC, which is one of the possible approaches to the incremental cost accounting.

**TELRIC – Total Element Long Run Incremental Cost**

The TELRIC methodology has been developed to provide the most efficient, forward looking, incremental cost evaluation, according to the FCC recommendations. It relies on the following assumptions:

• Provides the incremental cost for an incremental demand of service.

• It gives a Long Run evaluation, namely the period of time in which all costs can be considered variable. In dealing with investments in TLC, this is likely to be a well-fitted hypothesis.

• It considers cost of an “efficient” Operator. That is, installing infrastructure, we have to take into account only the latest technology.

• The methodology is based on a Bottom-Up / Scorched Node approach.
Steps to follow to determine costs:

- First of all it is necessary to define the demand for the service to be provided. According to the nature of the service, it may be defined in terms of customers, Erlang of traffic, number of junctions and so on. These inputs need to be sufficient to feed the dimensioning process that follows.
- Once the inputs are available, a dimensioning process is activated to provide the infrastructure needs to satisfy the demand. This step is performed through network planning tools, whose choice relies on the Operator needs and strategies. At the end of the dimensioning process, the number and interconnection of each needed component are calculated.
- The investment for every component is determined through the price list. Therefore the total investment for the infrastructure is derived.
- A depreciation policy is applied to obtain the annual cost per component.
- Components are then grouped by the functionality they perform into Elements, i.e. control, access, link, …
- By adding the annual cost for the components of every element, the annual cost of the element is obtained. To relate the element cost to the demand originating it, a driver is applied.
- The service cost are then obtained by summing up the corresponding element costs.

This procedure ensures tracing every step for cost allocation and provides costs on different aggregation basis: components, elements, service yearly cost, service with respect to demand.

On the other hand, the incremental approach is thought to be weak in dealing with OAM costs, especially when they are shared or common ones.

The main approach adopted for TELRIC is in principle common to every incremental methodology, where differences among them are originated on different initial assumptions. The following scheme summarises the above procedure.
Figure 16 The TELRIC scheme (incremental methodology)

The adoption of the incremental methodology for cost analysis should be carefully considered in case of investment analysis. That is, since its original application was promoted by the NRA’s for interconnection problems, it generally bears with it a certain number of “strong assumptions”, which need to be evaluated and, eventually, re-stated.

The procedure conserves a very powerful approach to the equipment and installation cost accounting and, as it will be developed further in the project, with appropriate hypothesis, it can be effectively used for investment analysis.

Market Modelling

Introduction

The goal of the P901 Project is to provide methods which facilitate the investment decision process in a telecommunication company. They should enable to draw different scenarios and evaluate their consequences. The objective of Market modelling is the same but reduced to the scenario field of market.

Within the market modelling concept, we will examine the market in order to understand all its bits and pieces, how they work, their correlations and interactions with the environment. With this examination, it will possible to model it and analysing its impact on an investment decision. In other words, how the market impacts the company in terms of revenues and costs should be found.

Phase1: examine the market

Short description:
Identifying/defining factors describing the market and its environment.\[30\]
Extensive description:

As mentioned above, the scenario field to be analysed is the market. The scenario field consists of the environmental factors acting on the decision field, that is to say the investment. These environmental factors are the ones that have to be identified at this stage.

The market can be divided into two main areas, namely the Micro and Macro Environment. The Micro Environment consists of the forces close to the company that affect its ability to serve its customers. The Macro Environment consists of the larger societal forces that affect the whole Micro Environment. The goal is to split up these two environments in components, which can be considered as time invariant. Their future should almost be independent of any evolution of the scenario field.

Example:
Phase 2: select the most important factors.

Short description:
What are the most influent factors on the company and its investment decision?\[31\]

Extensive description/example:
Market modelling is a wide area. In order to get at the end a usable (not too complex) method and tool, a concentration on the most relevant model and factors is crucial. Therefore, having identified influent factors, it is now important to select the most influent ones. In a workshop all kinds of influent areas and influent factors could be collected using a brainstorming technique called "6-3-5 System". This system allows that every other member of the group will further develop initial factors created by the first person.

![Figure 19 Influent areas and Influent factors](image)

The factors collected will already be a first summary of factors identified in phase 1. The workshop will generate lots of factors, which will have to be clustered into domains. In order to reach a manageable number of factors, the most influent factors will be worked out using an influence matrix.

For this step, software tool as the systemische Wirkungsmatrix“ (influence matrix in English) developed by the Fachhochschule Bern“ may be used, see section 2.4. (They allow a metering of the influence of each individual factor towards all other factors).

Phase 3: Market models and methodologies

Short description:
Find out tools/models/methodologies, which would help to understand the behaviour of the previously identified factors \[32\], \[33\]
Extensive description:
Each factor identified is a source of uncertainty in the investment decision, which has to be taken into account. At this stage, we will try to model these factors. This could require a different approach depending on the nature of the identified factors. If all the factors were so called hard factors, then the traditional ways for calculating sales revenue and brand profit (e.g. using spreadsheets) would still be sufficient. However, with regard to so called soft factors (e.g. advertising is regarded as a soft factor because the it may be effective, partially effective, or not effective at all), its impact may be measured in terms of number of new customers or volume of sales. In this case, where more soft factors or vulnerable factors (factors that represent uncertainties or are associated with risk) are involved then the Dynamic Modelling Concept could produce better understanding of the revenue generation process and its results.

![Figure 20 A general Market Model](chart)

In this phase, techniques such as game theory and system dynamics may be used for modelling the relations between the different factors (hard and soft ones); see section 2.4.

Phase 4: Implementation

Short description:
Use a tool, which would contain/reflect, the results of preceding phases.

Extensive description/example:
An investment planning document could contain two parts, a descriptive and a financial one. The goal of this phase 4 would be to draw a template for these two parts based on the findings we made during the previous phases. The financial part would contain all the mathematical and dynamic models and the descriptive part the other methodologies.
Real Options theory

Introduction

This section gives an introduction to the concept of real options and its use in investment projects. The variables that describe call option are discussed. The opportunities and limitations of real options are discussed as well. A more detailed description of the mathematics involved is presented in the Deliverable 2.[1]

The concept of Real Options

The concept of real options or option pricing captures information that is not seen in traditional approaches such as the discounted cashflow analysis (DCF) and NPV rule. Most investment projects are like a call option on a common stock: the investor has the right but not the obligation to make an investment. The project value fluctuates stochastically and most investment options (or investment opportunities) are not a “now end never” opportunity. In some situations, there will be a value connected to deferral of an investment [34]. This extra value of deferral stems from two factors:

1. Interest earned on money that could have been invested from the start
2. Reduced risk during the period of deferral

Financial theory and the equations of Black-Scholes [35] are used to quantify the total value of the project which includes the NPV value and the added value; the so-called option value. Typically an investment project is divided in two distinct phases where the second phase is initiated by a large discretionary investment. A good example of such an investment is an upgrade of the access network by laying out fibre closer to the customers. Instead of calculating the traditional NPV for the whole life cycle of the project, the adjusted NPV is taken as the sum of NPN of phase 1 and the option of phase 2 assets.

However, the investment study using options can turn out less simple than indicated in [35] because due to the factors that counteract the value of deferral, namely lost revenues related to phase 2 assets (upgraded network) and competitor pre-emption.

As indicated large R&D related investment projects are uncertain. Uncertainty means for example, that the future demand of services will be up or down, in relation to the forecasted demand. So uncertainty has two sides: the “good side” and the “bad side”.

The fact that an investor will exercise the option only if the project is favourable and not exercise under unfavourable conditions is overlooked in conventional DCF analysis. An increase in uncertainty (and thereby in volatility), increases the investment opportunity (=option value) according to and [35] in view of the manager’s action in response to uncertainty. This is the so-called asymmetry on the value [36] on the opportunity to invest in the project, the first asymmetric effect of uncertainty.

However, an increase in the value of the option does not mean an increase in the willingness to invest: an increase of economic uncertainty reduces the willingness to invest, because the increment in the investment opportunity value is due to the waiting time.

The following table lists the five variables that describe an option and which are used in Black-Scholes equation for pricing an option [34] and [37].
<table>
<thead>
<tr>
<th>Investment opportunity</th>
<th>Variable</th>
<th>Call option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present value of a project’s Operating assets to be acquired</td>
<td>$S$</td>
<td>Stock Price</td>
</tr>
<tr>
<td>Expenditure required to acquire the project assets</td>
<td>$X$</td>
<td>Exercise price</td>
</tr>
<tr>
<td>Length of time the decision may be deferred</td>
<td>$T$</td>
<td>Time to expiration</td>
</tr>
<tr>
<td>Time value of money</td>
<td>$r_f$</td>
<td>Risk-free rate of return</td>
</tr>
<tr>
<td>Riskiness of the project assets</td>
<td>$\sigma^2$</td>
<td>Variance of returns on stock</td>
</tr>
</tbody>
</table>

**Table 1 Option Variables used in Black-Scholes equation**

The NPV value and option value is identical when the investment can no longer be deferred.

The investment project is divided into two phases according to [34]. $S$ and $X$ are calculated. Now we are able to calculate the NPV metric $NPV_q$:

From option pricing theory we know that the value of a call option increases with:

- Increase in variance of the underlying asset ($\sigma^2$)
- Increase in the value of the underlying asset ($S$)
- Increase in the time to expiration ($T$)
- Increase in the risk free rate ($r_f$)
- Decrease in the exercise price ($X$)

Some limitations of the option pricing should be mentioned at this point:

- In the text and in the references given, we have only considered European Options, which can only be exercised on expiration date contrary to American Options (these are more complicated to analyse than European Options!) that can be exercised at any time no later than expiration
- A financial option on a common stock is proprietary; only the owner can exercise it without worrying about competition for the underlying security. However, options related to penetrating new markets or geographic areas are shared and can be exercised by every any player. This is highly relevant for the coming competition in the telecommunications industry!
- Large R&D investment projects are compound in nature, which means that they must be seen rather as links in a chain of interrelated projects rather than independent projects.
Tools Survey

Introduction

The description of the main tools found during the Survey is analysed. The purpose of this chapter is the comprehensive analysis of the available tools during the period of the survey. Each tool is categorised in a specific main category according to its orientation and specification. In each section describing a specific tool the main characteristics are analysed and a general conclusion for the usage of the tool within the P901 EURESCOM Project purposes and framework is included. The work has been carried out in order to be possible for a telecommunication engineer and a network planner to understand the possible functions of each tool so during the P901 project the appropriate tool or tools can be selected and utilised.

The tools are categorised according to their orientation. The main categories in which this part of the document is divided are: Telecommunication Investment Strategic, Dimensioning, Market Modelling and Risk Analysis tools. The first category concerns tools able to implement and finally evaluate an investment project as they take into account several economical issues, network architectures and use telecommunication based cost databases. The usage of the others categories is supplementary in order to provide their methodology and outputs (results) as an input to the first category tools. Furthermore, an extensive analysis in these categories is essential due to the fact that the investigate parameters from these tools are critical for a comprehensive evaluation of an investment project.

Telecommunication Investment Strategic tools

OPTIMUM/TERA methodology

Introduction

The TERA techno economic assessment methodology is based on the work carried out within RACE 2087/ TITAN. In that project, the methodology (implemented in the TITAN tool) has been applied in various business case studies.

The methodology was improved during the ACTS/OPTIMUM AC226 project and implemented in the OPTIMUM tool. At that time, methodology extensions were driven by the aim to evaluate the introduction of advanced telecommunication services and the study of new network technologies including their introduction in existing networks.

During the ACTS/TERA AC364 project, the methodology was further extended towards better analysis of risk and network externalities. Currently these elements are being implemented in a new TERA tool version.

This section summarises public deliverable 6 of TERA project entitled “New Tool Documentation” Feb1999.[38]

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6 RACE: Research and Development in Advanced Communications Technologies in Europe.
7 TITAN: Tool for Introduction scenario and Techno-economic evaluation of Access Network.
8 TERA: Techno Economics Results from Acts
Overview of the Methodology

The general framework of the TERA techno-economic evaluations is shown in Figure 21.

Steps in the Network Evaluation

The following main steps are needed in the techno-economic evaluation of any network solution (investment project study):

1. Specification of the service scenario (set of services to be provided). Necessary applications and future needs can be determined from a survey. The market penetration of the services over the study period has to be defined. The services have associated tariffs i.e. the part of the tariff that is attributed to the network under study. From the combination of market penetration and tariff information TERA calculates the revenues for the selected set of services.

2. Definition of a relevant architecture scenario to provide the selected service set. This assumes network-planning expertise and is mostly outside of the framework of the TERA methodology. However, TERA includes a generic type of geometric model, that will facilitate the network planning by automatically calculating lengths for cables and ducts. When the build-in model is not suited for the network under study, the open TERA tool environment allows for relatively simple implementation of any model needed. The result of the architecture scenario definition is a list of the network cost elements (investment in equipment, cables, cabinets, ducting, installation etc.) and the distribution of these network components over the different hierarchical levels of the network. An extended database with information on the cost of network components, including information on the evolution of the costs as a function of time, is an integrated part of the TERA tool. This database is extended with information on the specific case under study.

3. Running of simulations on the model (service/architecture scenario) specified in the previous steps.
4. Interpretation of the results and drawing of conclusions. A main goal could be to select an optimal architecture based on the economic outputs from the tool.

**Scope of the Network Study**

The present TERA methodology allows to model, dimension, and calculate cost of both the transport and switching part of the network in addition to the access network models used with previous versions of the techno economic assessment tool. This was done by extending the number of network levels available in the geometric model and by studying the required resource sharing and traffic dimensioning problems.

**Multiple-service and Multiple-operator situations**

The situation where the end service is supplied by several service/network operators is very probable in the multimedia era. The earlier TITAN methodology, used for the evaluation of access networks, assumed that there exists only one interface to another operator. The TERA tool is capable to handle these more complex operator situations.

**Key Model Inputs**

The main inputs for the model evaluations are the network architecture and service scenarios. The subscriber density is the most important parameter to the geometric model.

**Network Architecture Scenario**

The **architecture scenario is defined in a shopping list**, which indicates how the network is rolled out during the study period. The shopping list defines the amount of equipment and services needed in the network as a function of time.

**Service Scenario**

The service scenario defines how many subscribers are connected to a certain service at a certain moment and how much revenue one user means for the network operator per year. **The penetration of the service**, expressed in terms of number of users subscribing to the service versus time is a key input to the model.

**Subscriber Density**

The TERA methodology supports the use of a geometric model to calculate cable and duct lengths in the network. The main input to the geometric model is the subscriber density. This parameter is often used to study the sensitivity of the cost of the system to various geographic conditions.

**Key Model Outputs**

In the evaluation of investment scenarios there can be several points of view. Depending on the complexity of the scenario, various commonly used indicators like Payback Period, Net Present Value (NPV) or Internal rate of Return (IRR), can give different results in comparisons. Because of this, it is often necessary to use several figures of merit for the studies to get a thorough understanding of the economics for each scenario. In most of the cases these evaluations have some less accurate inputs. In these cases it is advisable to apply sensitivity analysis and/or risk assessment methodologies to these inputs using multiple figures of merit as indicators.

Some of the key TERA model outputs are time series over the study period and
others are constant values. The key outputs are,

**Investments**

Because the TERA methodology studies scenarios, investments are usually spread over the study period. To get a single figure of merit for the total investment, the future investments are discounted to the start of the study period using the conventional discounting formula. The total discounted investment cost is usually called **First Installed Cost**.

In the TERA methodology the network is subdivided into a hierarchy of flexibility points and link levels (Geometric Modelling). Links interconnect flexibility points. All links or flexibility points in the same hierarchical level form a so-called network level. The current implementation of the methodology allows the investments to be analysed based on physical location of the cost components in the network (by hierarchical network level).

**Revenues**

In most of the evaluations the calculation includes the revenue from the services. The TERA methodology handles the revenue simply by using a service connection tariff and estimating a certain annual tariff for each service per connected customer. In general, both connection tariffs and usage tariffs are time series over the study period. It must be noted that revenue in TERA refers to the part going to the network operator, not the service provider. This is not a limitation of the methodology (open tool could be change).

**Profits**

These are calculated from the revenues, investments, depreciations and taxes.

**Cash Flows**

These are calculated from the other relevant economic parameters in a standard manner.

**Life Cycle Cost**

Life Cycle Cost is defined as the sum of global discounted investments and global discounted running (or OA&M) costs. This value represents the total cost for constructing and running the network over the study period.

Often the sole reason for a techno-economic study is the evaluation of the cost of the proposed network build. The reason might be a new network or an upgrade of the existing network. In these cases it is not always necessary to add any service revenues to the study and the final result of the study can be either First Installed Cost or Life Cycle Cost of the project. In this case this methodology and the tool are especially suitable for comparative studies between competing network technologies.

**Cash Balance**

The Cash Balance or Cumulative Cash Flow time-series is a very informative figure for a specific network/service scenario. Especially for a green field case it gives much information in a single picture.

A typical Cash balance curve for a network scenario goes first deeply down to the negative side because of the high initial investments. If the scenario is profitable, the cash flow turns positive fairly soon and the Cash Balance curve starts to rise. The lowest point in the Cash Balance curve gives the amount of funding required for the
project. The point in time when the Cash Balance turns positive gives the Payback Period for the project.

In an investment scenario where most of the expenditure happens at the beginning of the study period, the Payback Period gives a good indication of the efficiency of the investment. If the scenario is more complex, that is, if there are for example several technology steps in an upgrade situation, it is not possible to define a single Payback Period. It is still possible to use the Cash Balance curve as an indicator for the profitability of the scenario. In these cases it is important to study the trend of cash flow at the end of the study period.

### Net Present Value (NPV)

The Net Present Value gives a single figure of merit for a project. Its definition is the Sum of Discounted Cash Flows plus Discounted Rest Value of the project. It is a good indicator for the profitability of the scenario especially in these cases where the Payback Period cannot be used because major investments are spread out in time.

The weakest point in this figure of merit is the definition or calculation of the rest value of the network. There are several ways to try to define this value. The usual approach uses the bookkeeping value of the network as the Rest Value because it is the only figure that can be calculated from the inputs already available.

![Cash Balance Curve](image)

**Figure 22: Cash Balance Curve**

### Internal Rate of Return (IRR)

IRR is the discount rate at which the NPV is zero. If the IRR is higher than the opportunity cost of money, then the project is viable.

If the scenarios to be compared are not similar, for example if the size of these networks is different, these can not be easily compared using Net Present Values. In these cases Internal Rate of Return gives a good indication on how good “value for money” these projects have.
**OA&M Methodology**

The Operation, Administration and Maintenance (OA&M) approach in the TERA methodology states that OA&M costs are divided into three separate components. Conceptually the three components are defined as follows:

- **M₁** - Represents the cost of repair parts. This component is included automatically in the model and is proportional to the cumulative investments in the network.

- **M₂** - Represents the cost of repair work. This is also automatically included in the model and is calculated as,

  \[ M_2 = P_1 \frac{MTTR}{MTBR} \]

  with,

  - \( P_1 \), the cost of labour, defined as a time series over the study period,
  - \( MTBR \), the Mean Time Between Repairs, included in the database per component,
  - \( MTTR \), the Mean Time To Repair, included in the database per component

- **O&A** - This component represents Operation & Administration costs and it has to be included manually when building models. Typically it would be driven by services, say by number of customers, or by number of critical network elements.

**New Methodology (OPTIMUM)**

![Diagram comparing TERA/OPTIMUM OA&M methodologies](image)

Figure 23. TERA/OPTIMUM OA&M methodologies compared
Total maintenance costs

The total maintenance cost caused by a single cost component in year \( i \) is

\[
M_i = (M_i + M_j)_i = \frac{V_{i-1} + V_i}{2} \left( P_i \cdot R_{class} + P_1 \cdot \frac{MTTR}{MTBR} \right)
\]

where

- \( V_i \) is the equipment volume in year \( i \)
- \( P_i \) is the price of cost item in year \( i \)
- \( R_{class} \) is the maintenance cost percentage (defined by choosing MaintenanceMaterialClass (see appendix on class definitions) for every cost component)
- \( P_1 \) is the cost of one working hour
- \( MTTR \) is the mean time to repair for the cost item in question
- \( MTBR \) is the mean time between failures for the cost item in question

Geometric Modelling

The cost of digging trenches, installing ducts and cables is crucial in the economics of any telecommunications network infrastructure. A geometric model is used to estimate the amount of cable, ducts and civil works (trenches) required in such network. On a conceptual level, the geometric model is a function that takes several inputs such as subscriber density, network topology (star, ring, bus, Virtual Cable Route Model for Fibre Networks\(^9\)), average over-length (adjustment of model outputs), duct availability, etc. and outputs values like trench length, duct length and cable length. As the geometric model delivers the basis for the quantity calculation of some very important cost components, it is an important and fundamental step towards the broader task of techno-economic modelling of a telecommunications project. Various geometric models were developed and used in the RACE projects SYNTHESYS and TITAN and in the ACTS project OPTIMUM.

The basic structure of the SYNTHESYS model and its variants is based on a star topology and a polygon geometry. In many cases this is a valid assumption, but there are cases where the polygon structure is not ideal. Because of this, TITAN has developed a completely new geometric model which is more flexible in many senses. This model allows modelling of clustered areas where subscribers are not homogeneously distributed. The topology can be a star, ring or bus or a combination of these. In addition, the shape of the model area and location of flexibility points within the model area are taken into consideration.

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\(^9\) The Virtual Cable Route Model was defined within the project ACTS/IBCoBN but is used within the project ACTS/TERA as an add-on to the TERA geometric model
Cost Component Price Evolution

Theoretical considerations show that by combining a standard demand logistic curve for the growth over time of the accumulated component volume with a learning curve \([39,40,41]\), every component can be classified by four parameters \([42]\). These are the component price today \(P(0)\), the learning curve coefficient \(K\), the time it takes for the accumulated volume curve to go from 10\% to 90\% of the saturation value \(\Delta T\) and the value of the accumulated volume today \(n(0)\), normalised to the saturation value. The last parameter is the inverse of the assumed marked potential normalised to the current cumulative volume. The \(\Delta T\) and \(n(0)\) are the only two parameters that need to be estimated by forecast methods.

The Cost Database (Cost Modelling)

The TERA tool database contains cost component data at a given reference year for material, installation, civil works, operations and maintenance. The price-curve for each cost component can be calculated by means of learning curve data and volume data. Learning curve data and volume data are classified in relevant groups/classes. This simplifies the addition of new components and makes it easier to compare price evolution of various components with different functionalities. For each cost component, a learning curve class and a volume class have to be specified in order to predict the price curve. The classes are stored in the database.

Note: the same classification principle is used for categorising cost components in relation with depreciation of investment and OA&M behaviour.

The data structure can be visualised as follows:

![Figure 24: TERA Database Structure](image)

Service Demand

The demand for the applications depends on the tariff. One possibility to estimate service demand is to investigate the willingness to pay for given applications. This leads to demand forecast, which in turn allows the calculation of penetrations, based on the calculated costs of providing the service.

Another possibility is to estimate the maximum potential use for the applications and then make an S-curves (logistic model etc.) as an input to the forecasts.

The third alternative is to enquire directly by the potential customers about their expected forecasts for the applications.

A fourth alternative is to make a simple analysis focused on the development of demanded capacity for the customers and not look too much at the applications. Based on historical data and also subjective evaluations, forecasts of demand can be produced.
A mix of the methods suggested may be used or one specific method which may change from business case to business case.

The demand will vary depending of the type of company. It is possible to identify the variation if the survey is carried out among different type of companies.

**Geographic Demand**

If a comprehensive market survey is carried out and the results from each company is grouped in defined demographic strata, it is possible to estimate the communication need also in other geographic areas by taking into account the distribution of number of companies in each area.

**Traffic Characteristics**

Some assumptions have to be made regarding traffic generated from each application. For some applications the estimated traffic characteristics can be found in the literature. It is also possible to differentiate these results by carrying out a market survey asking different type of companies about their expected traffic behaviour.

The approach so far has been to estimate the subscription and traffic demand generated in each geographic area. Another aspect is to estimate the traffic between geographic areas. One method for making traffic matrix forecasts between geographic areas based on accumulated broadband traffic (generated from separate geographic areas), is to map the broadband traffic proportional with some correlated traffic - for example the financial transaction flow between the same geographic areas.

**Risk Analysis**

When performing sensitivity and risk analysis, the uncertain parameters are described by suitable probability density functions. **Note that various model variables can be correlated.** The techno-economic scenario is then calculated a certain number of times using Monte Carlo or Latin Hypercube simulation; each time a random number is picked from each distribution. The distribution in the outputs e.g. net present value (NPV) can then be analysed. **The risk analysis could be perform using ADD-in tool with Microsoft excel.**

**Network Externalities**

A theoretical model is developed (within the framework of TERA Project) based upon a three-dimensional demand function for telematics combined with a logistic curve reflecting the externality effects. The main outcome of the model is a function where the relationship between the size of the market and willingness to pay depends on the population size and income level of the region where telematics networks are installed. One of the issues under consideration by TERA Project using the TERA/OPTIMUM tool is the study of the so-called network externalities effects in the establishment and uptake of telecommunications services. The model is also tested now using a numerical example in TERA Project.

**Use of the OPTIMUM/TERA tool in the EURESCOM P901 Project**

In the previous chapters several important issues are underlined in order to provide useful information to the evaluators. In addition to these issues we may also consider the following parameters for OPTIMUM/TERA tool.
• The majority of the partners are experienced with the tool. It is very important to minimise the time required for the familiarisation with the tool because the project period is short.

• TERA (AC-364) [43] project Leader could provide all shareholders a license for using the tool for the purpose of EURESCOM. So there is no extra expenses for the project.

• We must focus on the programming capabilities of the tool. During the project period several new economical factors (a new methodology) could be used and they must be applied into the model. OPTIMUM/TERA tool is open to programming using Excel equations or Visual Basic code. Generally, only MS-Excel knowledge is needed and a novice user is able to develop a model.

• The calculation of the basic economical parameters is possible and extra parameters can be used.

• The demand model can be applied into the model as a time sequence that shows the evolution of the penetration for service.

• There is an OAM cost implementation into a Powerful Database, which is frequently updated, from TERA and EURESCOM projects.

• Worth to mention is the Add-in functionality for Risk analysis using Crystal Ball tool.

STEM

Introduction

This section gives a description of STEM, which is an advanced and widely used tool for techno-economic tool. The tool is designed by Analysys Ltd [44]. The Analysys STEM modelling system is a software platform for the development of financial models of telecommunication networks, services and businesses. Using STEM, the financial implications of alternative scenarios and strategies can be assessed and compared. STEM is pre-programmed with standard telecommunication and financial calculations with an easy-to-use Windows interface. This concept provides the user with a professional platform and give the user more confidence in the results than complex and often messy spreadsheets built from scratch.

STEM runs under Windows 95, Windows 98 and Windows NT.

STEM and financial modelling

The concept of STEM allows the user to develop financial models of telecommunication operators describing the services that are offered, the market segments to which the defined services are offered, and over which networks the services are launched.

STEM helps the decision maker to answer critical questions such as:

• How much does the network cost (OPEX and CAPEX)?
• What is the NPV of the investment project?
• How are overheads allocated?
• What are the main cost drivers?
• What risks can be expected

STEM makes it possible to model the relationship between the demand for telecommunication services (measured in terms of number of connections and amount of generated traffic) and the resources that the operator has to deploy - including network equipment, staff, vehicles, land and buildings, civil works etc.

STEM allows to analyse scenarios in a structured way and includes a variety of plotting routines where the scenario outputs can be shown in the same graph.

As is the case in all techno-economic tools, models for the demand, the cost evolution and the dimensioning rules of equipment, the tariff evolution of services, OA&M costs, and overall economic parameters such as project discount rate and tax rate are included.

The outputs are for example NPV, IRR, cashflows, balance sheet and profit and loss statement.

Who uses STEM?

STEM is used by:

• major public network operators (PNOs) - for tariff studies, interconnect pricing, cost analysis of services, competitor analysis and modelling, life-cycle costs of alternative technology strategies (e.g. fixed versus wireline access, supplier A or supplier B etc.), business case evaluation and roll-out planning.

• new operators - to investigate roll-out strategies for network infrastructures and to present quantified economic cases when lobbying regulators on interconnect agreements.

• regulators - to analyse the costs of alternative technologies, to justify interconnection and USO (universal service obligation) costs and to explore the impact of competitor interaction as well as price controls.

• equipment vendors - who wish to understand the cost structure of their customers in order to assist in product planning and in sales presentations. The cost of replacing existing equipment with new technology is important in such assessments.

Financial model of STEM

The service demand, tariff evolution of services and cost trends of cost elements are selected by the user. This is the actual modelling. The heart of the STEM tool which is the financial model calculated all the economic statements and metrics that are necessary when assessing telecommunication investment projects.

The following list contains some of the most common financial items covered by STEM:

• Long-term borrowing
• Share capital
• Dividends
• Gearing (=debt/(debt+equity))
• Tax
• Surplus Cash
• Cashflows and NPV
• Profit and loss statement
• Balance sheet
• Churn costs

The STEM paradigm

The STEM modelling system is a unique method for representing, in a structured manner, the relationship between service demand, network resources and tariffs. Whereas many techno-economic modelling systems such as OPTIMUM and ASTRA are mainly geared to access networks (OPTIMUM is more flexible), STEM allows the user to create a complete description of a telecommunication operator or a part of it (e.g. the access network in a given area). Once the invest project is defined in STEM, alternative strategies can be compared.

There are seven element types within STEM:
• Services
• Resources
• Functions
• Customer bases
• Locations
• Transformations
• Cost indices

The three “key elements” of the STEM modelling systems are Services, Resources and Functions as shown in Figure 25.

Figure 25 Key elements in STEM

In the following, a brief introduction to the characteristics of the STEM elements is given.


**Services**

These elements represent the services offered by the operator. The services are specified by the number of connections, annual traffic, busy hour traffic, tariffs (as a function of time). The service definition is used to calculate revenues and to give input to the Resources element which is described later. As mentioned earlier, STEM is flexible in many ways. - A complete operator business (although complex with many network elements and services) or only a part of the operator business (for example access network) can be described. Also the tariff definition is not necessary when only cost evaluation is performed. If required, a churn tariff can be specified.

**Resources**

The particular types of equipment e.g. ATM switches, DSLAMs and xDSL modems are represented by the Resources element. A Resource (network element) is described in terms of its physical characteristics and costs including physical lifetime, cost evolution, maintenance costs and unit capacity. The Resources element is analogous to the cost database of the OPTIMUM tool.

The service demand are met by the Resources in terms of the necessary number of various network elements each year (like the shopping list in the OPTIMUM tool). Installation costs, running costs etc. are calculated for each year in the study period.

**Functions**

Functions represents groups of Resources which perform a particular role within the network - this might be a network function, such as a local switch, or an organisational function, such as a personnel department. By grouping like Resources together, STEM can model the dynamic process of replacing one element with another, thereby representing the costs of replacing old equipment with new technology.

**Customer bases**

Customer bases represent the customers belonging to different segments (defined by the user) for example residential and corporate customers. The number of customers are calculated from the size of the market segments, the penetration of the services as well as the operator market share.

**Locations**

Locations represent the logical positions of network Resources such as local exchanges, base station sites, international and exchanges. The number of Resources allocated to each Location is generally time-dependent and is given by the network roll-out which again must satisfy the service demand of the customers at any given time.

**Transformations**

Transformations are used to represent special relationships between calculates quantities in the STEM model. It hat the advantage that you can update relations in a more systematic way than changing Excel equations and dragging. The transformations that are specific to certain Resources or Services can be shown in a pop-up window when clicking on the relevant icons. Examples of transformations can be the number of linecards per rack or conversion of busy-hour traffic into Resource capacity that needs to be installed.

**Cost indexes**
Cost indices represent the elements which make up the cost of purchasing and installing Resources (capital costs). Examples of cost indices are the cost indices of basic components such as electronics, fibre cable, copper cable, cabinets and ducts. For each of the cost indices, a trend is specified describing the future evolution related to present cost. The modelling of the cost evolution of network equipment is different from the methodology used in the OPTIMUM tool. In the OPTIMUM tool, each component belongs to a class for example electronics with a given learning curve, price in given year and parameters that describe the logistic curve (volume effect). In STEM the approach is different. For each of the Resources, the capital cost is specified in terms of the cost indices which make up its total cost. Together with the cost trend of each cost index, the future capital cost is calculated. An example: suppose that the capital cost (start year) of a given Resources is 50% electronics, 30% optics, 20% powering. The cost trends are given in relative decrease in cost: 10%, 7% and 1% per year respectively. The capital cost of the Resource at time $t$ is therefore given as

$$CapitalCost(t) = CapitalCost(0)\left[0.5(0.90)^t + 0.3(0.93)^t + 0.2(0.99)^t \right]$$

**The STEM calculation Cycle**

The calculation cycle of the STEM modelling system is shown in Figure 26. Tariffs, capital investments, running costs, depreciation are calculated as time-series as is the case in plain Excel. The STEM system is not an open environment; the system is updated in pop-up menus and dialogue boxes when clicking on specific items. This approach guarantees a more systematic handling of complex investment projects but it makes difficult to include new methodologies.

![Figure 26 The STEM calculation cycle](image-url)
STEM, a first evaluation

There is no doubt, that STEM is a powerful modelling systems. It is widely used within major incumbent operators as well as regulators. Its concept of a user-friendly graphical interface makes it easy to get an overview of specific parts of the network that is analysed and the characteristics of the elements such as costs are only a few clicks away.

In future versions of the STEM tool, incremental cost methodologies such as TELRIC will be included.

It is however not realistic within the time-frame of P901 to use STEM in the analyses of selected investment project for at least two reasons:

- the license is quite expensive. Even though the specific operator already has a license, additional licenses are not cheap and some administrative problems may arise when sharing the license costs between different departments/units within the company!
- the STEM modelling system is quite huge with many menus and options and it will take some time to become a “super-user”. An intensive course (4-5 days) will probably be needed.
- It doesn't have an open interface for making possible to include new methodologies.

INVAN

Introduction

This section describes the main characteristics of the INVAN tool (INVestment ANalysis of general telecommunication network). Some alternatives for using the INVAN tool in the P901 project are included at the end of the document.

The INVAN tool is an economical analysis plug-in for a set of dimensioning tools. It allows to show in a more accounting way the dimensioning results of the Telefónica planning tools (SDH, WDM, ATM, cellular, access, …). INVAN has an interface with them.

By taking the dimensioning results of the planning tools, INVAN is able to calculate different profitability indexes related to the investment project of installing the dimensioned network. NPV, IRR and payback period are calculated.

Input data

For performing these calculations, INVAN needs a set of input data:

- **Number and type of equipment**: it may be entered manually or read from a dimensioning tool. It includes the number of each network element, life period, installation and deinstallation time and a flag indicating if the equipment is purchased or rented.
- **Variation of costs**: for each network element, the variation of the purchasing and rental costs should be specified as a time series (or alternatively by using one of the defined cost reduction functions). This variation reflects the effects of learning and competition between suppliers and the effect of discount due to volume of acquisition.
Additional cost information: the maintenance cost percentage, residual value, amortising criteria and the rental costs (connection, month fee and churn costs) should be specified.

Incomes estimation: a time series with the incomes flow in all the years of the study period should be specified.

General data: information needed for the economical evaluation and scenario comparison should be specified as well. According to that, values for the taxes percentage, inflation, loan interest rate, non-risk investment interest rate and the length of the study period are needed.

Output data

By using the information presented in the previous section, INVAN calculates the typical investment evaluation criteria: NPV, IRR and PP.
Additionally, INVAN shows the following information:

- Variation of the NPV with the used discount rate.
- Cash flows for each year
- Splitting of costs into: new equipment, amortising, maintenance, rental and operation costs
- Profits and losses account for each year of the study period. Spanish accounting criteria are used. Then, assets and passive accounts are presented. The results are split into ordinary and extraordinary operations. The taxes are evaluated as well.

INVAN allows as well to compare different investment projects. The NPV variation of the same scenery with different general or financial data may be compared. Or, alternatively, different scenarios may be jointly shown. By analysing the joint variation of the NPV, the Fisher point of the two projects may be graphically located.

**Use of the INVAN tool in the EURESCOM P901 Project**

As explained in the previous sections, INVAN performs similar calculations than OPTIMUM ones: NPV, IRR and PP of the different investment projects. However, there are several differences between INVAN and the OPTIMUM tool

- INVAN has a direct interface with several planning tools.
- INVAN considers the effect of competition between suppliers and acquisition volume in the cost variation.
- INVAN considers directly the deinstallation of equipment in the middle of the study period.
- INVAN presents the results in an accounting way. OPTIMUM uses a more “free format”.

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**Figure 28: Comparison of the NPV of two different scenarios**

[Image of Figure 28: Comparison of the NPV of two different scenarios]
• INVAN allows to compare different scenarios inside the tool. The comparison of scenarios in OPTIMUM should be done externally.
• INVAN doesn’t have connection with a cost database. OPTIMUM has a direct link with an ACCESS cost database.
• OPTIMUM allows to customise the graphical and numerical results. INVAN is a closed tool, and only the pre-programmed results may be obtained.

According to this information, two different usage scenarios for INVAN in the P901 project may be thought:

1. Joint use of the INVAN tool with the Telefónica planning tools.
2. Use of some INVAN concepts inside the OPTIMUM tool.

The first alternative would allow to solve in a direct way the dimensioning problems related to the investment project (by using the Telefónica network planning tools). On the other hand, it has the drawback of the closed-environment that INVAN is. Then, it would be difficult to include new methodologies for taking into account other investment analysis methodologies (costing, market or externalities) that the P901 project is investigating.

The second alternative is more prone to joint work with other Project participants. Additionally, the open-environment of the OPTIMUM tool makes the work of adding new aspects in the investment evaluation methodology to be easier. In any case, there are several ideas that are present in the INVAN tool, but not in the OPTIMUM one:

• Consideration of competition between suppliers and acquisition volume in the cost variation of the network elements.
• Consideration of the deinstallation of equipment in the middle of the study period.
• Output results shown in a more accounting way
• Comparison of different scenarios inside the tool.

Some of these aspects are possible updates for the OPTIMUM methodology, and this may be utility of the INVAN methodology to the P901 project.

**TOPAS cost modelling & tool**

TOPAS stands for "Tool zur Optimierung von Ausbaustrategien". It was developed in the frame of an internal project of Deutsche Telecom based on the knowledge of the strengths and the weaknesses of TITAN.

The network specific models (like the Synthesis or the OPTIMUM model) are separated from the core of the program. The description of a network model is more general, consisting of network nodes and network elements as two classes of objects. The number of network elements is calculated from the relation between node requirements and system limits (which have to be specified in the database) - this is a similar procedure like in Astra. In the core of the program you can define each kind of networks (not only hierarchical structures). The limitation will arise if you choose a specific network model for the support of building up a network scenario. The modelling of the cost of the network elements (operation costs, price evolution) is the same like in OPTIMUM.
The ABOT tool

Tool and methodology description

The ABOT (Access Business Opportunity Tracing) methodology and tool was developed by ERICSSON AB [45,46]. The ABOT method is a software based business modelling tool implemented in Quattro Pro, as described in the figure below:

![ABOT method components](image)

**Figure 29 The components of the ABOT method**

The basic input data are:

- Geographical data
- Gross National Product per Capita
- Existing services and operators
- Services to be deregulated
- Strength and service mix of likely players
- Tariff level per service.

These input data then together with the database forms the required inputs to the model itself. The model calculates the Net Present Value per home passed over the investment period for each access project of each operator in an iterative process. The ABOT matrix in turn displays the NPV per operator for different service mixes.

Use of the ABOT tool in the EURESCOM P901 Project

The tool is an access network tool for strategic level evaluations, which handles multiple access solutions. In addition, one of its key features is the multiple competitor handling (service and competition simulations). It is easy to use, but at the same time probably is of limited suitability for concrete network projects. The component cost modelling is for instance very coarse. Some of the approach taken with the ABOT tool might nevertheless be useful in the work with defining the framework of the P901 studies, as for instance the market segmentation used in ABOT, in which both different spending levels of different households for the existing services as well as willingness to pay for new services are taken into account. However, ABOT documentation is very scarce, and the tool is not available according to the information we have. Thus the most P901 can get out of ABOT is probably some inspiring ideas on how to approach some parts of the issues we are facing.

Dimensioning tools

REFORMA

Introduction

This section describes the main characteristic of the REFORMA tool, [47]. Some alternatives for using the REFORMA tool in the P901 Project are included at the end of this section.
The generic name REFORMA covers a family of computer tools devoted to the planning of core networks supporting mainly optical fibre. These tools have been developed and are used in Telefónica since 1991 to dimension trunk networks. The initial versions of this family included only PDH systems. Nowadays, the last version of the REFORMA tool covers both PDH, SDH and WDM architectures. This version is Windows 95 based.

For a dimensioning problem the following inputs should be specified and given for REFORMA:

- network (nodes with available functionalities, links between nodes, with length)
- equipments (node prototypes, with capacity and cost data)
- transmission demands (with source, destination, capacity units and capacity, routing, protection and restoration rules if any).

Based on the above information, the REFORMA tool generates detailed dimensioning results (number of needed fibres and transmission equipment). Additionally, based on the cost input data, installation first costs are calculated as well.

**Network topology**

PDH, SDH and WDM technologies can coexist in the network. The primer intends to be installed plant, and the latter ones are used to upgrade the network to cope with the demand excess. Of course, the PDH plant may not exist at all.

The network is formed of an unlimited number of nodes. The nodes represent the different kinds of locations where equipment can be installed. Each node might have PDH, SDH and WDM equipment.

Different equipment may be installed in the nodes: TS, ADM, DxC 4x1, DxC4x4, WDM point to pint multiplexers and OADM. The dimensioning algorithms generate the number and type of equipment that should be installed in each node. This information depends on the traffic patterns of the scenario, protection and restoration strategies, type of domains (mesh, rings, optical) and so on.

The tool uses a multilayer hierarchy model. The multilayer hierarchy provides the representation of the multiplex structure as well as the transmission systems, fibres as cables, which constitutes a vertical representation. The considered transport layers are: VC-12, VC-3, VC-4, multiplex section layer, electrical system layer, optical system layer, fibre layer and cable layer. Each transport layer is a graph, containing the subgroup of nodes and the edges that represent the interconnections among those nodes in the layer.

The tool also handles the concept of subnetwork or domain. A domain is a subset of network nodes and a subset of connection links among the nodes. The domain provides a horizontal decomposition, orthogonal to the vertical decomposition of the transport layer hierarchy. Each domain has a prototype according to functional features related to the topology, routing, protection, level of hierarchy and technology.

The PDH prototype domains are:

- **Primary**: It is a subset of primary nodes and two secondary nodes. The topology in the cable layer can be a total or partial mesh. In the system layer, each primary node is a point to point connected to each secondary node.
- **Secondary**: It is a subset of secondary nodes. The topology in all the layers are meshes totally or partially connected. In these subnetworks, restoration is possible.

The SDH prototype domains are:

- **Two-fibre self-healing rings**: They are a subset of nodes with at least ADM/TS prototype. It is possible to define different protection schemes: Subnetwork connection protection, shared multiplex section protection and dedicated multiplex section protection.

- **Meshed**: They are a subset of nodes totally or partially connected. The protection schemes are: without protection, restoration, linear 1+1 multiplex section connection.

The WDM prototype domains are:

- **Point to point WDM systems**: two nodes are linked with a WDM point to point system. Electrical protection is used in this case.

- **Two-fibre OMS-SP rings**: They are a subset of nodes with at least OADM and DXC prototypes. Optical shared multiplex section protection is used. In this case. The SDH prototype is a meshed one.

The user can define any number of hub nodes in each domain. These hub nodes allow the connection among domains.

A scenario can have three networks (PDH, SDH and WDM). Each network is formed by a set of domains connected by hub nodes. This set of domains in the network can have a level of hierarchy, considered for the circuit routing. Therefore, it is possible to route the circuit with or without hierarchy. For example, in a PDH network the hierarchy is primary-secondary-primary. In a SDH network it is possible to have one-level, two-level or three-level hierarchy.

The tools include a module to help the user to define rings with some criteria. This module solve the problem to determine the number of rings, the number of nodes in each ring (also related to node clustering) and the interconnection among rings. Two different ways of combining rings are considered:

- **independent rings**: the network is made up of a set of overlapped rings guaranteeing that each demand is routed in a single ring.

- **dual homing rings plus independent rings**: The network is made up of rings interconnected through one or two cross-connecting nodes. The constraint that each non cross-connect node should appear in almost one dual homing ring must be satisfied. Additionally, independent rings can also be used.

**Traffic demand**

The tool considers circuits demand between couples of nodes. The demands are identified by the supported type of service, transmission speed and required availability. The considered services are from 2 to 140 Mbps. Four availability options are considered:

- **1+1 or 1:1 protection**: The demand has two different routes that cannot share any cable.

- **With diversity**: A demand has as much disjoint routes as the specified grade of diversity.
• Low priority: A demand can only use the route of another 1:1 demand while no failure is available.
• Related demand: Two demands with different source and destiny cannot share any cable in their routes.

**Input data**

The following data are needed for dimensioning a network scenario:

• The nodes. In each node, it must be specified its PDH and SDH behaviour.
• The cable layer topology: The tool deduces the fibre layer topology.
• The existing PDH systems, if any.
• The PDH, SDH and WDM domains. It implies: nodes, cables, hubs, domain prototype and protection schemes.
• Circuit demands: type of service, binary rate, protection scheme, grade of diversity and routing domains.
• Values of the availability parameters of the network elements implied in the reliability calculation model.
• Values of the parameters required by the cost model for each network element.

**Main planning functions**

The tool has the main planning tasks:

• Automatic or guided routing of circuit demands along the physical graph guaranteeing the path diversities and protection criteria specified by the user.
• Grouping of circuits, through the hierarchical levels of multiplexing, up to the transmission speed of the transmission systems.
• Optimised design of the standby network guaranteeing 100% restoration capabilities for single failures.
• In REFORMA-C, routing, grouping and standby network design are focused on the conservation of the existing routes and exploding of the installed transmission systems.
• Determination of the speeds of transmission systems to be installed and dimensioning of the required equipment in nodes and arcs.
• Reliability analysis of the routes.
• Economical evaluation of the network.

**Output results**

The REFORMA tool produce both textual and graphical results on:

• Transmission routes and reliability degree associated to each circuit demand.
• Restoration paths for interactively defined failures.
• Intermediary level of groups (2 to 140 and VC-1 to MTS-1) used by each demand.
• Required equipment and their cost.
Network elements cost

In order to evaluate the cost of the network, the REFORMA tool consider two types of elements:

- Physical cable infrastructure: its costs are linear functions of their capacities and lengths.
- Transmission equipment (WDM, SDH and PDH). Its general cost model depends upon its type, and it is modelled by a fix cost plus protection functionality cost plus cost per port and kind of port. Additionally, costs for the crossconnects include the cost of the switching matrix for various capacities. They refer to OADM, WDM point to point multiplexers, synchronous terminals, ADMs, crossconnects, line regenerators, EDFA, etc.

Moreover, REFORMA considers special costs related to the equipment reallocation operation in order to perform a proper exploitation of the existing routes and the installed transmission systems.

Use of the REFORMA tool in the EURESCOM P901 Project

As previously stated, REFORMA is a network planning tool that allows to dimension general trunk networks. According to this information, REFORMA cannot be used separately for performing all the calculations required by the P901 in the trunk network scenarios due to the following reasons:

- Although it allows to perform calculations on installed first costs, it cannot be used for performing advanced cost calculations: service cost breakdown, marginal costs, TELRIC, and so on.
- No tariffs are considered. Then, only cost calculation are possible.
- Additionally, the demands are an input to the planning tool. Then, it is not possible to consider any relation the demands and other input. This relation is needed as an advanced market model is considered.

On the other hand, the REFORMA tool is able to perform intermediate calculation on the dimensioning process of trunk network scenarios. From this point of view, the REFORMA tool may be complementary from other strategic planning tools. Additionally, the REFORMA tool may be used for helping on the drawing of simplified dimensioning rules for WDM and SDH architecture.

For example, a techno-economic tool such as OPTIMUM doesn’t include any information on the number of fibres rings needed in a scenario. In this case, the designer should input manually the equations that draw the number of each equipment and fibre infrastructure. REFORMA tool, in this framework, is able to provide useful information for deriving these equations.

INPLAN

Introduction

The aim of this section is to describe the main features of INPLAN tool, in order to allow a better understanding of its potentialities in the investment analysis.

Initially an overview of the architectural model and the software structure is presented; and then some implications of using INPLAN in P901 project are included.
The INPLAN tool

The INPLAN (Integrated Network PLANning) tool has been implemented by CSELT to support Telecom Italia in the planning activity of Regional Broadband Networks. It consists of a set of software modules operating in an integrated software environment. The tool can evaluate the impact on regional Network equipment and infrastructure (in terms of technical quantities and related investments) of different scenarios characterised by:

- Technical and / or architectural alternatives in the access and Transport Network
- Mix of services provided on Broadband platforms (POTS, ISDN, SDVB, Online, VoD), and related introduction items (percentage of penetration, traffic splitting among local, regional and national levels, etc.).

The two main features of INPLAN are:

- The integrated approach to the network planning, i.e. an “integrated planning” (using the same tool) of different network sections traditionally considered separately (Access Network, Switching Network and SDH transmission Network correspond to three software modules integrated in one tool).
- The use of a reference database collecting main data about present regional networks structure (nodes and links characteristics, subscribers, etc.) on which planning activity must be performed.

The architectural model

In Figure 30 the reference architectural model used in INPLAN is shown. The model represents a generic broadband Regional Network.

![Figure 30 INPLAN reference model for the BB Regional Network](image_url)

Access Network

The Access Network extends from the NT (Network Termination) on the user side to the access node, named ANT (Access Network Termination), on the network side, which is the border between the Access and the Transport Network. Each ANT is
connected to one or to Local Switches, depending on the options selected for the switching network.

The Access Network structure can be selected among a set of solutions:

- ATM PON
- SDH ring
- Radio (LMDS systems)

FTTE, FTTCab, FTTB, RTTCab are the supported configurations. The architectural and dimensioning accuracy achievable with the PON solution is higher compared with the other kind of solutions.

**Transport Network**

The regional Transport Network extends from the access nodes to the Transmission Gateway Nodes towards the national network. In the Transport Network can be identified the switching layer and the transmission one.

The Switching Network is based on a two-level hierarchical structure (Local and Backbone), with each local node connected to a couple of Backbone nodes in load sharing.

Two different options are considered in the tool:

- A short to medium term scenario, with two parallels Switching Network (both hierarchical), one for Broadband services (ATM) and the other one for Narrow band services (if considered).
- Possible medium to long term scenario, with one integrated Switching Network (ATM) for all services.

In order to support the planner’s work, networking algorithms have been developed for the automatic research of best paths between L.O. areas and ANT nodes, ANT and Switch nodes, etc. Moreover, SW routines perform automatic sizing and economic evaluation of alternative solutions. In particular, the tool can perform the sizing of Switch nodes and of Access systems using (depending on selected options) a statistical “traffic algorithm”, based on services penetrations foreseen, required bandwidths (upstream and downstream), traffics per user estimations, accepted traffic losses, etc.

For the provision of interactive video services (VoD-like) and IP services, Local and regional servers are included in the model but they aren’t dimensioned.

The Transmission Network is based on SDH technology and connects the ANT to the Local Nodes, the Local Nodes to the Backbone Nodes, and the Backbone Nodes to the Transmission Gateway Nodes (if not co-located). As far as the topology is concerned, it can be point to point or ring.

**The software structure**

The SW architecture of INPLAN is shown in [Figure 31]. HW/SW platform is based on a high level PC, equipped with Windows NT, Microstation graphic and Oracle database developing environment.

A main feature of the tool is the employment of a Oracle DB for each Regional Network structure. Accessing the DB it is possible to retrieve detailed information about the existing network, such as:
• The list of existing Local Office nodes with related data (hierarchical rank, subscribers number, copper distribution network parameters, etc.);
• Existing fibre optic carriers on the paths between nodes (number, length and size of cables, kind of laying, etc.);
• Alternative street connections for new fibre optic cables laying (if required).

The “Graphic Interface Module” allows creating a graphic representation of the physical regional network, logically linked to the Oracle DB. Background cartography, geographically referenced, can be employed for a right positioning of network nodes in the model. However, the Graphic Interface module and the background cartography should be considered optional features, which can assist the designer in dimensioning the network; in fact, for example, on the graphic interface the planner can manage all network elements (i.e. add/erase nodes and links, etc.) and edit related data.

Use of the INPLAN in the EURESCOM P901 Project

INPLAN is a tool to support the broadband regional network planning as regarding access, switching and transmission network. Once the dimensioning has been carried out it evaluates the installation first costs (IFC).

A generic economic evaluation tool, very simply, could be structured this way. Starting from the demand of telecommunication services the network is dimensioned. Once the dimensioning has been carried out we can arrive to the economic evaluation. Considering that network dimensioning is a necessary step towards any economic evaluation, INPLAN could be used in this step of the process; in fact it can guarantee a detailed dimensioning of the network, and its output could feed more specific tools, which allow economic evaluation.
Figure 32 Uses INPLAN within an economic evaluation

On the other hand the use of INPLAN implies several constraints:

1. INPLAN is a tool implemented to plan Telecom Italia broadband regional network thus it cannot be delivered “as is”. This fact implies that either EURESCOM purchases a licence or calculation will be performed only in CSELT.

2. The second constraint, maybe bigger than the previous one, is related to INPLAN database. At the present time the tool is fed by Telecom Italia database thus it contains confidential information regarding Telecom Italia network. Therefore it will not possible to use it; hence we will have to fill the database with new data. This is good because we can tailor the dimensioning to our requirement but it isn’t easy to generate a completely new database because a lot of information and costs tables must be input; in fact INPLAN works properly only if this information are provided.

3. The third constraint arises when using INPLAN as feeder to another tool. In fact INPLAN it is not an “open” tool and, for example, it is not possible to simply add a new service. Thus if we decide to feed another tool with INPLAN outputs, the services and the architectures expected for them, must completely match in both tools.

If we want to use INPLAN in order to help specific economic tools (in the sense that some of its formulas could be integrated in this tools) it is not easy. In fact most of INPLAN algorithms and formulas require detailed information (contained in the database). In conclusion INPLAN could be provide useful indication only if it is used completely naturally with all the constraints before stated.
Market modelling tools

Systemische Wirkungsmatrix (Influence Matrix)

Description

Influence Matrix is a simple technique that is used to identify the most important drivers and factors for a given subject. Therefore, if the subject is market modelling, then it could be used to identify the most important market drivers and factors.

The technique is applied when the number of drivers and factors are too many. In this case, by identifying and selecting the most important factors, a simple and manageable model can be designed. The concept is developed by the „Fachhochschule Bern“.

The first step is to list all possible parameters and factors that may have an influence on the subject - in our case the subject is market modelling. The next step is to place all the factors in a matrix and make an assessment of their influence on each other. An absolute assessment of the influence is often difficult to do, and indeed it is not needed. Furthermore, and for our methodology, it seems to be sufficient to apply four classifications of influence degrees, such as the following:

- No Influence = 0
- Weak Influence = 1
- Moderate Influence = 2
- Strong Influence = 3

These values are then put in a matrix table to indicate the influence of a vertical parameter (or factor) on a horizontal one.

The following 4 examples are shown on the following diagram:

- **A** indicates that the Influence of Access Technology (1) on Customer Mobility (5) is weak (i.e. = 1).
- **B** shows that the Influence of E-Commerce Development (7) on Demand for Services (6) is moderate (i.e. = 2).
- **C** demonstrates that the Influence of Competitors (3) on Expected Quality (10) is strong (i.e. = 3).
- **D** illustrates that Demand for Services (6) has no Influence (i.e. = 0) on Regulation (18).
Let’s consider a smaller example (in the table below) and see what the most important factors (or parameters) in a Project are.

### Table 2

<table>
<thead>
<tr>
<th>Influence of vertical on horizontal factor</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>AS</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual’s capability</td>
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<td>19</td>
<td>323</td>
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<td>Organisation</td>
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<td>16</td>
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<td>Team play</td>
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<td></td>
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<td></td>
<td>17</td>
<td>340</td>
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<tr>
<td>Information flow</td>
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<td>23</td>
<td>414</td>
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<tr>
<td>Infrastructure</td>
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<td></td>
<td>14</td>
<td>182</td>
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<tr>
<td>Norms and Standards</td>
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<td>Investment attraction</td>
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<td>9</td>
<td>90</td>
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<tr>
<td>Customer attraction</td>
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<td>14</td>
<td>140</td>
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<tr>
<td>Quality of deliverables</td>
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<td>12</td>
<td>312</td>
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<tr>
<td>Project control</td>
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<tr>
<td>Target setting</td>
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<td></td>
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<td></td>
<td>12</td>
<td>252</td>
</tr>
<tr>
<td>PS</td>
<td>17</td>
<td>18</td>
<td>20</td>
<td>18</td>
<td>13</td>
<td>2</td>
<td>3</td>
<td>10</td>
<td>26</td>
<td>18</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>1.1</td>
<td>0.9</td>
<td>0.9</td>
<td>1.3</td>
<td>1.1</td>
<td>7.0</td>
<td>6.3</td>
<td>0.9</td>
<td>1.4</td>
<td>0.5</td>
<td>0.4</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Since the main objective of this exercise is to understand the importance of each parameter, we need to consider the following:

- The sum of every row is so called the **Active Sum (AS)**, for every system parameter. This sum shows how strong the parameter influences the other parameters. In the above example, with a value of 23, “Information flow” has the highest degree of influence on the other parameters.

- The sum of every column is referred to as **Passive Sum (PS)**, for every system parameter. This sum shows how strong the parameter is influenced by the other parameters. In the above example, with a value of 26, “Quality of deliverables” is influenced the highest, by the other parameters.

- P is the product of AS and PS, which shows the **Networking degree** of a parameter. The higher the value of P, the stronger is the parameter’s networking degree in the whole system. In the above example, with a value of 414, “Information flow” has the highest degree of networking in the whole system.

- Dividing AS by PS results in the quotient Q, which shows the **Activity degree** of a parameter. A small Q indicates that the influence on a given parameter is greater than its influence on the other parameters. A parameter with Q<1 is referred to as a **Passive** parameter. The reverse is true for big Q. A parameter with Q>1 is regarded as **Active** parameter. In the above example, with a value of 0.4, “Project control” is the most passive parameter, while “Norms and standards”, with a value of 7.0, is the most active one.

Before making any conclusions, let’s remind ourselves of some weak aspects of the “Influence matrix”:

- The concept deals with the positive influences and not the negative ones. In spite of this weakness, the matrix approach helps to recover from side effects of such weakness.

- The concept deals with the values as constant, while as the time changes, the influences may also change. This means that “Influence matrix” is not able to capture the dynamic influence of different parameters, unless several tables are produced, across the time dimensions.

The tabular information can be presented in a graphical form. The software tool can generate such a graph that helps quickly to identify the Key Factors (key parameters).
Interpretation and Assessment

Now, what are the conclusions and what can we do with the results. The approach will help us to identify four types of parameters:

Active parameters (Q>1):
These parameters influence the other parameters a lot, while they themselves are less influenced by the others

Passive parameters (Q>1):
These parameters belong to a group, which has very little influence on the system. Any change in the system may have an influence on these parameters while in return they show no influence on the system.

Strongly networked parameters (big P):
Such parameters are engaged in a large number of influences. They strongly influence the other parameters while they themselves are also easily influenced.
Weakly networked parameters (small P):

These parameters influence the other parameters and thus the whole system very weakly. They themselves are also little influenced.

For a better understanding of a parameter’s behaviour, both P & Q of the parameter have to be examined. All the parameters in our example are positioned in the following diagram:

![Diagram example of the parameters](image)

**Figure 35 Diagram example of the parameters**

In the left part of the diagram are the passive components with small Q (<1) and, on the right the active ones with large Q (>1). The separating line between the passive and active components can easily be found.

Similarly, in the lower part of the diagram are the weakly networked components while in the upper part are the strongly networked ones. Here, the separating line is more difficult to be defined.

For our purpose, we would only be interested in the active (or nearly active) parameters, with the exception of key indicating parameters (e.g. a parameter like IRR in market modelling may eventually end on the left part of the table). Also, amongst the active ones, the very weakly networked parameters could be ignored. This will leave us with the blue coloured parameters in the above example.

**Conclusions**

With the utilisation of “Influence matrix”, we could examine a large number of parameters, and identify the most significant ones. The concept is simple, easy to use and effective. The quality of the outcome is very much associated with the quality of the assessment of the influences. It is recommended that such assessment exercise be
done in a group or workshop, for obtaining an optimal result. Therefore, the significant drivers / factors are the most active parameters with at least some degree of networking.

**GAMS**

(General Algebraic Modelling System) Copyright © 1998 GAMS Software GmbH, see [49].

The General Algebraic Modelling System (GAMS) is a game theory toolkit that has definitely developed for modelling and solving different types of optimisation problems. It provides a modelling environment support for different kinds of mathematical procedures and also the solvers (the solver is a special mathematical procedure for solving a programming problem). GAMS incorporates ideas from relational data base theory and mathematical programming, and merges these ideas to meet the needs of strategic modellers.

The user follows the same rules for different types of problems. So model generation is generic, it is independent of the solution algebra of the specific solvers. GAMS enables the user to build practical optimisation problems quickly and effectively.

**Advantageous features of the system**

GAMS makes possible the user to concentrate on the modelling of the problem. The system itself performs the time-consuming details. The tool is especially useful in case of large and complex mathematical programming problems.

The software is available both on PC-s and on workstations.

The GAMS high-level language formally is very similar to the commonly used programming languages. So it will be quite familiar to users having some programming experiences.

The user can change the formulation of a model very easily, and can change from one solver to another very simply. Model description is independent of the solution algorithm to be applied. Introduction of new methods does not require changes in the existing models. The representation of the problem’s logic is independent from the data.

Data has to be entered only once in familiar list or table form. Models are described in compact easy to read algebraic statements. Whole sets of constraints can be included in one statement, and GAMS automatically generates the constraint equations.

The system is flexible, models are portable from one computer to another. A model developed on a small PC can later be solved either on a larger computer.

GAMS is being enhanced and expanded continuously. It refers e.g. to language extensions, new system integration features, performance improvements and new subsystems.

The use of relational data model means that the allocation of computer resources is automatic. So, models can be built without taking care of the details of array sizes, address calculations, storage assignment, sub-routine linkages and so on.

The model is self-documenting in GAMS. The model development and model documentation is done simultaneously, so documentation is accurate and up to date.
The output is easy to read and to use. The solution report of a solver is formatted so that related equations and variables are grouped together. There is a possibility to tabulate the results very easily.

Models supported by GAMS

(Also the name of the different solvers specifically for the case can be seen.)

- Linear programming (LP)
  Solvers: BDMLP, CONOPT, CONOPT2, CPLEX, MINOS5, XA, ZOOM
- Non-linear programming (NLP)
  Solvers: CONOPT, CONOPT2, MINOS5
- Mixed-Integer Programming (MIP)
  Solvers: CPLEX, XA, ZOOM
- Mixed Complementarity Programming (MCP)
  Solvers: MILES, PATH
- Mixed-Integer Non-linear Programming (MINLP)
  Solver: DICOPT

Over and above these RMIP (Relaxed mixed integer programming), DNLP (Discontinuous non-linear programming) and RMINLP (Relaxed non-linear mixed integer programming) problems can also be modelled by GAMS.

GAMS solution of Game Theory models

The solution of game theory problems can be led into the solution of one or more of the above listed programming problems. In most cases game theory models can be formulated as MCP problems. GAMS has the implementation for the general N-player M-strategy Nash Game. In other cases the user has to prepare the implementation of the game to be solved.

The structure of a GAMS model

The GAMS representation of a programming problem is very similar to the algebraic representation, which is used in general by mathematicians. The algebraic representation refers to the indices of objects (considering e.g. markets, firms), to data concerning the above objects (e.g. demand, cost, supply, product quantity), decision variables (to be determined), constraints to be fulfilled and objective function to be minimised or maximised and so on. The GAMS representation of a problem is very similar to the algebraic one, the main difference is that it can be read and processed by the computer. Therefore a GAMS model is a collection of statements (which operate on the different components) written in GAMS language.
The basic GAMS components and their main functions

Main input components:

- **Sets**
  These are the building blocks of the GAMS models, containing the objects to which the indices in the algebraic representation refer. Of course there are typographical rules to define the sets.

- **Data (parameters, tables, scalars)**
  Data can be entered using three different formats: lists, tables (or matrices) and direct assignments. Using lists can be very useful when a parameter has one dimension, but this method can be very usefully applied in cases of sparse or super-sparse arrays or matrices. In cases when input data are derived from tables, the table format data entry can be very useful. In the case of the direct assignment functions are used for parameter declaration. The functions in the assignment statement may contain parameters that have already their assigned values.

- **Variables**
  The decision (or endogenous) variables are declared in a Variables statement. Each variable has a name, a domain, if it is not a scalar, and a text optionally. Every model must contain at least one variable, which is the quantity to be optimised (maximised or minimised). (GAMS has not explicitly an entity called “objective function”.)

- **Equations**
  In GAMS the word Equation encompasses both equality and inequality relationships. An equation name can refer to only one or several relationships. Equation definition statements are the most complex ones concerning their variety. The main components of an equation definition are the following: name, domain, domain restriction condition, relational operators, left-hand-side expression, right-hand-side expression.

- **Model and Solve statements**
  A Model in GAMS is a collection of equations. After defining a model, we can call the appropriate solver by using the Solve statement. It contains the name of the solution procedure, the name of the model, the variable to be optimised.

- **Main output components: Echo print, Reference Maps, Equation Listing, Status Reports, Results, Error Messages**
  These all refer to the outcome of the solution of the problem. This information helps the user to find errors in the representation, and helps documentation in case of a successful run.

An example for GAMS model structure:

```gams
$title Oligopolistic Competition - Examples from MP (OLIGOMCP,SEQ=133)
*
* References:
```

* Harker P T, "Oligopolistic equilibrium", Mathematical Programming 30 (1984) 105-111 (NB: The cost function given in this paper has a typo which has been corrected here.)

sets f firms /f1*f5/;

* \( f(q) = c q + \frac{\beta}{(\beta+1)} l^{-1/\beta} q^{(\beta+1)/\beta} \)
* \( f'(q) = c + \frac{q}{l} (1/\beta) \)

table data(f,*) cost function data
\[ \begin{array}{ccc}
   & c & l & \beta \\
   f1 & 10 & 5 & 1.2 \\
   f2 & 8 & 5 & 1.1 \\
   f3 & 6 & 5 & 1.0 \\
   f4 & 4 & 5 & 0.9 \\
   f5 & 2 & 5 & 0.8
\end{array} \]

parameter c(f), l(f), beta(f);
c(f) = data(f,"c"); l(f) = data(f,"l"); beta(f) = data(f,"beta");

positive variables
\[ p \quad \text{price}, \]
\[ q(f) \quad \text{supply}; \]

equations
\[ \text{demand} \quad \text{supply} - \text{demand balance}, \]
\[ \text{profit(f)} \quad \text{nash first order condition}; \]
demand.. \( \sum(f, q(f)) = 5000 * p^{**(-1.1)}; \)
profit(f).. \( c(f) + (q(f)/l(f))^{*(1/beta(f))} \)
\[ = p - q(f) * p^{**2.1} / 5500; \]
model oligop /demand.p, profit.q/;

* initial guess:
\[ q.l(f) = 10; \]
\[ p.l = (5000/\sum(f, q.l(f)))^{*(1/1.1)}; \]
solve oligop using mcp;
Availability

GAMS Demonstration System is available for free of charge. This is a restricted system, so without a valid GAMS licence the system comes with these limitations:

- Model limits:
  - number of rows: 300
  - number of columns: 300
  - number of nonzero elements: 2000
  - number of discrete variables: 50

- Compiler limits:
  - number of symbols: 1000
  - number of unique elements: 2000

The extended version (if someone needs it anyway) can be bought from the GAMS Development Corporation, see [50].

Supported platforms

The following versions of GAMS are available:

- 386/486/Pentium Version: This version runs on all DOS-compatible 80386 or higher PC with a math coprocessor and at least 4MB of memory. Runs under DOS, Windows 3.1, Windows 95, Windows NT and OS/2.
- Workstation version: Runs on Digital Alpha, Microvax, DECStation, VAX, HP 9000,300,700,800 series, IBM RS/600 series, SUN/SPARK and others.
- Mainframes and Super-computer Version: Runs on Alliant, Convex, Cray, Digital VAX, IBM.

GAMBIT

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The software was developed within the framework of the Gambit Project. The Gambit Project is funded in part by the National Science Foundation grants SBR-9308637 to the California Institute of Technology and SBR-9308862 to the University of Minnesota.

Gambit is a library of game theory software, written in C++ for modelling and solving n-person games given in either extensive or in normal form. There are two main tools for accessing the functionality of the Gambit library:

- Gambit Graphical User Interface (GUI)
- Gambit Command Language (GCL)

GUI is a program that offers an interactive graphics interface for the users. It is a menu driven program, which allows a user to interactively build up an extensive or normal form game. It solves the resulting game for Nash equilibrium using any of its built-in algorithms. It is able to convert from extensive to normal form. The Gambit GUI is not suitable for repetitive operations.

GCL is a specialised language that provides access to the programs in Gambit through a high level programming language. The language contains built-in data types for the different game elements. The language has flow control statements and user defined functions to facilitate the building of games or to make repetitive operations on games. However, it may often be convenient to build an extensive form game in GUI, and then operate on it in the command language. GCL can be used either in an interactive command line mode, or it can run in the background, taking its input data from a file.

Gambit GUI and GCL are compatible with each other, in the sense that they generate files that can be read by each other, and they call the same underlying library of functions.

**Supported platforms**

- IBM PC and compatible. Gambit is supported on any IBM PC compatible machine equipped with MS Windows 3.1 and above. A port to Win32 is in the works.
- Sun workstations. Gambit will run on most Sun workstations running either SUN-OS or Solaris. Either MOTIF or XView toolkits are required.
- IBM RS/6000. Gambit is supported on IBM RS/6000 machines running MOTIF.
- Hewlett Packard workstations. Supported using the MOTIF1.2 toolkit.

It is planned to develop versions that support Linux, Macintosh, OS/2.

**Installation of Gambit**

All the gambit files can be found at the Gambit World Wide Web site at:

http://hss.caltech.edu/~gambit/Gambit.html

The Gambit software Version 0.94 (Beta version) is of public domain, the files can be downloaded for no charge.
Representation forms of the games

A game can be specified in normal form or in extensive form in Gambit. The extensive form representation gives more information about the game than that of the normal form. The user-friendly Gambit GUI and the GCL language can be used to build up both kinds of games.

Extensive Form Game

The extensive form is a detailed description of a sequence of decisions made during the game. In this case the game is represented as a topological tree, that consists of nodes and branches. There is information that can be displayed, e.g. the probability of taking a branch, information set to which the node belongs to, the outcomes (payoffs), which are attached to terminal nodes. Figure 36 shows how Gambit GUI displays an extensive form game:

![Gambit display of an extensive form game](image)

The figure shows a simple two-player poker game, the description is as follows:

Each player places 1$ into the pot before starting. Player 1 (RED) draws a card, and he observes it, Player 2 (BLUE) does not know the result. Then Player 1 decides whether to FOLD or RAISE. If player 1 chooses FOLD, then Player 1 wins the pot, if the card is RED (a net gain of $1.0 to RED).

Player 2 wins the pot, if the card is BLACK (a net loss of $1.0 to RED).

If player 1 chooses RAISE, then player 1 throws 1$ into the pot, and 2 player moves.

If player 2 chooses PASS, then player 1 wins the pot (a net gain of 1$ to RED)

If player 2 chooses MEET, player 2 throws 1$ into the pot, and 1 must show the card:

If the card is RED, Player 1 wins the pot (a net gain of $2.0 to RED).

If the card is BLACK, Player 2 wins the pot (a net loss of $2.0 to RED)

In Gambit nodes are represented as horizontal lines, branches are two connected line-segments, “fork” and “tine”. Branches connect nodes to each other. A node can be root node, decision node or terminal node. In Figure 36 five nodes, which are followed by branches, are decision nodes, others are terminal nodes. The left side decision node is the root node as well. The root node represents the starting point of the game. At the decision nodes either a player or chance must make a decision. Branches represent different choices. The game ends at terminal nodes. In Figure 36 the outcomes are pairs of numbers, which follow the terminal nodes, and represent the payoff (e.g. profit, loss) of each player in case of reaching that terminal node. Decision nodes are represented by the colour of the player who makes a decision at
the node. If the decision is made by chance, and not by a player, the node and the
following branches are yellow.

Normal form game

Every extensive form game has an associated normal form. The payoff for a given
player under a particular strategy is computed as the sum of the realisation
probabilities of each node multiplied by the value of the outcome at that node. So the
payoffs in the normal form are simply the expected payoffs of each player from the
given strategy profile.[Figure 37] below shows the payoffs of the above game.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
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</thead>
<tbody>
<tr>
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<td>1.00,-1.00</td>
</tr>
<tr>
<td>31</td>
<td>-0.50,0.80</td>
<td>1.00,-1.00</td>
</tr>
<tr>
<td>12</td>
<td>0.00,1.00</td>
<td>0.00,0.00</td>
</tr>
<tr>
<td>32</td>
<td>0.00,0.00</td>
<td>0.00,0.00</td>
</tr>
</tbody>
</table>

Figure 37. Gambit display of a normal form game

Solution of the games

The solution of the games refers to the determination of the Nash equilibrium points,
in form of mixed or pure strategy equilibrium. Before computing the equilibrium
points, it may be useful to eliminate dominated strategies. This reduces the game, and
the program will run faster. If we want to find more than one equilibrium, then we
have to eliminate strongly dominated strategies. Any equilibrium of the original game
will be present in the reduced game. If we want to find only one equilibrium, we have
to eliminate weakly dominated strategies. Any equilibrium of the reduced game is an
equilibrium of the original game too.

Custom Solution

There are several algorithms implemented to solve games. It is possible to use Custom
Solutions for experienced users who are familiar with the properties of the individual
algorithms, where almost every parameter can be edited through solution-related
dialogue boxes. In this case the program makes no attempt to check for the validity of
the parameters. All the custom features can be selected in the boxes. Each solution is
controlled by three groups of settings:

- Algorithm
  Giving the actual algorithm to be used for calculating the equilibrium.

- Dominance
  In the case of NF-based algorithms dominated strategies can be eliminated first,
  just speeding up calculations. The type of dominance -week or strong - and the
  method to be used can be specified.

- Subgames
  Subgames may be marked to make the calculations faster.

Some algorithms need a starting point, this also can be given here.
Standard Solution

To allow simpler access to the basic features provided by the algorithms, there is a possibility of using the Standard Solution types. If the Standard Solutions are selected, the particular settings are then picked in the dialogue box. You can select what kind of equilibrium to compute - Nash or Perfect - and specify a maximum number of solutions to compute. When you select a Standard Solution setting, it automatically sets various parameters that control the computation. These parameters include how to eliminate dominated strategies, which algorithm to use for the computation, and the maximum number of solutions to search for. In case of normal form games the settings for each of the Standard Solutions are given in the following table:

<table>
<thead>
<tr>
<th>Type</th>
<th>Number</th>
<th>Game Type</th>
<th>ElimDom</th>
<th>Algorithm</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nash</td>
<td>One</td>
<td>2 person constant sum</td>
<td>Weak</td>
<td>LP-1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 person general sum</td>
<td>Weak</td>
<td>LCP-1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>N person</td>
<td>Weak</td>
<td>SimpDiv-1</td>
<td></td>
</tr>
<tr>
<td>Nash</td>
<td>Two</td>
<td>2 person</td>
<td>Strong</td>
<td>EnumMixed-2</td>
<td>Liap-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N person</td>
<td>Strong</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nash</td>
<td>All</td>
<td>2 person</td>
<td>Strong</td>
<td>EnumMixed-0</td>
<td>Liap-0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N person</td>
<td>Strong</td>
<td></td>
<td>Not guaranteed</td>
</tr>
<tr>
<td>Perfect</td>
<td>One</td>
<td>2 person</td>
<td>Weak</td>
<td>LCP-1</td>
<td>Not implemented</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N person</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perfect</td>
<td>Two</td>
<td>2 person</td>
<td>Strong</td>
<td>LCP-2</td>
<td>Not guaranteed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N person</td>
<td></td>
<td>Not implemented</td>
<td></td>
</tr>
<tr>
<td>Perfect</td>
<td>All</td>
<td>2 person</td>
<td>Strong</td>
<td>LCP-0</td>
<td>Not guaranteed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N person</td>
<td></td>
<td>Not implemented</td>
<td></td>
</tr>
</tbody>
</table>

Table 3

In the above table the algorithm’ name, the maximum number of solutions to be found is given. If this number is 0, the algorithm will only terminate when it has found all solutions. There are algorithms not guaranteeing to find all solutions (such as Liap).

In case of extensive form game one can select a refinement of Nash equilibrium to compute (Nash, Subgame perfect, and Sequential), and can specify a maximum number of solutions. (All the solution algorithms make use of marked subgames. They solve an extensive game by recursion through the marked subgames. If all subgames are marked, then any Nash equilibrium found will be a subgame perfect Nash equilibrium. Sequential equilibria prescribe optimal behaviour at any information set.) When you select a Standard Solution setting, it automatically sets various parameters that control the solution computation. These factors include whether to mark subgames before solving, how to eliminate dominated strategies, which algorithm to use for the computation, and the maximum number of solutions to search for before finishing the computation. In case of extensive form games settings are given in the following table:
<table>
<thead>
<tr>
<th>Type</th>
<th>Number</th>
<th>Game Type</th>
<th>Subgames</th>
<th>ElimDom</th>
<th>Algorithm</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nash</td>
<td>One</td>
<td>2-person constant sum</td>
<td>Mark</td>
<td>Weak</td>
<td>EF/LP-1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-person general sum</td>
<td>Mark</td>
<td>Weak</td>
<td>EF/LCP-1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>n-person sum</td>
<td>Mark</td>
<td>Weak</td>
<td>NF/SimpDiv-1</td>
<td></td>
</tr>
<tr>
<td>Nash</td>
<td>Two</td>
<td>2-person</td>
<td>Unmark</td>
<td>Strong</td>
<td>NF/EnumMiexed-2</td>
<td>EF/Liap-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>n-person</td>
<td>Unmark</td>
<td>Strong</td>
<td>EF/Liap-0</td>
<td>Not guaranteed</td>
</tr>
<tr>
<td>Nash</td>
<td>All</td>
<td>2-person</td>
<td>Unmark</td>
<td>Strong</td>
<td>NF/EnumMiexed-0</td>
<td>EF/Liap-0</td>
</tr>
<tr>
<td>Subgame</td>
<td>One</td>
<td>Perfect 2-person constant sum</td>
<td>Mark</td>
<td>Weak</td>
<td>EF/LP-1</td>
<td></td>
</tr>
<tr>
<td>Perfect</td>
<td></td>
<td>2-person general sum</td>
<td>Mark</td>
<td>Weak</td>
<td>EF/LCP-1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>n-person sum</td>
<td>Mark</td>
<td>Weak</td>
<td>NF/SimpDiv-1</td>
<td></td>
</tr>
<tr>
<td>Subgame</td>
<td>Two</td>
<td>Perfect 2-person</td>
<td>Mark</td>
<td>Strong</td>
<td>NF/EnumMiexed-2</td>
<td>NF/Liap-2</td>
</tr>
<tr>
<td>Perfect</td>
<td></td>
<td>n-person</td>
<td>Mark</td>
<td>Strong</td>
<td>NF/Liap-0</td>
<td>Not guaranteed</td>
</tr>
<tr>
<td>Subgame</td>
<td>All</td>
<td>Perfect 2-person</td>
<td>Mark</td>
<td>Strong</td>
<td>NF/EnumMiexed-0</td>
<td>NF/Liap-0</td>
</tr>
<tr>
<td>Sequential</td>
<td>One</td>
<td>2 or n-person</td>
<td>Unmark</td>
<td>None</td>
<td>EF/Gobit-1</td>
<td></td>
</tr>
<tr>
<td>Sequential</td>
<td>Two</td>
<td>2 or n-person</td>
<td>Unmark</td>
<td>None</td>
<td>EF/Liap-2</td>
<td>Not guaranteed</td>
</tr>
<tr>
<td>Sequential</td>
<td>All</td>
<td>2 or n-person</td>
<td>Unmark</td>
<td>None</td>
<td>EF/Liap-0</td>
<td>Not guaranteed</td>
</tr>
</tbody>
</table>

Table 4

In the entry for the algorithm column of the above table, first it is indicated whether the algorithm is applied to the extensive (EF) or normal (NF) form. Then the name of the algorithm is given. Finally, the number after the name indicates the maximum number of solutions to be found. If this number is 0, the algorithm will terminate when it has found all the solutions.

**Main features of GCL**

GCL is a simple, but powerful and flexible high level language for building, modifying and solving games given in extensive or normal form. It can be used for performing repetitive operations and procedures on games. Flow control statements makes the repetitive or conditional operations possible. With this capability GCL is also suitable for making certain types of econometric analysis of the games (e.g. one can investigate the effect of a parameter change).
GCL has a number of built-in data types to be used to describe the objects of the games. Data types may be of standard data types and also specialised ones representing the elements (e.g. players, strategies, nodes, information sets, actions) of the games. A GCL program consists of a series of statements. A statement in the GCL is an expression containing function calls. The function operates on objects of specified data types, and also returns an object and there are rules to be followed by the programmer. A GCL program uses the output of one function as input to the following function. In this manner very complicated objects (e.g. extensive form games) can be properly built. The objects in the GCL can be put into lists, and the functions can be run through a list, namely the function can be executed on each member of the list and it can result a new list. This also makes possible to perform repetitive operations.

Solution Algorithms implemented in GCL

Gambit has a number of algorithms to find Nash equilibrium. The appropriate algorithm to be used depends on a number of factors, most importantly, the number of players in the game, and the number of equilibrium you want to find.

- **EnumPureSolve**
  Computation of pure strategy Nash equilibrium is done by simple enumeration in case of a normal form game. All pure strategies are checked to see if they are Nash equilibrium. Optionally it can be set to find k Nash equilibria.

- **EnumMixedSolve**
  Finds all Nash equilibria (pure and mixed) of a two person normal form game.

- **GobitSolve**
  Computes an approximation to a sequential equilibrium of an n-person normal form or extensive form game.

- **GobitGridSolve**
  Performs a grid search to compute an approximation of equilibrium for a small two-person normal form game.

- **LcpSolve**
  This is a fast algorithm, which formulates and solves a two-person game (extensive or normal form) as a linear complementarity problem.

- **LiapSolve**
  Finds Nash equilibria via the Lyapunov function method. Works on either the extensive or normal form. This algorithm solves the problem as a function minimisation problem by the use of a Lyapunov function for Nash equilibria.

- **LpSolve**
  This algorithm formulates and solves the game as a linear program, and finds the minimax solution (a Nash equilibrium) of the game. This algorithm only works for two-person, constant-sum games.

- **SimpDivSolve**
  Computes a Nash equilibrium to an n-person normal form game based on a special subdivision algorithm.
As we have seen before in the tables presented for the Standard Solutions, the similar solvers (the same names without Solve) can be used in case of GUI.

**PowerSim® software application**

**Framework**

This section outlines the main features of PowerSim®, [51], a computer-based simulation package based on system dynamics that it may be used for business modelling. It has to do mainly with decision making, sensitive analysis and war gaming (competitive analysis in a given marketplace). PowerSim has been designed to provide the ability to make complex business simulators based on system dynamics technique.

**A word on System Dynamics**

System Dynamics is a computer-based simulation modelling methodology developed at MIT in the 1950s as a tool for managers to analyse complex issues. Its primary audience is still managers, although it has spread widely in academia, where professors and students use it to model systems from every conceivable discipline, from history and literature to biology, physics, and economics.

The word ‘dynamic’ implies change over time. System Dynamics does not see just events, but patterns of behaviour over time. This implies moving from event-oriented decision making to decision making based on patterns over time (patterns of system’s behaviour over time). A system’s behaviour is most easily ascertained using a plot of hard data, such as revenues, expenditures or net benefit. When these and other variables are plotted against time, they are called ‘reference modes’ as they become reference points in building a model of the real system. Looking at the time plots of the variables, any number of combinations between them may be seen (e.g. as sales increase, revenue decreases, because the growth in expenditures outstrips the growth in sales, or the opposite, an increase in revenues may correspond to an increase in revenues if expenditures drop as a result of economics of scale).

The term ‘structure’, as used in System Dynamics, refers to how the system elements are put together, that is, how they are connected to one another. The behaviour, as evidenced by the reference models, is a direct result of the structure. The main tools and rules of System Dynamics are listed below.

**Feedback loops**

A feed-back loop is a closed path that shows the circularity of cause and effect, considering the elements and interconnections that constitute the structure of a system. Each element acts as on the next, over and over around the loop. There are two types of feedback-loops: positive and negative.

Positive loops are reinforcing loops, compounding behaviour over and over again, amplifying it with each trip around the loop. For instance, positive loops are behind the growth of a company’s revenue, as seen in Figure 38 below. As revenue increases, there is more money to allocate to sales activities. The company may hire more salespeople or pay the current sales force for longer hours. This boost in sales activity in turn generates even more sales, which translate to more revenue for the company.
Positive loops generate the behaviour shown in Figure 39.

![Figure 38: Positive loop](image)

**Figure 39: Behaviour of a positive loop**

Negative loops are goal-seeking loops. They tend to cancel out any impetus that pushes the system away from the goal. In this way, they stabilise systems, as shown in Figure 40 below.

![Figure 40: Negative loop](image)

**Figure 40: Behaviour of a negative loop**

In this loop, as revenue increases from increased sales, expenses also increase, because the cost of producing every unit of output. The higher level of expenses leads in turn to a decrease in revenue. In this scenario, any increase in the level of sales is cancelled out by the resulting increase in expenses. Negative loops exhibit distinctive behaviour, as shown in Figure 41 below.

![Figure 41: Behaviour of a negative loop](image)
Real systems do not have only positive or only negative loops acting in isolation. The two types of loops interact throughout any complex system. The interactions of the elements of the system, within these two types of loops, produce a system’s unique behaviour over time.

**Stocks and flows**

Every element in feedback loops, and therefore every element in a system, is either a stock or a flow. Stocks are accumulations and flows are ‘take-outs’, in a way.

The value of a stock tells how the system is doing at any given point in time. This implies they are somewhat static or inactive. They have memory, which means they do not change instantaneously. A delay is involved in changing the level of any stock, through the action of flows.

Flows are action variables, creating dynamics when they accumulate in stocks. Without flows, stocks would never change, and there would be no dynamic behaviour. Thus, flows represent the system’s activity and are dependent on the values of the stocks, never on the values of any other flows. Because stocks are increased or decreased only by their associated flows and flows depend on stocks, an alternating stock-flow structure must exist for all systems.

**PowerSim Objects**

The entire structure of a given system can be represented in PowerSim by using icons representing stocks and flows, and defining the connections between them. They appear as rectangles and circles, as shown in the example of Figure 42 below. It represents the dynamic process of hiring-firing employees in a company.

![Figure 42: Alternating stock and flow structure](image)

In the diagram above, the cloud-like symbol to the left of the first flow and to the right of the second flow represent the source and the sink, respectively. This symbol indicates infinity and marks the boundaries of the model. In this simple structure, the stock is the workforce, measured in people, which is increased by the hiring rate (flow) and decreased by the firing rate (flow). The clouds tell that we are not concerned in this model with where the hired people come from or where the fired people go. That information is outside the model boundaries. In order to include this information, two more stocks would be required, extending the model boundary, as shown in below.

![Figure 43: Extended model boundaries](image)

System Dynamics uses some more modelling capabilities: constants (unchanging over the time period of simulation), auxiliary variables (used to combine or reformulate information) and table functions (auxiliary variables represented graphically). This is shown in Figure 44 below.
Figure 44: PowerSim: Constants, Auxiliary variables and Table functions representation.

Connections are made among constants, auxiliaries, and table functions by means of ‘information links’. These links show how the individual elements of the system are put together (in essence, they close the feedback loops). Information links can also transfer the level of the stock back to the flow, indicating a dependence of the flow on the stock, as well as the obvious dependence of the stock on the flow.

- **Flow**: A building block that influences levels. The flow is controlled by the connected rate variable, normally an auxiliary variable.

- **Information link**: A connection that gives information to auxiliary variables about the value of other variables.

- **Delayed info-link**: A connection used only when the auxiliary variable contains special delay functions.

Figure 45: Additional PowerSim modelling capabilities.

**PowerSim Constructor user’s interface**

A general view of the PowerSim Constructor user interface is shown in Figure 46 below. The simulation model is built within the boundaries of ‘Diagram1’, using the different model building blocks available (some of which have been described in above, such as stocks, flows, auxiliaries, constants and information links).

Figure 46: PowerSim Constructor GUI
PowerSim Constructor. Generic modelling example

The simple modelling example shown in the figure below simulates the interactions between the amount of merchandise the public orders to a given manufacturing company and its inventory and production levels.

---

**Figure 47 Modelling example**

**Modelled scenario**

A given manufacturing company experiences oscillations in its inventory and production levels, so it is proposed to build a model that explains the relevant interactions between the amount of merchandise the public orders and the inventory and production levels.

Production policy consists of two components, increasing or decreasing the inventory to match an optimal or desired level of inventory and keeping inventory high enough to cover the expected demand in the future. To be safe, it is decided to keep four times as much inventory on hand as it is thought to be needed to cover demand. In addition, production is set so that one-sixth of the discrepancy between the desired and actual inventory is corrected every week.

The assumptions about the future demand are based on the current order rate. The current order rate constitutes the real demand that the company faces. The company wants to correct one-eighth of the difference between the real and the expected demand every week. When the beliefs about the future demand change, this affect the desired level of inventory and the rate at which widgets are produced, according to the production policy described above.
When widgets are produced, they are stored as inventory. No product can go from the production line straight to the customer, it must go into the inventory first. Shipments are made only from this inventory. Because the company keeps four times as much inventory as it thinks it will need at any time, it is believed it is possible to ship the necessary products to fulfil every order.

The main block types involved in modelling this scenario and what they represent are given in the table below.

<table>
<thead>
<tr>
<th>Modelled concept</th>
<th>Block type</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory</td>
<td>Level</td>
<td>Represents an accumulation of items, in this case widgets.</td>
</tr>
<tr>
<td>Production</td>
<td>Flow (In-flow)</td>
<td>Production is a flow that adds to inventory.</td>
</tr>
<tr>
<td>Shipment</td>
<td>Flow (Out-flow)</td>
<td>Shipments drain inventory.</td>
</tr>
<tr>
<td>Production dependent</td>
<td>Link</td>
<td>Inventory has an effect on production.</td>
</tr>
<tr>
<td>on Inventory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desired inventory</td>
<td>Auxiliary</td>
<td>Desired inventory is not a real accumulation of inventory, so it can be represented with an auxiliary.</td>
</tr>
<tr>
<td>Time to correct inventory</td>
<td>Constant</td>
<td>Time to reach the desired level of inventory. It does not change throughout the simulation, so it should be represented with a constant (freely chosen by the company).</td>
</tr>
<tr>
<td>Order rate</td>
<td>Auxiliary</td>
<td>Order stream from customers</td>
</tr>
<tr>
<td>Shipments dependent</td>
<td>Link</td>
<td>The company ships the products to fulfil orders from inventory. In this case, Shipments have been set equal to Order rate.</td>
</tr>
<tr>
<td>on Order rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected demand</td>
<td>Level</td>
<td>Takes market information and converts it into action that controls how much the company produces.</td>
</tr>
<tr>
<td>Change in expected demand</td>
<td>Flow</td>
<td>Rate representing the change in the Expected Demand.</td>
</tr>
<tr>
<td>Time to change</td>
<td>Constant</td>
<td>Time factor to represent how long it takes to adjust expectations about demand to real demand.</td>
</tr>
<tr>
<td>expectation about</td>
<td></td>
<td></td>
</tr>
<tr>
<td>demand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected demand</td>
<td>Link</td>
<td></td>
</tr>
<tr>
<td>influences Production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected demand</td>
<td>Link</td>
<td></td>
</tr>
<tr>
<td>influences Desired</td>
<td></td>
<td></td>
</tr>
<tr>
<td>inventory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inventory coverage</td>
<td>Constant</td>
<td>The inventory should cover four weeks of expected demand.</td>
</tr>
</tbody>
</table>

Table 5
Running the model

The graphs following below are the output of the simulation.

![Graph 1: Expected Demand, Order Rate, Production vs Time](image1)

![Graph 2: Inventory, Desired Inventory vs Time](image2)

The model behaviour is as follows. Until period 20 all the variables appear as horizontal lines, indicating that the model is in equilibrium. The model is knocked out of equilibrium by the Order_Rate value after period 20, revealing the dynamic behaviour of the system. The results of the shocks are viewed in the behaviour of the other variables. Expected_Demand can be seen to increase, but ever more slowly, until it reaches the new level of orders coming in. The rate at which it increases is slowing because the flow changes Expected_Demand according to the discrepancy between the Order_Rate and Expected_Demand. This discrepancy is at its largest when the shock occurs. From then on, Expected_Demand is growing, which makes the discrepancy smaller and smaller, thus causing less to be added to the stock each time period. Production rises above the Order_Rate before settling into equilibrium again. Production is driven by two elements, Desired_Inventory and Expected_Demand. Both Expected_Demand and Desired_Inventory are rising.

The increase in Production is evident from the behaviour of the Inventory. As Shipments are equal to the Order_Rate, the increase in Shipments immediately starts to drain the Inventory. When Production reaches the Order_Rate, Inventory reaches
its minimum level. This occurs in approximately time period 25. From then on, the Production rate is higher than the Shipments rate, so Inventory is increasing. After time period 25, as the gap between Desired_Inventory and Inventory closes and Expected_Demand reaches the Order_Rate, Production decreases until it is in equilibrium. After approximately time period 70, the entire model is in equilibrium at the new, higher level of orders.

Use within EURESCOM P901

PowerSim may be used within the EURESCOM P901 Project to simulate various competitive telecommunications markets.

The simulations, featuring different scenarios (i.e. a variable number of telecommunication operators and regulators), would allow to experiment different business strategies and see how the final results are influenced by the market variables involved. Often through the process of trial and error, the final output of the simulation would be optimised by redefining all the tactical and financial implications of a business decision.

<table>
<thead>
<tr>
<th>PowerSim ®</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages</td>
<td>Disadvantages</td>
</tr>
<tr>
<td>Flexible for many graphical cross-correlations among all the simulated variables and parameters.</td>
<td>It may not be useful for specific tasks within the project (e.g. network planning or cost modelling).</td>
</tr>
<tr>
<td>Not difficult to use. Easy-understanding GUI.</td>
<td>Requires a highly abstract thinking.</td>
</tr>
</tbody>
</table>

Table 6 Advantages and Disadvantages of PowerSim ®

Risk Analysis

Crystal Ball Pro

Introduction

This section gives an introduction to Crystal Ball which is a user-friendly, graphically-oriented forecasting and risk analysis program that works with Microsoft Excel.

Crystal Ball is easy to learn and easy to use! Unlike other forecasting and risk analysis programs, the user does not have to learn unfamiliar formats or special modelling languages. All one needs is to create a spreadsheet model. Crystal Ball is based on a technique called Monte Carlo simulation, which will also be described in this document.

Monte Carlo simulations

Monte Carlo simulation is a classical approach used to assess the impact of the uncertainty in multiple input variables (independent variables or assumptions). In the model, all the uncertain input variables are assigned probability density functions. In each run of the simulation, random numbers are picked from each probability
distribution and the model calculates the output values (dependent variables or forecasts). At the end of the simulation, we have a thorough statistical description of the output e.g. the NPV of an investment project. The Monte Carlo simulation methodology has advantages as well as drawbacks compared to sensitivity analysis.

When performing “what-if” or sensitivity analysis only one assumption is change at a time to see the change in one ore more outputs. Exploring the range of possible outcomes is therefore next to impossible using sensitivity analysis. While sensitivity analysis tells you what is possible it does not tell you what is probable!

A Monte Carlo simulation takes into account the probability of outcomes. Further, correlation between uncertain variables can be catered for. However, there is one drawback or hurdle when using this methodology:

1. It is laborious and often even impossible to determine the “right” probability density functions for the assumptions
2. It can be even more difficult to identify meaningful values for the correlation between assumptions
3. Last but not least: there is a challenge when it comes to interpreting the results and explaining them to managers!

The question is now: how can we tailor our risk framework in order to make the use of Monte Carlo simulations more appealing and reliable?

Methods that provide quantitative information on related uncertainty parameters and risk factors are dealt with in Deliverable 2, [1].

Choice of probability density functions

How do you know which distribution type to choose for each assumption? If you have historical data, Crystal Ball [52] matches your data against each continuous probability distribution (Normal, Lognormal, Weibull etc.). A mathematical fit is performed to determine the set of parameters for each distribution that best describe the characteristics of the data. The quality or closeness of the each fit is judged using a goodness-of.-fit test [53]. The distribution with the highest ranked fit is chosen.

However, if you don’t have any historical data to rely on which is obviously the case for let’s say penetration or market share of future services that do not exist today, generic assumptions must be made. For example a market share is automatically fixed between 0 and 100%, therefore a limited distribution should be chosen in this case. The Beta distribution has the flexibility because mean value and standard deviation can be assigned independent of the upper and lower limits (contrary to the rectangular distribution).

If for instance you have an uncertain variable that in principle can take any value between 0 (zero) and infinity a Lognormal distribution could be relevant if:

- The uncertain variable is positively skewed with most of it’s values near the lower limit
- The natural logarithm of the uncertain variable yields a Normal distribution

In other assumptions, discrete distributions like e.g. the Binomial distribution might be relevant

In Figure 49, the types of probability distributions handled in Crystal Ball are shown:
For each of the uncertain variables, it is recommended to write down all the information you have about the characteristics such as mean, variance, limits, skewness, symmetry etc.

In the Crystal Ball terminology, independent variables/cells that are assigned uncertain via probability distributions are called “assumptions” whereas the resulting outputs are called “forecasts”. A simple example is

**Multivariable sensitivity analysis**

After having determined the probability distributions of the uncertain variables in the model, a multivariable sensitivity analysis is carried out. A multivariable sensitivity analysis is simply a Monte Carlo simulation without correlation of assumptions. The assumptions are ranked by contribution to variance of the output. The assumptions that have insignificant contribution to the output variance(s) are eliminated from the model. The number of assumptions is now narrowed down. This has two major benefits:

1. The problem is clarified and there are fewer variables among which to determine correlation
2. The calculation time decreases

The number of uncertain assumptions, the number of forecasts (e.g. NPV) and the number of runs in a simulation have a dramatic impact on the required memory and thereby calculation time of the simulation.
Correlation
In the “real world”, assumptions are not independent; there will inevitably be correlation between some of them.

When the values of two variables depend upon one another in whole or in part, the variables are considered correlated. If the increase in one variable results in the increase of the other variable, the correlation is called positive. If the increase in one variable results in the decrease of the other variable, the correlation is called negative. The amount of correlation is described by the correlation coefficient $r$ ranging from $-1$ to $0$ for negative correlation and from $0$ to $1$ for positive correlation. A correlation coefficient of $0$ indicates that the two variables are unrelated.

Rank correlation is used to correlate assumption values. This means that assumption values are replaced by their ranks from lowest to highest value by the integers 1-N, prior to computing the correlation coefficient. This method allows us to define correlation between non-identical distributions [52]. The correlation coefficient is calculated from:

$$
\text{Corr} = \frac{n \sum_{i=1}^{n} xy - \sum_{i=1}^{n} x \sum_{i=1}^{n} y}{\sqrt{n \sum_{i=1}^{n} x^2 - \left( \sum_{i=1}^{n} x \right)^2} \cdot \sqrt{n \sum_{i=1}^{n} y^2 - \left( \sum_{i=1}^{n} y \right)^2}}
$$

where $n$ random numbers are picked from the two distributions $x$ and $y$.

After having identified the relevant variables to consider in the model, correlation is now introduced and the simulation is run again and the output statistics are analysed and interpreted. There is no exact formula that gives you the number of runs necessary in a simulation. A moderate number, let’s say 1000 is a good starting point. Later this number can be increased to 2000. If the impact is significant, the number of runs must be increased further until some level of convergence is seen.

Optimisation under uncertainty
When analysing complex problems dealing with uncertainty it is important to distinguish between uncertainty which is not controllable by your organisation and so-called decision variables. Decision variables such as pricing strategy parameters and roll-out metrics can be optimised to get “optimal” results under given uncertainty. Optimal does not mean optimal in a strict mathematical sense, but a set of good solutions given certain criteria. OptQuest® [53], which is an add-in to Crystal Ball, incorporates metaheuristics to guide its search algorithm towards better solutions. Metaheuristics is a family of optimisation algorithms that includes genetic algorithms, simulated annealing, tabu search and their hybrids. The approach used by OpQuest uses a form of adaptive memory to remember which solutions worked well before and recombines them into new, better solutions. Since this technique does not use the hill-climbing approach, it does not get trapped in local solutions.
CASPAR

Computer Aided Simulation for Project Appraisal and Review

Provided by the Project Management Group, Department of Civil and Structural Engineering, UMIST

The CASPAR program is particularly effective in the assessment of risky projects or of the appraisal of projects in the very early stages when data is subject to most uncertainty.

The basic model of the proposed project can be re-run with data changes. Alternatively, the implications of risks and uncertainties can be determined by performing sensitivity and probabilistic risk analysis. The relative effect of delays, changes in costs, revenues and efficiencies can be demonstrated.

In principle, any piece of data is uncertain and could assume a range of possible values. The basis of any risk analysis technique is to allow the data to assume this range of values. For example, duration and costs for specific activities are not given single values, but are considered over a range of values within which the decision-maker believes they are likely to lie.

At the simplest level, each risk may be treated independently of all others with no attempt made to quantify any probability of occurrence. The effects of each risk may then be accumulated to provide a range of estimated values. Greater sophistication can be achieved by incorporating probabilities and the interdependence of risks into the calculations.

The greatest value of risk analysis in the early stages of a project is to establish confidence limits for the cost and duration predictions and to indicate the adequacy of contingencies included in the sanction estimate. Both, sensitivity and probability analysis have an important function related to project management as the simulations quantify the consequences of any action or inaction.

The CASPAR time program

To perform a time risk analysis, the project is first represented by a network that defines activities of work and their relationship with one another. The effect of changes in activity durations on the duration of the project can then be assessed.

Sensitivity Analysis

In the time program, a sensitivity analysis can be performed to assess the effect of change in the duration of individual or small groups of activities on the project end date.

During a sensitivity analysis, the program takes each activity, or group of activities, in turn and alters the duration's over the defined range. For each change of activity duration, a new project end date is calculated and a range of project end dates is thus produced. The sensitivity analysis results can be presented as a sensitivity diagram.

Time Probability Analysis

Each estimate of activity duration can be represented by optimistic, pessimistic, and most likely duration. In general, the probability of occurrence of the most likely duration will be the highest, while the probability of the optimistic and pessimistic duration occurring will be lower. This defines a probability distribution for the
activity. The probability of all the activities being completed either at their optimistic or pessimistic duration is very small. In practice, some will tend to their optimistic duration, some to their pessimistic duration, and the majority will attain their most likely duration. Monte Carlo techniques provide a method of calculating the cumulative effect of this by substituting different values for the duration of each activity into the network. These values are randomly chosen within the limits of the optimistic and pessimistic duration and according to the specified probability distribution. This is repeated a number of times. In the same way as each individual activity has its duration described by a probability distribution, so will the calculated project end date.

Probability analysis in the CASPAR time program is concerned with the effect that uncertainty can have on the whole project network, and therefore allows the user to alter the duration of each activity. The probability analysis produces output for the project end date, every activity, and any milestone.

The CASPAR cost program

The CASPAR program was designed to be used at the project appraisal stage. At appraisal, there is likely to be a degree of uncertainty about most of the data available. Using single data values (considering CASPAR as a deterministic model) gives one result for each of the economic parameters. But, since the data is estimated it lacks certainty. If it is assumed that the single data values are best estimates, the final result conveys a false degree of certainty and obscures any bias that may have been present in the best data estimates.

In the cost program, risk analysis produces a range of values for the economic parameters which highlight the effect of delays, changes in costs, and so on. (CASPAR shows the effect of risk analysis on internal rate of return, net present value, cash balance (cost), cash lock-up, and payback period.)

To allow every piece of data in a cost model to assume a range of values would require considerable computer power to manipulate and store the data that would be produced from all the possible combinations of values. A microcomputer does not have this capability. Moreover, this would probably bring a higher degree of sophistication into the appraisal process than is either justifiable or advisable. The CASPAR program therefore, allows the user to specify ranges for up to twenty risk variables at a time. The risk variables in CASPAR are defined in terms of various elements of the deterministic data. A percentage range change is defined for each risk variable and all data elements of the variable will be altered over this percentage range. In the simplest case, the duration of one activity may define a risk variable. In more complicated cases, activity durations, costs and quantities of resource may all be combined in one variable. The expertise required of the user in defining the variables and building the model initially to allow for fully defined variables is considerable.

In a probabilistic risk analysis, each variable is allocated a value within the defined range according to a defined probability distribution. However, in reality, one variable may be directly affected by another; delay in design may affect the construction duration for example. This linking of certain variables such that they do not choose values within their range totally independent of other variables is known as ‘correlation’. However, the degree of correlation between variables is often difficult to quantify, and (subjective) judgements by the program user are necessary if correlation is to be used. The CASPAR program allows the user to make these subjective judgements.
Sensitivity analysis

The sensitivity of the economic outcome of the project to the occurrence of any one risk or uncertainty can be assessed. Sensitivity analysis looks at each risk individually and independently. CASPAR takes each variable in turn and alters the value of each element of the variable over the defined range in a given number of steps. For each step new economic parameters are calculated and so a range of outcomes is produced.

In practice, a sensitivity analysis will be performed for a large number of variables in order to identify those which have a high impact on the economic parameters, and to which the project will be the most sensitive. With experience, the number of variables assessed can be reduced since those having a high impact on a certain type of project tend to become easily recognisable.

Although CASPAR allows only 20 risk variables to be assessed in any one sensitivity analysis run, this can be repeated any number of times to allow sensitivity analysis on an unlimited number of variables.

If several variables are assessed, a graph of the results is a useful presentation that quickly indicates the most sensitive or critical variables.

Probability Analysis

In reality it is likely that some combination of the variables considered individually during a sensitivity analysis will occur. It is also highly unlikely that the probability of each value within the chosen range will be equal. To assess the implications of different probability distributions and the combination of the variables, CASPAR will perform a probabilistic risk analysis. However, a problem arises in trying to calculate the probability of occurrence of specific outcomes of the risks, (and therefore in defining the probability distributions). For many risks there is insufficient objective or historical data upon which these calculations can be based. It is therefore necessary to make subjective judgements and this often leads to scepticism of this form of risk analysis. But it should be remembered that subjectivity is not absent from single figure estimates.

In the probabilistic risk analysis, different values of the variables are combined in a Monte Carlo simulation. The frequency of occurrence of a particular value of any one of the variables is determined by defining the probability distribution to be applied across the given range of values. The types of distribution allowed by CASPAR are as follows:

- Triangular
- Stepped triangular
- Uniform
- Stepped uniform

A triangular probability distribution has been assumed for each variable over the range of variation. The range specified for each variable indicates the promoter’s opinion of the degree of uncertainty about the original predictions (the most likely prediction).

CASPAR could be a good tool for making a risk analysis during the implementation phase of investment projects provided that the original project plan already exists. Depending on the results it can be made a contingency plan or ones can be used to support a Real Option.
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