



**SAAD DAHLAB UNIVERSITY OF BLIDA 1**  
**Institute of Aeronautics and Space Studies**



Master II / Aeronautical Structures

Course Material

# **Project Management**

by

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**Objectives of this course:** This course aims to introduce students to the principles and methods of project management, enabling them to effectively plan, organize, monitor, and evaluate project implementation. It emphasizes goal definition, cost, time, quality and risk management, as well as teamwork and communication. Students will also learn to use modern project management tools.

**By the end of this course, students should be able to:**

- ) Understand the key concepts, roles, and lifecycle of a project.
- ) Clearly define project objectives, deliverables, and scope.
- ) Develop a comprehensive project plan including cost, time, resource, and risk management.
- ) Use project management tools for monitoring and control.
- ) Lead and coordinate a project team effectively.
- ) Communicate clearly with stakeholders.
- ) Apply modern project management approaches.

**Key Words:** Project Management, Project Lifecycle, Planning, Objectives and Deliverables, Cost and Resource Management, Gantt Chart, Critical Path (PERT/CPM), Risk Management, Quality Assurance, Performance Evaluation, Monitoring and Control.

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## Introduction

The organisation and management of an enterprise is increasingly considered from the viewpoint of gaining a competitive advantage, seeing that the technical equipment of other firms may be the same as theirs and technology can often be acquired. Organisation and management are more difficult to imitate and so determine the characteristic of winning strategy i.e. uniqueness.

The continuous evolution of technology and competitive and market dynamics convince managers, though the firm may be only carrying out traditional activities of production and control, of the wisdom of focusing greater attention on the management of change and innovation. It should be deemed competitive and strategic rather than confined to the mere role of supplier of specifics for the routine activities.

The risks increase but also the opportunities. It is important to be prepared to play a proactive role; if a project could be considered a wager on the future, this should be the best that could be done and its pursuit the propellant of all the activities.

The power to innovate and a firm's success are becoming closely linked to its ability to manage product development projects, service planning and improvements in the firm's internal and strategic processes in short management-by objectives.

The change should be managed not just to avoid being swept away, but to use as a competitive weapon. If we define a project as a group of integrated activities aimed at carrying out one or several objectives of quality within a certain time and with a limited budget and availability of resources, it is clear how important project management is and its close correlation with the firm's performances.

This *modus operandi*, besides being the basis of industrial production, is essential in civil and industrial construction sectors, engineering services and the increasingly popular engineer-to-order and turnkey contracts. Its use can be extended to the reorganisation of Public Offices and various research projects, whether commissioned by local, national Community authorities, for which a strict organisational–managerial approach is required.

It should be remembered that though product design and development (integrated with manufacturing and marketing techniques), design and service management (including Public Administration) and engineer-to-order production are very different activities, they have a common denominator that is they are strongly oriented towards customer satisfaction.

This course describes in a precise but practical way the most recent principles and techniques of project management, at the highest international standards. The course deals with the project management applied to the industrial sectors, in particular the engineer-to-order and plant construction according to international contracting. It is unique because of the integration of project management fundamentals with the practices of international contracting, which characterise planning, design and construction of large works (such as plants and machinery) in the industrial sectors.

The challenge faced, having analysed numerous techniques on project management, was of making a contribution to a subject that is, on one hand, going through a phase of rapid growth at times almost explosive and on the other quite broad and varied.

Up-to-now this topic highlight how difficult it is to link the exactitude of scientific management with the practical needs and variety of the projects themselves. The objective is then to present a text that is methodologically exact but at the same time manageable!

The methodology, tested in numerous qualified firms, describes a company-wide and multi-project approach to management, involving all areas of the firm in an integrated system of projects.

In particular the Company-Wide Project Management (CWPM) approach aims at implicating the innovative processes, adopting a philosophy resembling the one Total Quality Management (TQM) applies chiefly to operational activities (remember the importance of procedures in the Manual of Quality), in that case extended upstream as far as the design function, thanks to the concepts of upward quality and reduction of the sources of variability. Similarly, that notion (in all and with all the areas and skills of the firm) can lead now to a greater diffusion of project management even in the opposite direction, that is from upstream to downstream, stretching from the traditional sites (technical and planning offices) to the whole enterprise.

In such a situation, first the principles and instruments of project management are developed internally and then exported, having been reclassified as systemic and made available to all. They have now become an occasion of integration and a method of coordination. In addition, the self-same creation of projects is modified. They can arise and/or be required anywhere in the firm because they are linked to change, improvement and the firm's need to be a dynamic organism in a dynamic environment. If TQM identifies and involves all the subjects that can contribute to quality and service, CWPM has the onerous but determinant task of offering tools to these subjects so that they can improve quality system and make it dynamic and flexible: in other words, to manage change and innovation.

The greater complexity of the environment now necessitates managing several projects at the same time, i.e. as a project portfolio, using other principles and techniques determined by Multi-Project Management. These concentrate on the organisation of human resources shared among the projects, and pervade the strategies to the point where the so-called multi-project/multi-product strategies (such as the platform projects, design transfer, etc.) are side by side with the traditional ones of product and project strategies.

# Chapter I

## The Project Management Process and Management of Contract Work

### I.1 Project Management: A Process-Based Approach

A project can be defined as a set of complexes, coordinated activities with a clearly defined objective that can be achieved through synergetic, coordinated efforts within a given time, and with a predetermined amount of human and financial resources.

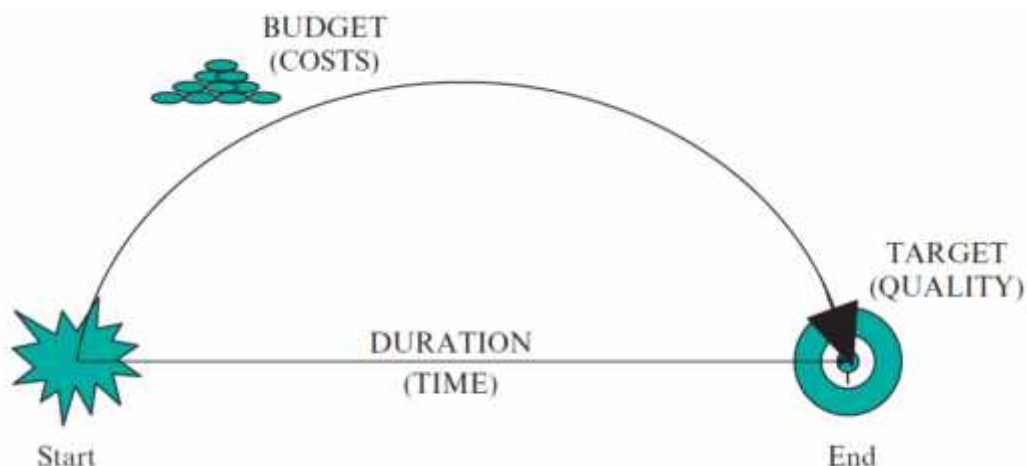
What distinguishes a project (no matter its degree of innovation) from all other activities carried out in a firm is that it always has a beginning and an end. It is temporary and sooner or later will finish (either because the objective has been achieved, the scheduled time has passed, the financial resources have been used up, or the organization involved has closed down).

But what does managing a project mean? Managing means dealing with variables that can be more or less influenced: it is impossible to manage when no variation is allowed or, likewise, when the factors are beyond control, since managing means making decisions and acting accordingly (i.e. planning and executing interventions).

What can be managed are those variables that are typical of a project, since they are linked to its definition. The main variables are as follows: 1.Quality, 2.Time, 3.Costs, 4.Resources.

The first three variables are project performances, whereas the last represents the (human and technological) restraints limiting the activities needed to execute a project (e.g. the availability or saturation of the resources within 24 h, etc.) (Fig. I.1). *A project is an organizational process*, and hence has all its features.

According to the Oxford English Dictionary, a process can be defined as ‘a continuous and regular action or succession of actions, taking place or carried on in a definite manner and aimed at achieving some result’. A business process consists of a set of activities; each activity in turn is formed by elementary operations, requiring specific resources, and is aimed at achieving an objective that concurs, with those of all the other activities, to the overall goal of the process, a goal that integrates the objectives of the various activities.



**Fig. I.1** Characteristics and performances of a project

It must be stressed that all these activities have a synergic effect on the process (i.e. the overall result is greater than that sum of the single, partial results) and require the involvement of a variety of departments/units (which can be considered as reservoirs/incubators of the expertise needed to carry out the process) within the organization.

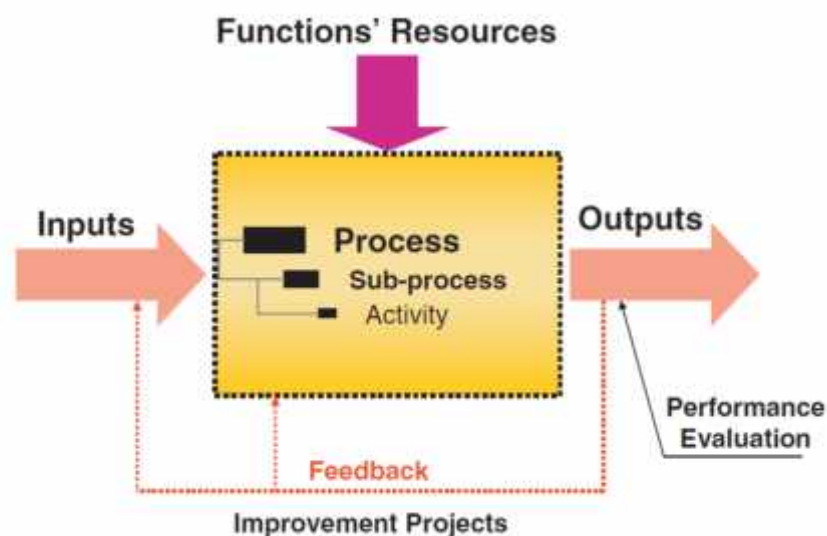
To produce outputs destined for downstream, the activities forming a process require upstream inputs, as well as the competency of the resources carrying out the activities (resources *borrowed* from the departments/units of the company): upstream and downstream can coincide as described in more detail in the next few pages with other processes carried out inside the company or by external suppliers and external customers, respectively (Fig. I.2).

A process thus structured helps distinguish between output (or *result*), internal, and input (or received) performances, making it easier to determine where to carry out measurements and therefore estimate the performances with a greater degree of precision.

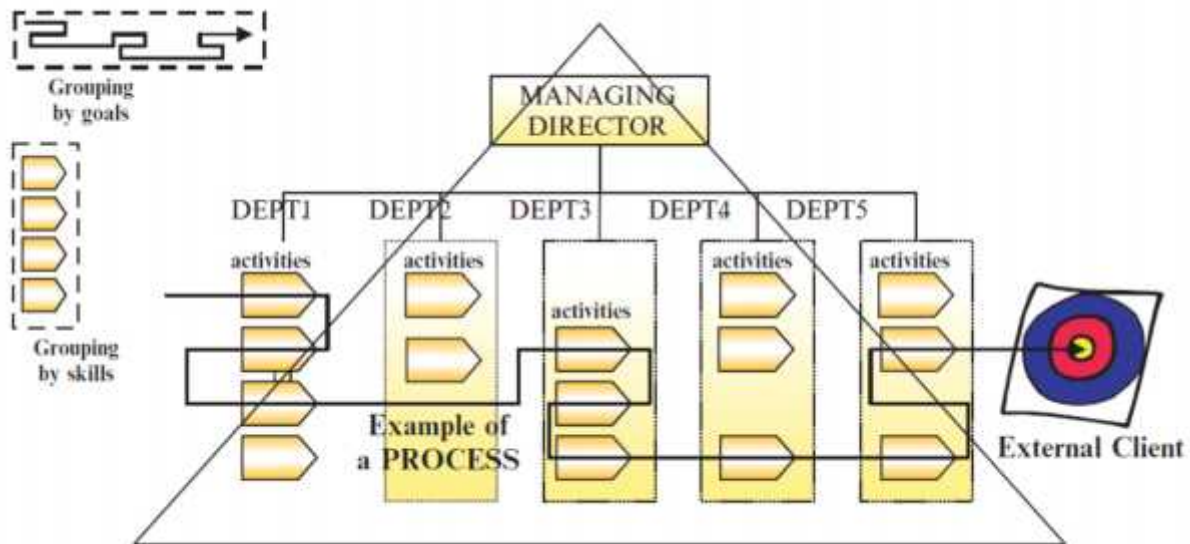
Moreover, by assessing the output and taking into account the cause effect relationships between received and internal performances, it is possible to establish where to intervene in the most effective manner, selecting and managing the portfolio of improvement projects.

A process can also be viewed as the place where value addition is created, or, in other words, every process generates value addition. Therefore, process logics combine the typical input/output approach of the system theory with an economic approach, taking into account that ‘a process is a combination of activities requiring one or more inputs and creating an output with a value for the customer’ and that ‘processes constitute a network where the activities of a certain process serve to add value to the inputs deriving from the previous process’.

Figure I.3 shows the integration between processes and departments (each department – the rectangles – covers part of the organizational chart). An example of a process is shown, spanning the organization to reach its targeted external customer: in order to do so, a variety of activities (depicted as oriented polygons) must be coordinated, exploiting the resources of the different departments. Human resources can be grouped according to skills (with respect to the departments) and goals (with respect to the processes). Consequently, a single human resource necessarily belongs to only one organizational unit (and therefore holds a unique position on the company’s organizational chart), but may contribute to more than one process.



**Fig. I.2** A process consists of activities transforming inputs into outputs, thanks to resources loaned by the functions/units of the company



**Fig. I.3** Integration between functional organization (by departments) and process management: a process is a set of activities requiring resources that belong to departments

The process owner operates transversally with respect to the company’s departments (although he may also be in charge of a specific unit). The process owner defines the goals of the process, coordinates the activities, manages the resources exploited for the process, establishes procedures and interventions, identifies the characteristics of the process and the performance indicators, and chairs all activities aimed at improving the performances of the process. In other words, the process owner acts as an entrepreneur within the clearly marked boundaries of the process.

The process owners differ, in expertise and tasks, from the managers of the organizational units (function/board/department/office), as illustrated in Table I.1.

| Authority                            | Skills                                                                                                                                                                                                                                | Activity/performances                                                                                                                                                |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Director of an Organizational Unit   | <ul style="list-style-type: none"> <li>• Ability to maximise function results in relation to objective-aimed parameters</li> <li>• Technical specialisation</li> </ul>                                                                | <ul style="list-style-type: none"> <li>• Preside over technical quality</li> <li>• Comply with function budget</li> <li>• Manage resources efficiently</li> </ul>    |
| Process Owner (process management)   | <ul style="list-style-type: none"> <li>• Ability to act as entrepreneur of one’s process</li> <li>• Responsibility for results</li> <li>• Relational skills with upstream and downstream</li> <li>• Team leadership skills</li> </ul> | <ul style="list-style-type: none"> <li>• Satisfy downstream customers</li> <li>• Involve/motivate human resources</li> <li>• Manage resources effectively</li> </ul> |
| Project Manager (project management) | <ul style="list-style-type: none"> <li>• Ability to manage change</li> <li>• Forecasting talent</li> <li>• Wide knowledge (even if not in depth)</li> <li>• Team leadership skills</li> </ul>                                         | <ul style="list-style-type: none"> <li>• Achieve project objectives</li> <li>• Comply with project budget</li> <li>• Comply with project time schedule</li> </ul>    |

**Table I.1** The three managerial *hats*

But there are also differences between a generic process owner and that particular process owner who is the project manager. In fact, if it is true that a project is an organizational process (having inputs/activities/outputs and involving resources from various departments), not all processes are projects, because not all the processes have a precise beginning and end (for example, a manufacturing process is not a project because manufacturing continues for many months/years, until the manufacturing specifications change through an innovation project).

As a consequence, a project manager has all the responsibilities of a process owner, plus those deriving from starting and ending a job.

## **I.2 Operations Management and Project Management**

Company management can be differentiated into specific management (with activities that are specific for the sector/compartment) and extra specific management (with activities usually of a financial nature that are independent of the field/ sector where the company operates).

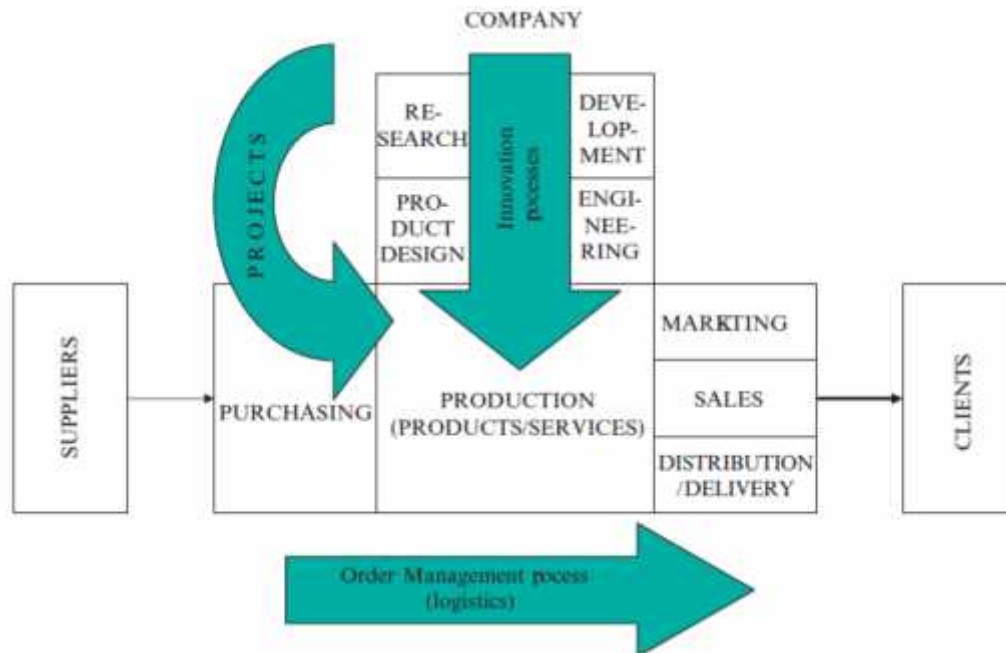
Many departments require specific management: Production (including the delivery of services, if the company operates in this field), Procurement, Trade, Marketing, Distribution/Supply, Design, Process Engineering (Technology/ Machines or similar), Research & Development (R&D). For the sake of simplicity, without considering the supporting Functions/Boards (Administration & Control, Personnel Human Resources, Information Systems, etc.), the functions listed previously can carry out two types of processes (Fig. I.4):

- Order execution (or production on forecast), characterised by more or less repetitive activities complying with standards
- Innovation, a process characterised by change and the absence of reference standards

Because of the repetitiveness of operations, the type of management required for the former process is also known as Operations Management, and consists in managing the (logistic) flow of materials and information that starts from the upstream supplier/company interface (the Procurement Office) and flows through the various Production Departments, finally reaching the downstream interface with the customers (i.e. Marketing, Trade and Distribution).

All the activities of this process refer, in a more or less formalised manner, to the standards defined during the process of innovation/change. The management of the latter process is known either as Innovation Management, with reference to the result of the activity characterising it, or Project Management, with reference to how these activities the projects are carried out.

Innovation/Project Management must therefore produce new standards for routine activities or, every so often, define new and better standards for the products/ services delivered (Design department) and the production processes involved (Engineering office), on the grounds of various factors, including the results obtained by the upstream R&D unit.



**Fig. I.4** Functional units and key processes in a firm

The Project Management Institute – PMI (in PMBOK – A Guide to the Project Management Body of Knowledge, 3rd ed., 2004) explains how operations share various characteristics with projects (both are carried out by persons, exploit limited, available resources, and are planned, executed and controlled); however, ‘operations are ongoing and repetitive while projects are temporary and unique’.

‘A project can be defined in terms of its distinctive characteristics: it is a temporary endeavour undertaken to create a unique product or service. Temporary because each project has a definite start and finish. Unique because the product or service somehow differs from all other similar products and services.’

Table I.2 illustrates some distinctive traits of the two types of management: Operations Management on one hand and Innovation/Project Management on the other.

The main difference between the two processes emerges when analysing the meaning of the performance triad (cost/time/quality) characterising both processes (Table I.3).

In the case of Operations Management, quality is first of all synonymous with conformity. With reference to one of the key principles of Total Quality Management, quality is produced upstream, during the stages of design/engineering, and an effort must be made to reduce, and possibly eliminate variance along the production chain, so as to conform to the standards established for the product/process. It is the task of the Innovation/Project Management to produce quality (objective quality), while quality certifications require a standardization of the procedures purchasing, production, and so forth, but also when delivering services, establishing trade relationships, etc. and compliance with the given specifications.

|             | Operations management       | Innovation/project management |
|-------------|-----------------------------|-------------------------------|
| Activities  | Continuative                | Intermittent                  |
| Focus       | The periods                 | The single project            |
| Reference   | Stable                      | Uncertain                     |
| Scope       | Productive                  | Creative                      |
| Control     | Feedback (actual)           | Feed-forward (forecast)       |
| Centres     | Cost centres                | Investment centres            |
| Departments | Purchasing–Production–Sales | R&D–Design–Engineering        |

**Table I.2** Distinctive characteristics of operations management and innovation/project management

|         | Operations management | Innovation/project management |
|---------|-----------------------|-------------------------------|
| Quality | Conformance           | Level (objective)             |
| Time    | Standard time         | Duration                      |
|         | Delivery time         | Time-to-market                |
| Costs   | Standard costs        | Budget of expenditure         |

**Table I.3** Differences in the performances between operations management and innovation/ project management

As regards time, Operations Management establishes reference standard times for every operation, and defines delivery times that the customer can rely on: longer times mean bad performance; shorter times mean that the specifications made by the Design and Engineering departments can be improved. Project Management, on the other hand, refers to duration of the activities: there are no specific references, because by definition these activities are new, liable to change and their duration can only be estimated.

There are also considerable differences as regards cost performances: in operational activities, the evaluation of this parameter usually depends on whether standard costs have been respected, whereas it is impossible to do so in the case of innovative activities, since there are no standards, and the only restraint is the budget. In practice, however there is rarely a clear distinction between the performances of the two types of processes: even in the case of operational activities it is often necessary to make some slight changes in response to unpredicted situations, whereas in innovative ones in order to limit the uncertainty characterising them it is advisable to have some degree of standardisation, by relying for example on past experiences to establish the duration of the activities, exploiting part of pre-existing projects to limit the magnitude of the new project or estimating costs on the grounds of reference standards.

### I.3 Types of Projects

Company-Wide Project Management (CWPM) considers the firm as a source of integrated and coordinated projects.

Quality is not enough: products and services must be continuously improved, hence the need for innovation. The latter can be regarded as a competitive weapon, a strategy that requires careful planning. Innovation concerns both the design and development of the product/service, and the definition/updating of the manufacturing processes (and/or service delivery).

In all these activities, the customer must be the focal point, the target at which companies must aim with all their might and main. In many cases, customer satisfaction takes the form of customisation, and projects are carried out in compliance with the customer's specifications; this is known as Engineer-to-Order (ETO), and is particularly common in the fields of civil constructions, industrial engineering and engineering services.

But nowadays this is considered insufficient, because flexibility has also become an essential feature. Time-Base Competition is already a reality in many sectors. Planning flexibility means managing change, making plans to improve performances (by reducing delivery times, increasing productivity, etc.), revising the existing organizational structure (internal units, the pool of suppliers and the sales network), modifying procedures (relative to the production planning and control, procurement, plant maintenance, technical assistance services, etc. Business Process Reengineering BPR) and even rethinking/revising strategies (strategic turnaround).

In brief, there are at least three spheres of business where Project Management methodology can be successfully applied, determining different types of projects:

- Product/process innovation (design and development of new products and services)
- ETO contracts (for production, construction, services)
- Strategic, organizational and managerial change (aimed at improving the company's performances).

## **I.4 Managing Innovation**

The relationship between market demand and innovation can occur in five different ways:

- The development of technology incorporated into a product triggers a demand (a past example of technology push was the demand for microprocessors).
- The demand already exists, and product innovation responds to it (as in the case of many pharmaceutical products).
- Product innovation stimulates and develops a pre-existing demand (as in the past, in the case of photocopying machines using normal paper).
- Product innovation makes a latent demand emerge (as in the case of mobile phones).
- Innovation can give new life to a pre-existing demand (even in mature sectors, as in the case of Swatch watches).

In the case of technology push, the development of technology should precede that of the product, because of the following:

- Because of its increasing level of sophistication, technology requires much longer development cycles than products do.
- The dynamic, volatile nature of the market requires the companies to have a vast amount of technology at their disposal, from which to choose in order to start production.

On the other hand, in the case of demand pull, product development should precede that of technology, because of the following:

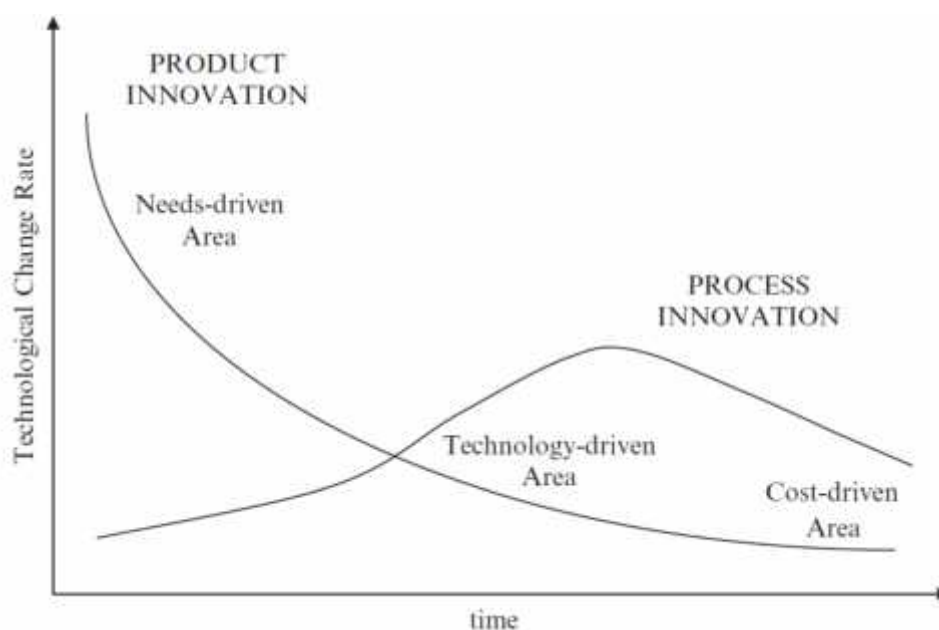
- Customers are increasingly more demanding; hence, the companies must focus more on the product, its concept and the harmonious, functional integration of its various parts.
- The great technical and functional interdependency of the various components, as well as the need to economize, using parts and sub-assemblies from other projects, past and/or present, make the management of a product portfolio a key priority, and privilege the development of new products instead of technology.

The development of (product and process) technology follows the traditional path of R&D: from pure or basic research (usually public and always pre-competitive), which is aimed at advancements in the various fields, and so shed light on phenomena and define the principles governing them, to applied research (incorporating a wealth of knowledge and expertise for a specific purpose), which will finally lead to the development of innovative solutions by means of prototypes and pilot runs.

It can be stated that while the processes of Operations management and Product/Project management refer to the customers of the present and the near future, respectively, R&D processes are aimed at satisfying the customers of the distant future.

R&D is what links research to the market: it traces a path along which many projects will perish (R&D projects have in fact a high death rate) and in its last stage includes the area typical of technological innovation, regarding both product and process. It is in this area that the more specific processes of product design and development are carried out.

Except for the case of process innovations that are not aimed at a specific product (but are made for instance to increase productivity the introduction of automated plants is an example or to improve management practices), the processes of product design and development include both product and process innovation, usually with a prevalence of the former during the first stages of development and of process innovation in the latter stages (Fig. I.5).



**Fig. I.5** Development stages for products and production processes.

In the latter case, innovation reaches the company through various channels, such as those established with the suppliers of plants and materials, at trade fairs, or observing the competitors (including small but innovative niche companies), collaborating with universities, public or private research institutes, joint ventures and so forth. On one hand, in joint ventures, the actual innovative content may be inferior and more easily imitated, but on the other hand, also the risks are more limited.

When innovation derives from an exogenous source, there can be problems concerning the transfer of technology, as well as the difficulty of properly spreading and exploiting it throughout the company. An important figure that should be present in the firm is the so-called gatekeeper, a person possessing great relational and technical skills who is in charge of keeping in contact with the potential sources of innovation.

Since human resources play a key role in creating innovation, it is also important to keep in mind those factors that can hinder creativeness, in a detailed analysis, describe various types of obstacles:

- Of a perceptive nature (difficulties in defining the problem or a tendency to define it in too rigid a manner, inability to perceive all the various aspects of a problem or the tendency to consider only some)
- Of a cultural nature (inclination to resist change, tendency to consider the problems from a scientific and economic viewpoint only, neglecting social and cultural aspects)
- Of a psychological nature (the fear of making mistakes, the inability to accept the initial ambiguity of a project, a propensity to curb one's creativeness, a tendency to evaluate, rather than generate, ideas)
- Of an intellectual nature (no flexibility, insufficient ability to learn from previous experiences, lack of relational skills)
- Of an environmental nature (inability to trust colleagues and collaborate with them, the presence of an autarchic chief, lack of material and financial means)

As well as these hurdles on the path to innovation, there can also be problems in the way technical competencies develop and spread inside a company; technological innovation must therefore go hand in hand with organizational innovation: the organization/innovation relationship is bidirectional, in the sense that innovation modifies the organization producing it. It is also important to keep in mind that nowadays, innovations are mostly organized in portfolios and consequently, each innovative project must be considered from a multi-project management point of view.

## **I.5 Legal Aspects and Contract Administration**

A contract is a legally binding agreement stipulated by two or more parties and characterised by specific obligations. Contracts usually consist of a list of conditions, which may be general (conditions that are standard to all, similar contracts), special (disciplining that particular contract) and technical (regulating how the contract is materially executed). Contractual clauses are listed both in the general and special conditions.

It is possible to distinguish between the following:

- Sales contracts, i.e. contracts having as object the transferral of the property of standard goods, services or rights at a certain price

- Contract work, where one party, by organizing and managing the necessary means at his own risk, becomes responsible for delivering a good or a service whose characteristics are specified by the client in exchange for a certain sum of money

A sales contract provides for the mere transferral (obligation to give) of goods or services that already exist in the firm's catalogue (standard goods or services); in the case of goods, it is unimportant whether these are made before or after the customer's purchase order (make-to-stock or make-to-order, respectively).

Contract work, on the other hand, provides for the delivery of a good or a service that does not exist in a catalogue, and whose characteristics are specified by the client (obligation to do).

In practice, contracts are often a combination of both, so given the legal implications it is necessary to define the prevailing component. This assessment must be based more on the object of the contract than on economic considerations (i.e. whether the value of the work is greater than that of the materials): for this reason, it is appropriate to consider contract works also known as work orders or job orders as those that are necessary to deliver works that are not ordinarily mass-produced, but are custom-built in response to a specific order (because in this case, work prevails on materials).

According to this type of contract, the output must be delivered by an enterprise; for this reason, the contractors may decide to temporarily join together in order to execute the work. In this case, all the contracting companies must answer to the customer, although to different degrees:

- There may be a clear distribution of tasks (as in the case of a consortium).

- The organization and management are common to all, and there is a sort of shareholding of the contract work, which is not however officially divided among the various parties (this is the case of a joint venture, which can therefore be considered by all means a real new company, although of limited duration, whose scope is to fulfil the terms of the contract).

## **I.6 Types of Contract Work**

The contracting companies can do either of the following:

- 1.Receive the specifications directly from the client (or, if they are subcontractors, from the contracting company).

- 2.Design and/or engineer the product in-house (namely, Engineer-to-Order ETO).

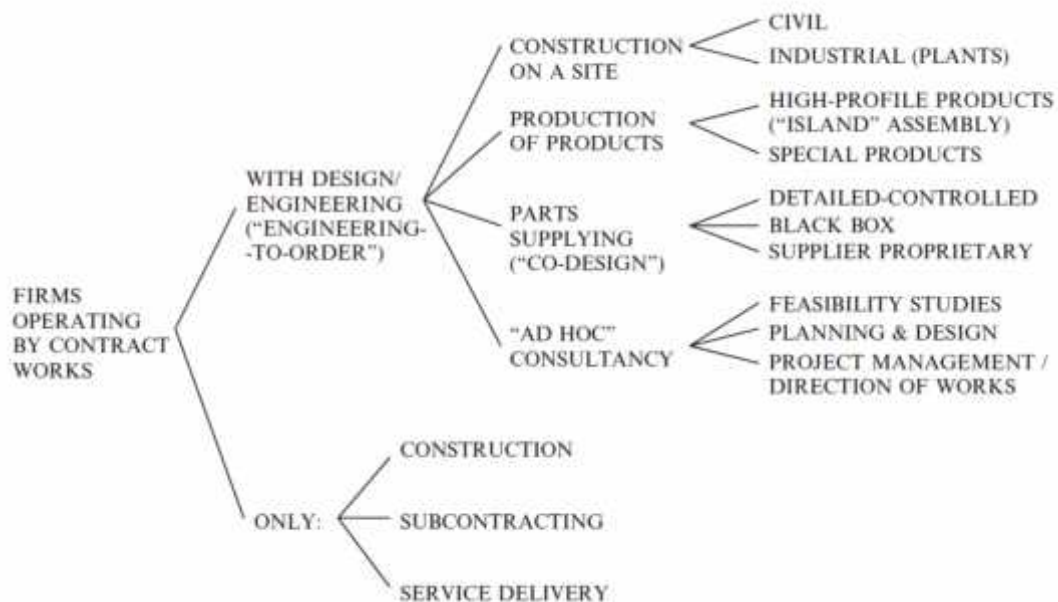
In the former case, a given company is required to deliver an output that complies with the specifications defined by the client and listed in the contract: this is often the case of civil construction companies, subcontractors, or firms offering specific services. These firms receive a job order, legally defined by a contract, requiring little or no design/engineering.

In the latter case, the customer also requests design and engineering, or engineering alone. The design and engineering is done ad hoc for the customer, hence ETO companies only carry out these activities when receiving an order, in the form of a contracted job (contract work or work order).

ETO companies usually manufacture/deliver/supply, as well as design/engineer, the following (Fig. I.6):

- Buildings/infrastructures and industrial equipment/plants
- Products of remarkable size and value, manufactured and/or assembled in an island mode (i.e. not along a manufacturing/assembly line) such as ships, aero-planes, machinery, etc., and special products, which, although smaller, are engineered to order: their specifications are only in part provided by the customer, hence the contractor must design them ad hoc
- Parts and sub-assemblies, which are made-to-order by the suppliers, who must also design and/or engineer them (Co-design).
- Services alone, of an engineering type, which must respond in detail to the customer's requirements.

Construction companies receive an order to carry out a job (usually, buildings and public infrastructures, such as roads, railways, airports, etc., or equipment and plants for the industrial sector) on a certain site.



**Fig. I.6** Firms operating by contract works

Usually the customer/owner only defines one contract, namely that with the General Contractor. This person is responsible for the entire construction job, is paid in proportion to the value of the building/plant/work, may carry out part of the work (usually the structural part) and find subcontractors for the remaining jobs (fittings and finishes). The owner can commission an architect/engineer to design the building/plant: the project will determine the technical specifications, which will be listed in the contract put out for competitive bid to find the General Contractor. Alternatively, the General Contractor may directly design the building/ plant: this is the case of Design–Build Contractors.

This type of contract has opened the road to a range of new legal agreements:

(a) The Management Contract (MC), according to which the client delegates the contractual side to the Manager (as in the case of the General Contractor), who in turn receives a fixed percentage (as in the case of a Construction Manager): the Managing Contractor has a greater margin of risk, and only delivers a service, without carrying out any tasks

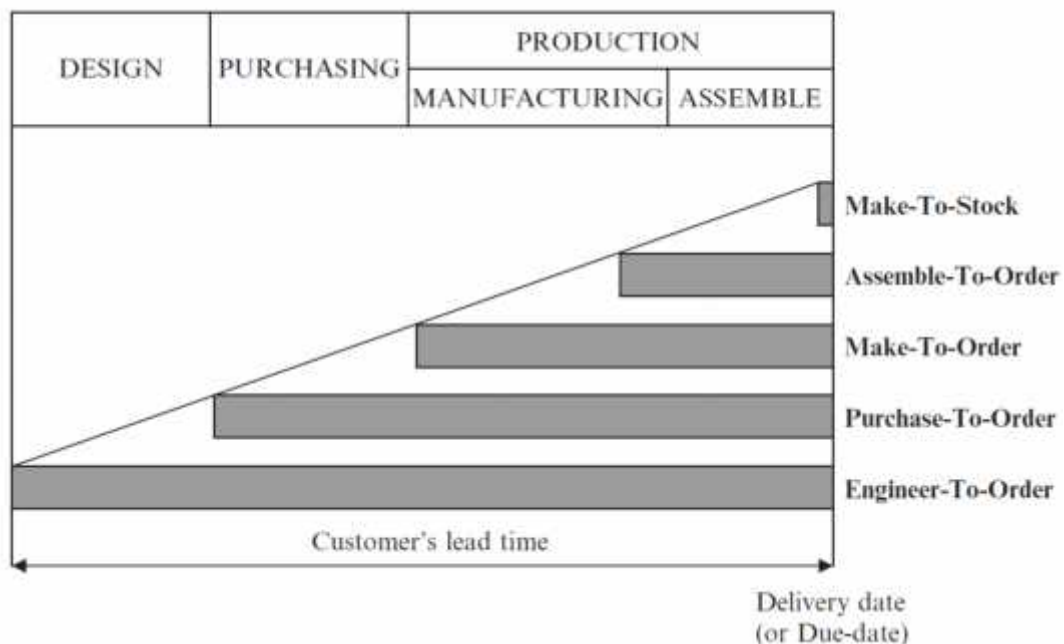
(b) The Design and Management Contract (DMC), where, as well as providing the competency needed to manage the project, the contractor must also coordinate the designers

(c) The Design, Management and Construction Contract (DMCC), providing for a figure similar to that of the General Contractor; only that in the case of DMCC the path to completing the offer starts from managerial services to which design and construction are added, and not the other way round.

Manufacturing companies can respond to the market demands with different lead times (Fig. I.7): the response can be more or less immediate (when operating in a Make-to-Stock mode – MTS, namely when production is carried out on prevision, and the goods are stocked whilst the company awaits orders), take longer times (including assembly time in the case of Assemble-to-Order – ATO, the entire production time in the case of Make-to-Order – MTO, and even procurement times when operating in a Purchase-to-Order mode – PTO), and reach maximum lead time when the customer also specifically requests product design and engineering (firms operating in an ETO mode).

ETO companies do not possess a catalogue of products, but can offer a vast range of custom made products starting from a basic catalogue of competencies; it is therefore possible to distinguish between the following:

1. Single custom orders (items from a basic, unofficial catalogue usually unknown to the customer are adapted to the specific needs of the client)
2. Repetitive custom orders (like the previous ones, but repeated in time a typical example is subcontractor orders)
3. Differentiated orders (always single, where design and engineering play a more important role than in the former two cases these can be considered as real engineering orders).



**Fig. I.7** How manufacturing companies can respond to the market demands

The suppliers of parts and sub-assemblies may also be requested to design and/ or engineer them (Co-design). In this case the customer can provide detailed specifications, requiring engineering only (detailed controlled), more generic ones (a so-called black box, where the property of the drawings either passes to the customer or remains in the hands of the supplier consigned drawings and approved drawings, respectively), and even greater margins of freedom (the typical supplier proprietary). When the specifications are entirely provided by the customer and are already engineered, the supplier can be considered by all means a simple subcontractor.

ETO companies can also offer engineering services alone. Typical examples are the engineering companies that offer technical and professional services in the fields of industrial plants, infrastructures and engineering work in general.

The services relate to these areas: (1) preliminary studies and investigations (feasibility, project financing, risk evaluation, geological surveys, etc.), (2) planning (in all its stages, from the preliminary ones to execution, including the preparation of documents for RFOs Request for Offer), (3) management processes (project management in a stricter sense, providing assistance during production/construction, direction of the works, purchases, inspections, routine maintenance, etc.).

These companies can also deliver turnkey plants or high-profile infrastructures: in this case, they not only act as consultants, but also as General or Main Contractors, directing and coordinating the activities of all the subcontractors.

## **I.7 The Life Cycle of Contract Work Orders**

The input for ETO companies is the opportunity to take part in a bid or the request to make a proposal, whereas the outputs can be housing estates, industrial plants or high-profile products, all designed ad hoc for the customer and built either in-house or by directing and coordinating the activities of subcontractors.

What characterises these companies is that they not only design the product, but also manufacture it; hence, the project is only completed when production ends, not after defining the product's specifications. ETO firms usually operate on an international level, often acting as main contractors, and can therefore work with various subcontractors or establish partnerships; they possess a know-how that ranges from understanding the basic technology of the end product to that relative to the product's architecture, as well as having the managerial competency to direct and coordinate the entire project.

Contract jobs can be divided into two stages: (a) bidding, which starts with the company's decision to present an offer for a certain job and can end with the stipulation of a contract; (b) operational activities, which include all the tasks needed to complete the job. The decision to respond or not to an RFO (bid – no bid) is usually supervised by the board of directors, since it is an important decision, which implies a variety of trade-offs and strategic opportunities for the company: visibility on the market, economic and financial convenience, availability of internal and external resources over a medium long period of time.

These companies usually require Multi-Project Management, because they are often in charge of various projects at the same time, each of which develops in two macro stages: planning/design and execution (Fig. I.8).

The macrostage of planning/design evolves from the initial concept to the planning of the output, which must respond to the functional characteristics specified by the customer; the overall system and the single parts are then designed, and this stage is followed by plans for its construction, defining the specifications, procedures and methods for setting up and performing operations and maintenance.

The macrostage of execution includes various stages: the purchase of materials/components/systems, the manufacturing/assembly activities, finding subcontractors, if needed, installation and/or testing, and delivery in other words, a set of activities that are carried out in different places according to the type of sector where the firm operates (housing estates, industrial plants or products, etc.).

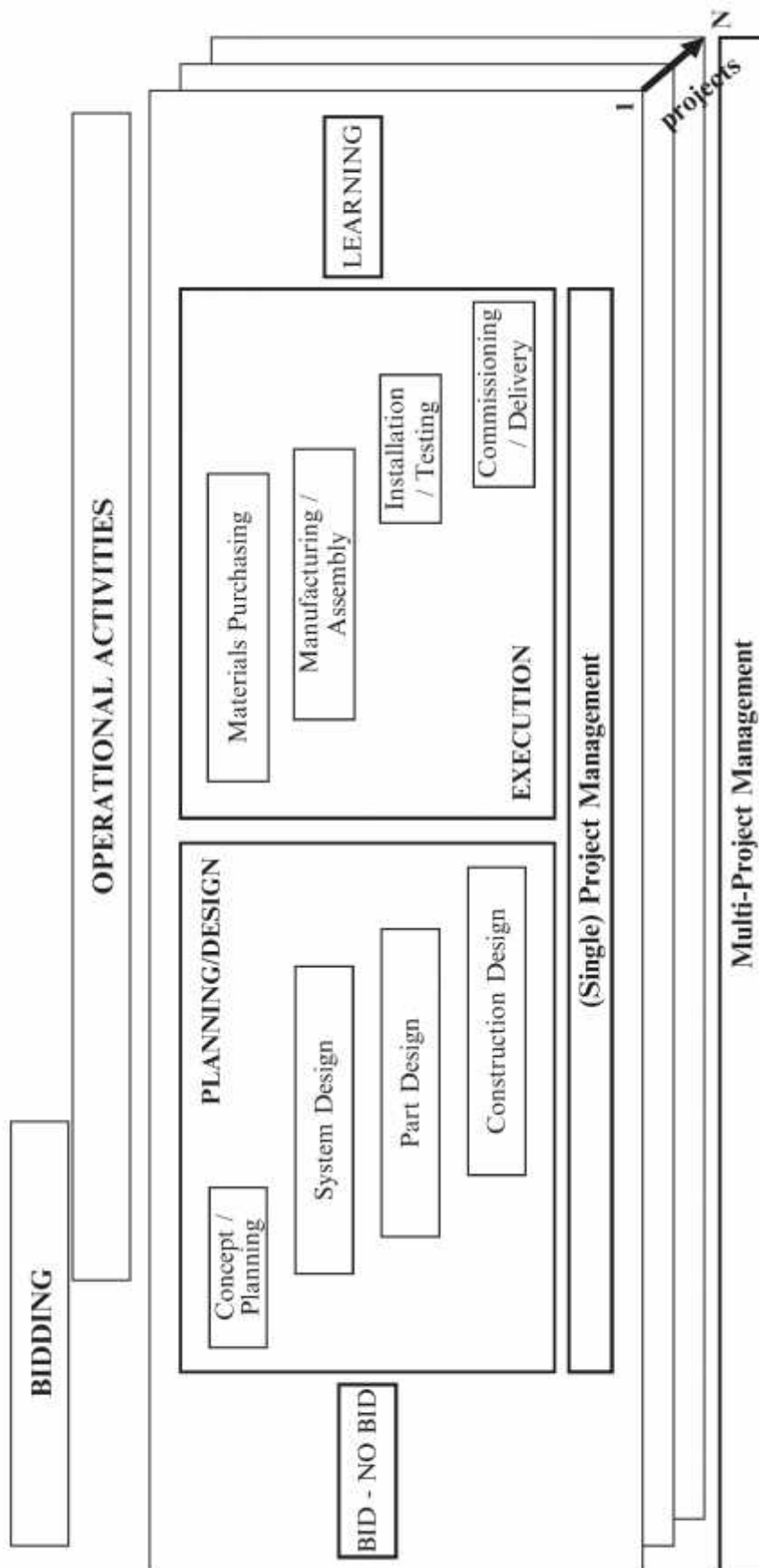
In all these cases, the project boundaries are well defined, for they are specified in the contract, the stipulation of which may be preceded by a certain degree of negotiation. The contract in fact lists the customer's needs, which are directly dictated by the client. When the contract also describes the designing and operational activities to be carried out, these are known as Contract Work Breakdown Structures (CWBS).

Particular care is devoted to defining the specific objectives (scope) of the project, because the company's overall performance depends on the results obtained in the single projects it carries out. There is an office in charge of managing the often intense and continuous relationship with the customer; the firm on the other hand always follows certain internal procedures, based on previous experience, to carry out the commissioned projects and find the solution to the many problems encountered. The existence of standard work breakdown structures (WBS) contributes to remarkable project economies.

ETO companies possess a technological capacity that allows them to bid for a certain job; the designing activity starts once the company has received the order; in other words, the resources are only activated once a contract is signed. Drawing up a contract is a critical moment, because decisions must be made concerning prices and the date of delivery (Fig. I.9). Estimating the price can be more or less simple, depending on whether the project can be broken down into standard structures (or chunks) that have already been developed and executed in the past. On the other hand, when defining the date of delivery, the company must consider the orders that have already been placed and those that are being negotiated, and whose workload is still undefined.

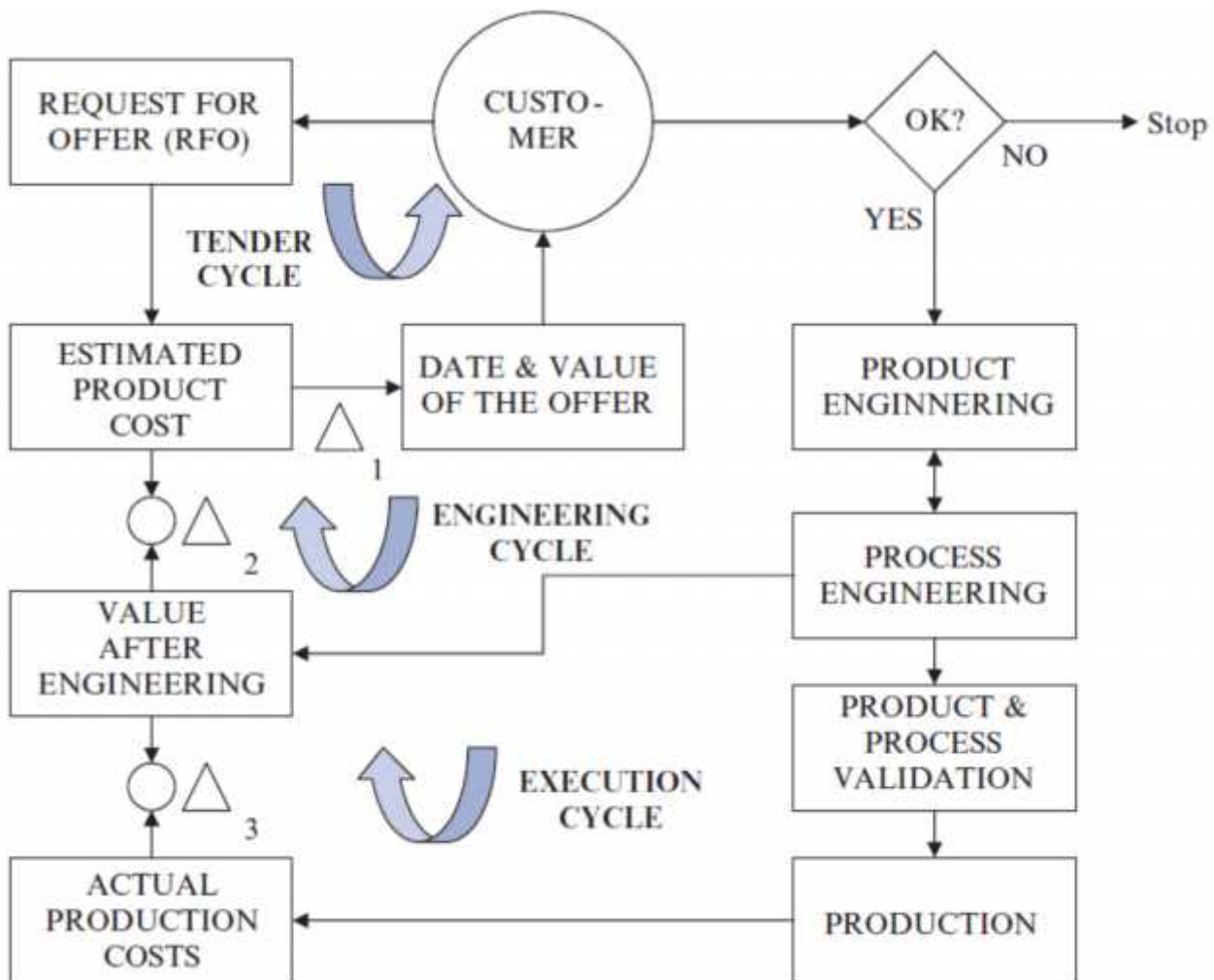
The importance of this stage is underlined by its other definitions, i.e. competitive bidding or scope management (the management of contractual goals as a compromise between customer satisfaction and the strategies of the company); in this context, an important figure is that of the proposal manager who is responsible for promoting and defining an offer, and for the following stage of contract stipulation.

Once the offer has been accepted, or when the bid has been awarded, it is necessary to engineer both the product and the processes needed to manufacture it. It is in this way that a costed cycle is obtained, illustrating the activities to be carried out and their estimated costs, which are examined in an analytical manner: obviously, the costed cycle and the estimate should coincide at the end.



**Fig. I.8** Stages of contract works

Figure I.9 illustrates the lifecycle of a work order, from engineering/costing to its execution; as depicted, there can be variances between estimated costs and value of the offer ( $\Delta 1$ ), between the value after engineering and that estimated beforehand ( $\Delta 2$ ), and between the actual manufacturing costs and value after engineering, a parameter indicating production efficiency ( $\Delta 3$ ).



**Fig. I.9** Cost cycles and variations in contract works

## I.8 The Organization of ETO Companies

To carry out the projects, ETO companies are organized in a matrix structure, resulting from the intersection of the company's permanent structure consisting of functional units and various temporary structures that are specifically set up for the project/job (Multi-Project Management).

If the resources of the various departments are allocated full time to an order once this decision has been made the traditional conflicts characterising the matrix structure tend to diminish: the resources must answer to the directors of the permanent (functional) structure as regards the achievement of the goals specified in the internal contract (concerning the allocation of the resources for a certain order), and the quality of the technical solutions for the project, which must

con-form to the company's standards and the specifications listed in the (external) contract, namely that made with the customer.

The project structure, set up by the project manager and the other managers and coordinators under his/her supervision, is responsible for the achievement of the global objective of a project (the schedule and the technical, qualitative, economical, and financial aspects), using the resources allocated for this purpose, unless the board of directors intervenes, requesting a different allocation of the resources amongst the open orders.

The permanent functional structure usually consists of the following offices or departments:

- Product and process / engineering
- Procurement or purchasing
- Production/construction
- Quality
- Safety
- Management control
- Administration/contract office
- (Multi-)project planning

The latter unit is in charge of formalising and centralising the planning of orders as provided by a Multi Project Management approach; its members include the company's top executives, who are in charge of defining order priorities and coordinating for all contracts the activities of the various offices/departments. This unit is also the source from which the project culture spreads throughout the company, a culture that is the key *raison d'être* of the enterprise.

The fundamental, technical expertise is instead in the hands of the engineering unit(s); the term engineering is usually preferred to design, because it describes better the activities carried out, which are based on the know-how possessed and calibrated to the specific demands made by the customer.

The (temporary) project/order structure includes the following figures (although not all may be present, depending on the type of order):

- The Project Manager, responsible for the work order
- The Contract Administrator, responsible for the contractual relationships with the customer
- The System Engineering Manager, responsible for the architecture and systemic integration of the building/plant/product
- The Planning Manager, responsible for the detailed planning of activities
- The Procurement Manager, responsible for purchases
- The Production Coordinator, responsible for in-house production
- The Expediting Coordinator, responsible for expeditions to a specific building yard
- The Subcontracting Manager, responsible for the jobs carried out by the subcontractors, who in turn are managed by a Coordinator

- The Field/Construction Manager, responsible for the building yard and the construction
- The Resident/Site Manager, in charge of verifying the availability of materials on the building site, coordinating labour and subcontractors, complying with the rules and legislation, and managing the relationships with the local institutions
- Specialist Leaders, directing the task forces working on a specific project
- The Quality Coordinator, ensuring compliance with the technical, quality-related and contractual specifications of an order
- The Safety/Reliability Coordinator, in charge of ensuring safety and reliability of the works and the product/plant made to a specific order
- The Commissioning Manager, responsible for ensuring the starting of the plant
- The Project Controller, monitoring the progress of times/costs for a specific order

In companies working to order, project managers must have greater cross-functionality than that requested for any other project (such as product development or company improvement). Now project managers must use all their organizational, administrative, commercial, financial and legal skills, as well as their technical and managerial know-how. In short, they act as managing directors, though only for a limited period of time, during which they have full ownership of the project.

## **I.9 From Engineering to Manufacturing**

The specifications made by the customer and stated in the contract are formalised in a design/engineering WBS. Since orders usually include manufacturing (or production-by-parts), there is a bidirectional link between this type of WBS and the manufacturing WBS.

All the activities revolve around a Master Production Schedule (MPS) which states the following:

- Which items are to be produced
- In what quantities
- When they are required

The first MPS issued is usually tentative. To ascertain its feasibility, it is necessary to check the production capacity requirements, which are considered at an aggregate level, i.e. only the gross requirement of resources per unit of end product (Rough Cut Capacity Planning – RCCP). Once this has been verified the schedule is approved.

Three factors are required to formulate a production schedule: (1) materials, (2) machinery/equipment, (3) human resources. Since machinery/equipment and human resources form the productive capacity (and their mix determines the level of automation), what must be scheduled and managed are the following:

- 1.The single items of materials (Material Requirements Planning – MRP)
- 2.The capacity of each work centre (Capacity Requirements Planning – CRP)

From a logical viewpoint, materials and capacity can be considered on the same level, although it makes no sense to schedule the capacity in the absence of materials. Hence, material requirements are scheduled beforehand, and once their presence is ensured, productive capacity can be planned. In the event of overload, workloads can be levelled or material is allowed to queue.

The requirement of materials is planned through the MRP technique, except in the case of materials of less value or importance for which the Re-Order Point (ROP) technique is used: in this case, the stock level displays a typical sawtooth pattern. MRP calculates the net requirement of materials from the gross needs, subtracting the available stock and the amounts that are being processed and are not yet assigned (materials exceeding previous requirements, and released for reasons of minimum lot size); production, assembly or purchase orders are released with an as late as possible logic, taking into account the lead times (relative to production or supply).

It must be noted that when receding from a future date (i.e. the time of release) towards the present, time availability may be insufficient (i.e. production should have already started): in this case, the MPS must be revised (the dotted feedback lines in Fig. I.10). If there are parent items, their release primes a gross requirement for child items. These parent child relationships between the various items are described in the Bill of Materials (BOM).

Figure I.11 shows an example of MRP calculation. The typical MRP record (one for each item) consists of four rows of information, periodically updated: (1) gross requirements, (2) scheduled receipts (existing replenishment orders not yet assigned), (3) stock availability (from a certain time zero on), (4) planned order release (this last row is the result of a calculation). To calculate this value, certain parameters must be specified, such as lot size (if operating by lots), production lead times (the production order of the 40 units in Fig. I.11 is released two periods before reaching the minimum stock threshold level, as the lead time is of 2 periods), safety stock, etc.

In the case of single contract orders, it is possible to plan material requirements through an MRP focusing on critical items, and in that of repetitive contract orders, through an MRP with planning bills; these facilities are already present in the more updated MRP modules, which are valid for cone and mushroom/sandglass-shaped bills of materials.

In cone-shaped BOMs, a limited number of end products, if not only one, are obtained by combining a large number of items (typical examples can be found in the aeronautical industry, shipyards, industrial plants, etc.). Items may be considered critical for a variety of reasons: technological (difficulties in their production), managerial (long production or procurement lead times), economical (high unit value) or structural (linked to other critical items). The MRP focusing on critical items gives them priority, and tries to limit subsequent variations (depicted by the dotted, feedback lines in Fig. I.10) as much as possible.



CRP is used to calculate the load profile for each work centre starting from planned order releases, routing files and open orders. Planned order release is indicated in the last row of the MRP record. These values are translated from physical quantities into workloads or backlogs (the lower section of Fig. I.11), which are generally expressed in hours per work centre. The routing files indicate the work centres and their requirements in terms of labour and equipment to complete the order. The CRP thus identifies the load profiles for released and planned orders in the various work centres. Load spreading among the work centres is carried out presuming that the latter have an infinite capacity; in the event of capacity overload, it is essential to level the loads (finite loading) and thus modify the MRP and, if necessary, even the MPS (the dotted feedback lines in Fig. I.10).

To avoid excessive levelling and changes of plans, it is advisable to use certain procedures to control the input/output loads on the work centre. Figure I.12 illustrates an example, indicating the planned and actual inputs and outputs. The input depends on the CRP, the output on managerial decisions and/or constraints due to a constant level of work; the interaction of actual inputs and outputs, starting from an initial backlog (equal to 20 in Fig. I.12) determines the actual load throughout time (in the example, it passes from 20 to 31 at the end of the fifth period, but the procedure makes it possible to analyse the four possible causes the rows corresponding to planned/actual and inputs/outputs – and find a remedy).

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|                                |    | 1       | 2  | 3  | 4  | 5  | 6  |        |
| GROSS REQUIREMENTS             |    |         | 50 | 30 |    | 38 |    | M.R.P. |
| OPEN AND NOT ASSIGNED          |    | 32      |    |    |    |    |    |        |
| STOCK AVAILABILITY             | 20 | 52      | 2  | 12 | 12 | 14 | 14 |        |
| PRODUCTION ORDER RELEASE       |    | 40      |    | 40 |    |    |    |        |
| Lot size = 40<br>Lead time = 2 |    |         |    |    |    |    |    |        |
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| WORK CENTRE<br>YYY      |    | PERIODS |    |    |    |    |
|-------------------------|----|---------|----|----|----|----|
|                         |    | 1       | 2  | 3  | 4  | 5  |
| C.R.P. PLANNED<br>INPUT |    | 15      | 15 | 0  | 10 | 10 |
| ACTUAL<br>INPUT         |    | 14      | 13 | 5  | 9  | 17 |
| CUMULATIVE<br>VARIATION |    | -1      | -3 | +2 | +1 | +8 |
| MNG PLANNED<br>OUTPUT   |    | 11      | 11 | 11 | 11 | 11 |
| ACTUAL<br>OUTPUT        |    | 8       | 10 | 9  | 11 | 9  |
| CUMULATIVE<br>VARIATION |    | -3      | -4 | -6 | -6 | -8 |
| ACTUAL<br>BACKLOG       | 20 | 26      | 29 | 25 | 23 | 31 |

**Fig. I.12** Input/output control for a work centre: data are expressed in man-hours (the darkened cells contain the data; the white ones the solution)

Up to this stage, planning can still be changed: in other words, only a what-if simulation has been made to obtain an Available-to-Promise (APT) date of delivery. With the passage of time, it soon becomes indispensable to freeze the decisions that have been made; else it would be impossible to respect the delivery date for the order. This step leads into the horizon of irreversibility (Fig. I.10): all the orders regarding production, material purchasing and processing by outside contractors are thus placed. Planning is over, and from this moment that which has been scheduled must be performed. These last stages are governed by Shop Floor Control (SFC).

SFC – often aided by local software – has the following tasks: (1) to verify and dispatch the definitive production orders (by checking documents, quantities, presence of materials), (2) allocating the resources to the production centres in compliance with the priority rules for scheduling, namely the definition of the start and end date for each activity, (3) collecting data, monitoring and tracking (i.e. constant traceability of the orders and their progress), (4) if required, interventions and corrective actions (e.g. extra work, alternative cycles, lot breakdown, subcontracting, etc.), (5) order reporting, until it is closed.

These rules of scheduling priority concern activities that can be managed autonomously within the given period (for instance, in a day) in accordance to global planning (in other words, respecting the scheduled WBS, MRP and CRP for each period) and leaving the necessary margins for operational

flexibility. These are rules such as minimum slack (the difference between the deadline and the time needed to complete processing), FIFO (First-In–First-Out), etc.

In a multi-project environment, it is also necessary to take into account the project (order) priorities; the most typical are (a) the closest delivery date, (b) the importance of the customer, (c) magnitude of the penalty, (d) the importance of the order in terms of payoff or profitability. The system used to manage them is based on project core categories, namely filters that make it possible to classify information according to (a) department/unit/team, (b) contracts, (c) penalties, (d) the project manager.

The earlier stages are executed by single information modules, which are integrated by means of MPCS (Manufacturing Planning and Control Systems). These systems, originally devised for the management of materials (MRP Systems), are now used to manage capacity, complete the overall planning and carry out SFC. Nowadays they are commonly known as ERP (Enterprise Resource Planning) Systems, because they extend to all the areas of the company not only production including trade, general and analytical accountancy, treasury, financial management, administration, personnel, and so forth. The latest step of this evolution is the NERP (Networked Enterprise Resource Planning) System, which integrates the planning systems of different enterprises (suppliers, customers, subsidiaries) by means of Web technologies (Extranet, XML language, etc.).

# Chapter II

## Project Strategy Management

### II.1 Breakdown Structures

A rational approach to projects requires the use of logical hierarchical structures or Breakdown Structures that replicate the way the human mind reacts when facing a problem, namely, breaking it down into subproblems, in order to analyse them at a greater level of detail.

In general, Project Management considers six breakdown structures, all inter-connected (Fig. II.1), which take into account the three managerial variables of a project (Time – T, Resources – R, Costs – C), as well as its functional–technical ones (Quality – Q):

- Product Function Structure (PFS)
- Product Breakdown Structure (PdBS)
- Process Breakdown Structure (PcBS)
- Work Breakdown Structure (WBS)
- Project Organizational Breakdown Structure (POBS)
- Project Budget Breakdown Structure (PBBS)

A project is the result of an idea, more or less destructured (concept idea), combining a why and a how, namely the reason why something new should be created (market demand, unsatisfactory performance, compliance with new regulations, etc.) and how to make the required change in the best possible way (technical, organizational and/or management innovation).

The concept idea is the starting point for defining a structure, known as PFS, that describes the functions of the project's output (a product, a different internal organisation, etc.) in a clear, hierarchical manner.

If for instance the project is for a new car, it is necessary to define, at an increasing level of detail, the functions it must possess: traction/drive, steering, braking, a function to dampen the unevenness of the road surface, one to accommodate passengers, hold the baggage, adjust the temperature, commands and controls, etc.

Traction in turn can be divided into various (sub)functions: fuel injection, combustion, the release of exhaust, power transmission and so forth, continuing to divide each sub-function into further (sub)sub-functions. The PFS generally consists of various levels: level 0 is the overall product; level 1 refers to the functional groups of the product, level 2, the functions of each functional group, and level 3, the sub-functions of each function.

In the case of contract jobs, the functions and performances are specified by the customer and are listed in writing in the contract.

Once the PFS (the tree of functionalities) is defined, it is necessary to identify what parts and sub-assemblies of the product are needed for each function. Hence, a PdBS must be made, namely a tree diagram that divides the product into sub-assemblies, which in turn are formed of various parts.

Hence in a car, the function traction will be carried out by the engine, the sub-function fuel injection by the pipes, pump and valves, that termed combustion by the internal combustion chamber and the spark plugs, etc.

The difficulty not only lies in breaking down the product into its functions, but even more in connecting the functions –level by level – to the various items listed in the bill of materials. When proceeding to greater levels of detail, only rarely is there a univocal correspondence between function and part: more often, a given function requires a number of parts, or a certain component may serve for various functions.

If product innovation is accompanied by process innovation, or when a company carries out a contract job, a PcBS must also be defined, so as to divide the new manufacturing (or construction) process into stages and operations, and link them to the parts and sub-assemblies that have to be made. When the manufacturing processes remain unchanged, a correlation should however be made between the PdBS and the (pre-existing) PcBS, so as to link the parts that have been designed to the processes required to produce them.

Once these links have been established, it is possible to identify the activities or work needed to develop the product, as illustrated in the bill of materials. These tasks too can be further broken down into groups and sub-groups (the branches of the tree) to reach the maximum level of detail, i.e. the Work Packages or WP, coinciding with the leaves. The project is the trunk of a tree, commonly known as WBS, which represents the (unscheduled) deployment of the work needed to complete a given project. Also in this case, the nodes of the family tree must be linked to those of the previous breakdown structures (PdBS and, if present, PcBS).

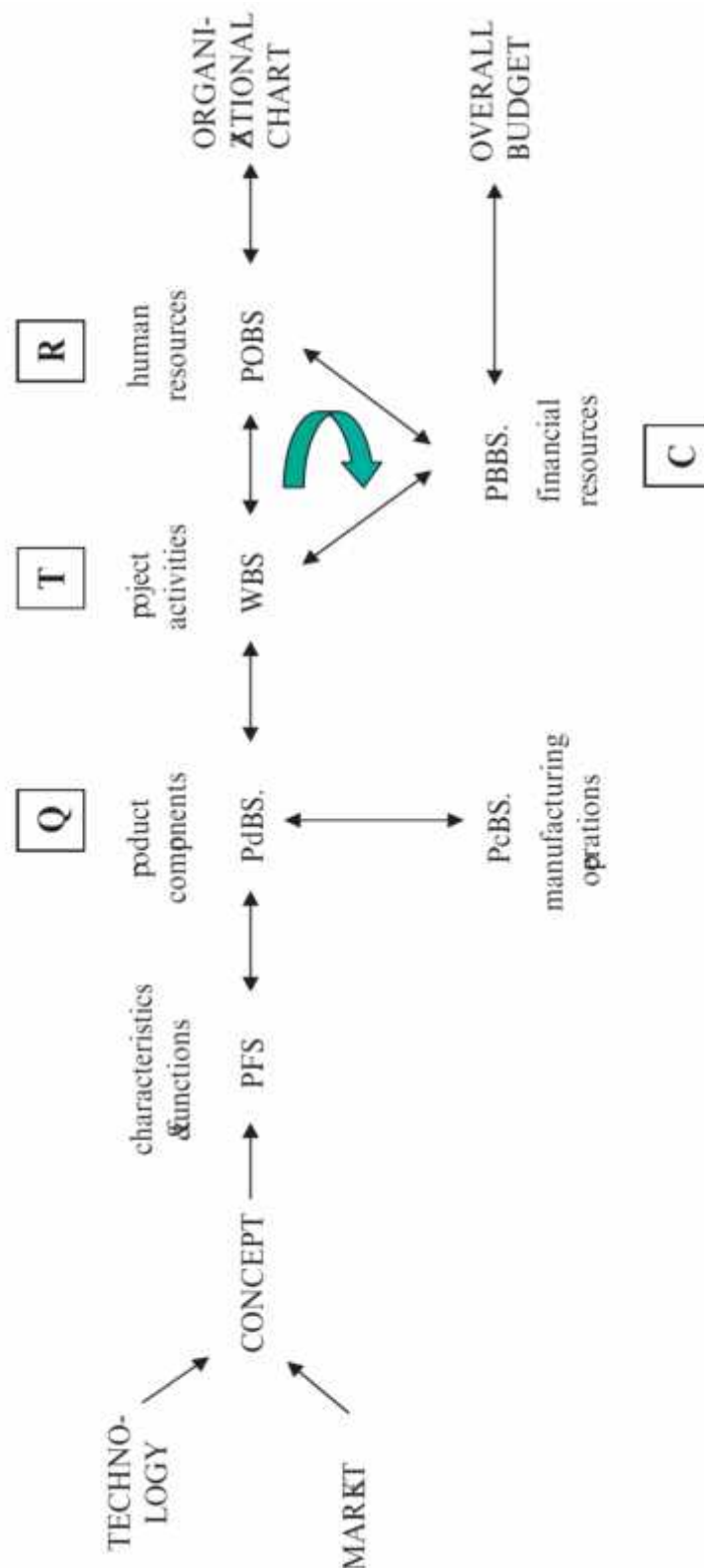
In its PMBOK – A Guide to the Project Management Body of Knowledge, 3rd ed, the Project Management Institute – PMI defines a WBS as ‘a deliverable-oriented hierarchical decomposition of the work to be executed by the project team, to accomplish the project objectives and create the required deliverables. The WBS organizes and defines the total scope of the project. The WBS subdivides the project work into smaller, more manageable pieces of work, with each descending level of the WBS representing an increasingly detailed definition of the project work. The planned work contained within the lowest-level WBS components, which are called work packages, can be scheduled, cost estimated, monitored, and controlled’.

So a work package is a set of elementary activities having well-identified interactions with other work packages and characterised in a univocal manner by inputs, outputs and internal activities; resources, execution times and ownerships can be linked to these packages, so that they become the basis to plan, budget, schedule and control the advancement of the project.

Although it defines the activities to be carried out, a WBS is usually made using a mixed logics approach: in other words, the breakdown process can take into account either the physical structure of the product (PdBS), independently of the future manufacturing stages (PcBS) and how these are planned or, vice versa, it can consider how the process is carried out, independently of the product’s.

The Work Packages (WP) of a WBS can be linked to Cost Accounts (CA), using an approach that was originally devised by the US Department of Defence (DoD) and is commonly known as Cost/Schedule Control System Criteria – C/S CSC or C.Spec. This procedure however is also referred to as C.Spec. two-dimensional system, hence a WBS is also known as a single C.Spec. The relevant document “MIL – Military Standard: Work Breakdown Structures for Defense Material Items” poses certain restrictions for the top three levels of the WBS, while the contractor has a greater degree of freedom for the lower levels. According to this document, the top three levels are

(1) the project itself, (2) the major elements of the project (e.g., a ship, but also equipment, system test and evaluation, training services, system engineering and the project management itself), (3) elements subordinate to level 2, i.e. sub-elements (e.g. for a ship, its structure, engines, the various plants on board, etc.).



**Fig. II.1** Breakdown structures and project management variables (quality Q, time T, resources R, costs C)

On the other hand, there are also other procedures that break down the project in a different manner. The PRINCE methodology (see the Web sites listed at the end of the book), for instance, considers two levels: the first one refers to the product distinguishing between (1) technical products, consisting of technical documentation, manuals, operational procedures, etc., (2) managerial ones, consisting of plans, description of the work required, management reports, etc. and (3) quality issues, such as the list of specifications, actions, etc. whereas the second level refers to the manufacturing stages and relative milestones. The PRINCE methodology calls this type of WBS a PdBS, a term that in line with the more accepted meaning is used instead in reference to the product's BOM.

Following is some advice on how to organize a WBS:

- At the higher levels, a logic of division by project areas should prevail, followed in turn by PdBS and PcBS logics.
- One criterion alone should be used for each level, so as to ensure uniformity of communication among the persons who operate at the same level or at higher/ lower ones.
- Breaking down should ensure greater ease in the management of the higher levels, which can be considered as integrated systems to plan and control, having a certain deliverable (or output) and measurable cost, time and resource performances.
- The number of levels should ideally range from four to six (not all the branches must necessarily have the same number of levels).
- The sub-levels should define sub-systems that can be managed more or less independently (and which must be tested in a later stage using a bottom–up approach, proceeding from the leaves to the roots of the family tree).
- Indirect i.e. management and control activities that are needed to deliver the project must also be taken into account (when part of the project is contracted, one or more branches of the WBS are further broken down, giving rise to Contract Work Breakdown Structures – CWBS).

Figure II.2 depicts the first levels of a WBS for the construction of a new plant; each node of the WBS is tagged with a hierarchical code or number that is equal to that of the levels (level 1 – project; level 2 – sub-project; level 3 – activity; level 4 – sub-activity).

WBSs can also refer to organizational or management changes aimed at improving performances: the ISO 9000 certification process is a project, as are Just-in-time (JIT) interventions, internal reorganization, the adoption of a new information system, revising the agents/retailers network, creating partnerships with suppliers, joint ventures, etc. All these projects require careful planning and the definition of the activities to be carried out, which are illustrated by the WBS.

Having defined the activities, it is necessary to allocate the human and financial resources needed for their execution.

As regards human resources, it is first of all necessary to define the competencies needed to carry out the activities defined in the WBS. The structure thus created (POBS) illustrates the tasks and responsibilities of the various parties, and indicates who the project manager is, there must not necessarily be a hierarchy (and consequent power to punish or reward), but only a series of ownerships that are established within the framework of the project. Given the nature of projects, the POBS is obviously only a temporary structure.

The POBS of the various projects are linked to the organizational chart of the company. Each employee can feature in a number of POBS, referring to different projects, or in different branches of the one structure. Obviously, the call by reason of competency must be made in such a manner as to ensure that the persons are not overloaded by work.

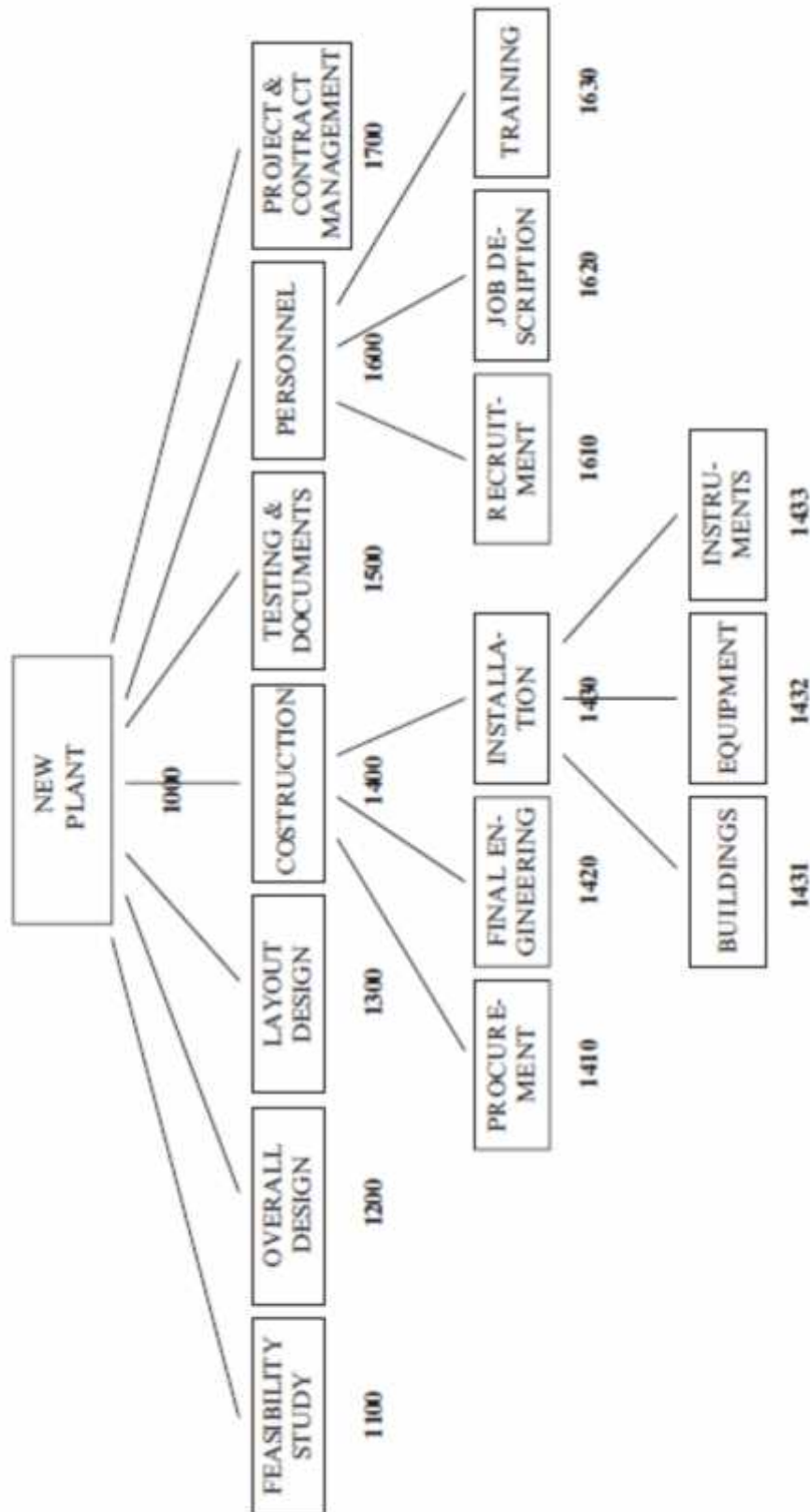
Although the nodes or elements of a POBS usually comprise resources coming from the Design and Engineering offices, they can, and indeed should, also feature employees working in other functional units, such as marketing, purchasing, production, etc.

If the human resources employed in the projects require valuable equipment or tools whose availability is limited, the POBS should also include the use of these (instrumental) resources, particularly when there is more than one project carried out at the same time.

Finally, the above resources – both human and instrumental (if relevant, namely if it is necessary to enter them as cost items in the framework of a project, because they cannot be considered as routine operations) require funds, which are provided by the project budget, part of the overall budget of the company. The PBBS breaks down this budget (which can also be the value of the contract job, minus the margin of profit) into cost accounts that, in a variable measure, must be linked both to the resources used (POBS) and the activities (WBS) that they will carry out. It is a question of costing (PBBS) who does (POBS) what (WBS).

In brief, the six Breakdown Structures differ in their nodes, which are as follows:

- Functions and characteristics in the PFS
- Parts and sub-assemblies in the PdBS
- Stages and operations of the manufacturing cycle in the PcBS
- Activities required for the execution of the project in the WBS
- Project resources in the POBS
- Project costs in the PBBS



**Fig. II.2** Example of Work Breakdown Structure (WBS) and relative coding

## II.2 Project Planning and Control

To manage, it is necessary to measure! More specifically, it is necessary to measure operational macro-variables linked to performances, which are namely quality (technical characteristics), time and costs. Resources must also be added to the list because, even though they are not performances, their availability, capacity and saturation levels must also be taken into account.

Project management consists of two stages:

- 1.Planning (prior to the start of the activities specified by the WBS)
- 2.Control and reporting (from the start to the conclusion of the project)

The stage of planning defines all the operational variables. The objectives of quality, time and costs (established by PdBS/PcBS, WBS and PBBS, respectively) are specified in detail, and the necessary resources are quantified and made available (as described in the POBS).

The necessary activities are worked out for each class of variables, and are listed here according to priority, rather than in a chronological order:

- 1.Budgeting (definition of the budgeted expenses and successive allocation of these costs according to the PBBS, taking into account the other breakdown structures depicted in Fig. II.1 – in particular the costs arising from the use of resources during the activities)
- 2.Scheduling (defining the start and finish dates for all the activities specified in the WBS)
- 3.Resource allocation (allocation of specific POBS resources to the WBS)

These activities are not carried out in succession, but in loops of greater detail and refinement: the forecasted costs are always better defined after analysing and scheduling each activity; scheduling in turn can be revised after allocating the resources, etc.

Control and reporting take place when the project is already under way. Their aim is to bring it to a successful conclusion within the terms laid down at the time of planning, intervening if variances occur.

In a more articulate manner, the Project Management Institute PMI identifies nine different areas for Project Management (planning + control):

- 1.Project Integration Management (the Multi-Project or Portfolio Management)
- 2.Project Scope Management (dealing with the definition of project goals and their connection with the project plan – it is similar to our Breakdown Structures)
- 3.Project Time Management
- 4.Project Cost Management
- 5.Project Quality Management
- 6.Project Human Resource Management (including the organization and management of competencies and team work)
- 7.Project Communications Management
- 8.Project Risk Management
- 9.Project Procurement Management

## II.3 Project Risk Management

In a project, the sources of uncertainty can arise from the following:

- Identification of the customer's needs
- Knowledge and management of technology
- Behaviour of the competitors
- Type and availability of the resources

These sources of uncertainty determine the so-called risk areas, which can be defined as those factors that are not fully dependent on project choices, in other words, that cannot be completely controlled or predicted, but that may have a great impact on the project and its performances, namely the following:

- Time – namely the duration of each activity and therefore, that of the entire project
- Costs – meaning both the cost of the resources and their exploitation rate
- Quality of the project's outputs (or deliverables)

Risk is an intrinsic element of a project, and the more the latter is innovative, the greater the risk. A project without a risk factor is not a project. Moreover, since its success depends greatly on its degree of innovation, the ability to manage risk is one of the most qualifying skills required when working on projects.

Risk Management techniques deal with management, in a stricter sense, or with financial aspects: in this latter case, the risk can be either transferred or retained.

The approach to risk management can be either reactive or proactive. A reactive approach is used to (1) manage risk, (2) correct mistakes and (3) compensate the negative effects that have occurred; a proactive approach on the other hand will attempt to (1) identify and manage risks, so as to avoid the onset of problems, (2) eliminate the causes of risk at the root, acting on the risk factors.

Since risk factors are an intrinsic feature of the projects, a proactive approach will attempt to prevent, rather than simply eliminate, risk. Five stages can be defined as follows:

1. Risk Identification
2. Risk Analysis
3. Risk Quotation
4. Risk Response
5. Risk Monitoring

In the stage of Risk Identification, an attempt is made to identify the potential risks inherent to the project in group discussions, by examining previous, similar experiences, formalising project restraints and opportunities. A risk can in fact be considered both as a restraint and as an opportunity, although characterized by a certain degree of uncertainty. Possible risks can be mainly ascribed to the aspects and features of the project's output (its innovative technical and technological content, excessive expectations regarding performances, low level of detail in the specifications, integration with other projects) and the management of the project (underestimated costs and times, overestimating the supplier's capacity, unskilled labour, wrong assessment of the workloads borne by the available resources). A check-list of the risks is thus prepared, together with

supporting documentation, which is signed by the project manager after discussing the matter with the persons in charge of the project and the heads of the technical offices and the functional units.

Having been identified, each risk is subjected to Risk Analysis, determining the likelihood of its occurrence and the severity of its effects on the performance of the project. It should then be possible to translate risks (even those affecting quality, times and workloads) into costs that multiplied by their probability express a quantitative valuation of risk.

On the grounds of the previous analysis, Risk Quotation is carried out to measure and rank the risks and consequently, the interventions; a maximum level of acceptable risk is also set, so that all risks having a higher value must be brought down to a level lower than the threshold using the appropriate actions. It is important that all persons involved are informed about this quotation, which is usually represented as a radar diagram depicting the risks and their value as concentric circles.

The first three stages (Risk Identification, Analysis and Quotation) are also known as Risk Assessment.

Risk Response includes all those actions that are necessary to bring the risks below the previously mentioned threshold levels. The interventions may be synergic and must follow the scale of priorities, since the efforts are made by a limited number of resources and must be addressed univocally. There must be a person in charge of organizing the actions, and once these are carried out, risks must be calculated once again (residual risk). The actions can be classified as follows:

- a) Context actions (defining specific internal programmes, operational agreements with customers and suppliers, revising the contract and excluding certain parts or price increases, getting insured, etc.)
- b) Internal actions (collecting further information, carrying out trials and experiments in advance, involving experts, divulging the issue of risk and organizing problem-solving meetings, eliminating activities and design solution characterised by a high level of risk, allocating the best resources and/or greater ones to the more risky activities as well as paying more attention to them, changing partners and resources or involving them more, moving the activities that are considered more risky out of the critical path, protecting the core output of the project, seeking guarantees for a minimum result, developing alternative solutions for the parts considered more risky and trying to modularise them, preparing contingency plans, etc.)

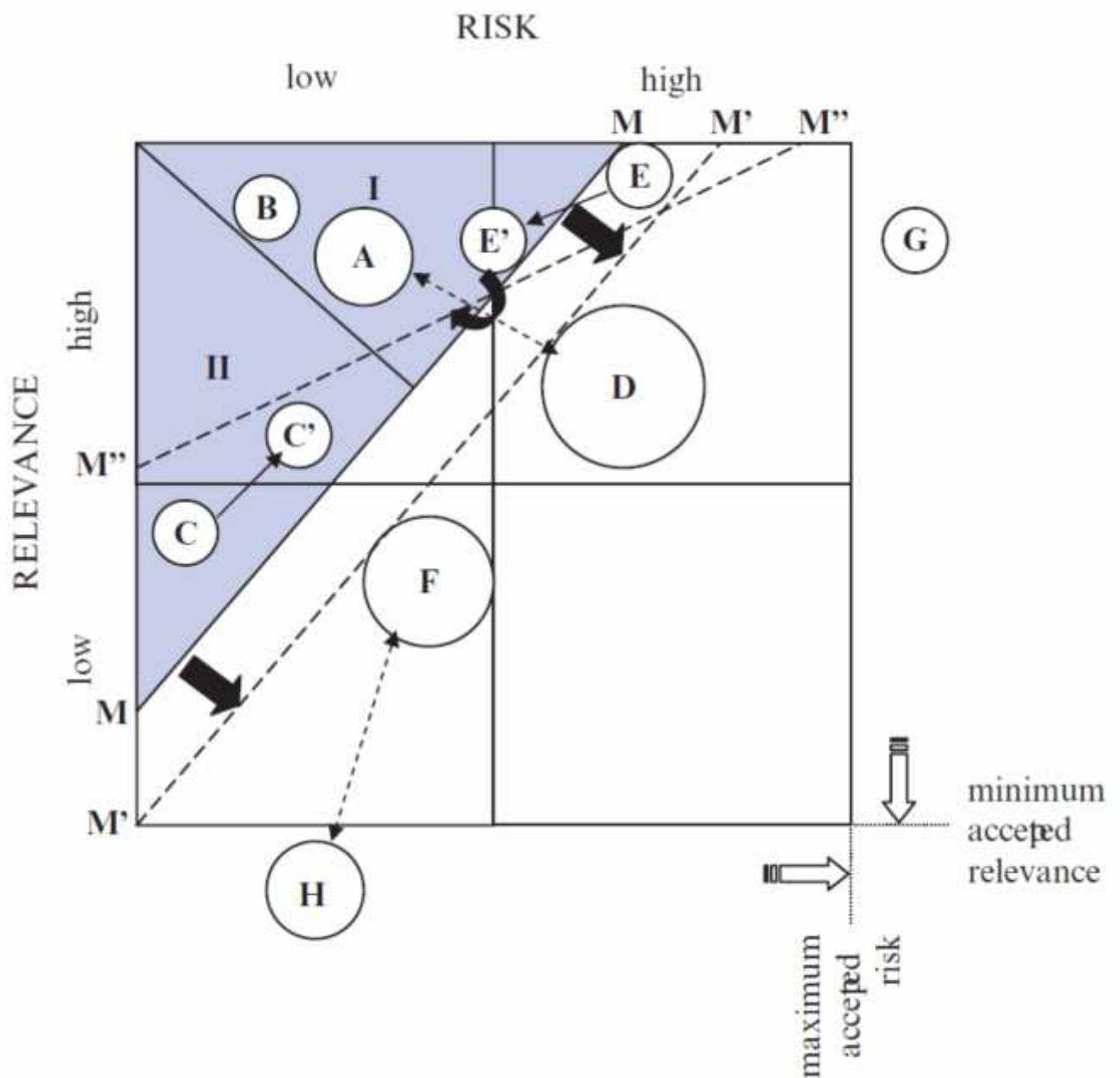
Risk Monitoring finally helps keep risks under control and reduce risk areas. Often paying a little more attention to this issue can reduce the risk itself – as in a basket-ball game, a time-out can work wonders.

If the project is linked to the execution of a contract job, the risk factor also depends on the type of contract issued:

- In a fixed-price contract, the price is defined, hence the supplier is responsible for all the risks, and in the event of greater costs occurring, the latter's margin of profit will be eroded.
- In time & expense contracts, the price is defined in relation to labour costs plus a certain margin, hence the customer takes upon himself the risks, even accepting longer times and hence greater costs to privilege quality.
- Maximum price contracts are based on the cost of labour plus a certain margin; these can reach a certain threshold level beyond which all costs are taken by the supplier (in this case the supplier and the client share the risk).

There are also standard procedures for Risk Management, such as the DoD document 4245.7 M “Transition from Development to Production, which requires templates for the development stages of a system till production is under way; the procedure deals with risk areas, how to reduce risks and schedule interventions.

From a graphical viewpoint, projects can be represented as circles in a two-dimensional relevance–risk matrix. The area of the circles is proportional to the use of critical resources, so this matrix is also known as 3R-matrix (Relevance, Risk, Resources). The main interdependencies between projects are indicated by dotted arrows connecting them, and when one is excluded, all connected projects are affected (as in case D with A, in Fig. II.3). All the projects that fall into the matrix are considered acceptable; however, on the grounds of the utility of each project for the company, and considering the restraints upon the resources, it is possible to define a triangular area representing the selected project portfolio (the shaded area depicted in Fig. II.3).



**Fig. II.3** Project risks and portfolio management

According to this type of representation, projects can be classified as follows:

- Class I projects (having great importance and a high level of risk), for which no delays are admitted; the aim is to reduce their development times, and in the event of conflicts, they have priority for the use of critical resources.
- Class II projects (having less importance and a lower level of risk).

When scheduling activities, care must be taken to limit the number of contemporaneous class I projects. It is also possible to depict multi-project management (MPM) improvement interventions, which can lead to the following:

- An increase in the availability of critical resources, or alternatively, an increase in their productivity (the project portfolio expands, passing from M-M to M'-M', incorporating project E but excluding project C)
- An increase in the ability to manage risk (the project portfolio changes, passing from M-M to M''-M'', thus incorporating project E)
- An increase in relevance, hence accepting a greater level of risk (for instance, the project is placed in position C')
- A reduction in risk, accepting a reduction in its relevance (for example, project E is allocated in position E')

## **II.4 Managing a Project Portfolio**

Multi-Project Management – MPM is becoming increasingly important, because a project portfolio ensures a greater competitive advantage than that achievable by means of a single project. There are at least two reasons for this:

- (a) the turbulence of the market environment, which makes it necessary to limit the otherwise increased risks by presenting a continuous set of innovations through an advanced project portfolio,
- (b) the links of interdependency that exist among projects, which are becoming increasingly stronger and restrictive due to the limited amount of available resources.

Project interdependency can refer to the following:

- Benefits: market synergies obtained by the one concept idea or family feeling
- Resources, which are shared by the different projects and pose certain restraints in their use
- Contents

Content interdependencies can in turn refer to the following:

- The commonality of certain parts with ones from other projects, either past (carryover), present (commonality in a stricter sense) or future (new generations)
- The fact of being part of a vaster system (for example, the project for a sub-assembly is part of a global product project)
- The link with previous platform or naked projects

MPM, or Project Portfolio Management, introduces the concept of families of projects that are characterized by similar development cycles and the same methods for scheduling activities and distributing workloads.

The MPM approach consists of the following steps:

1. Identifying the families of projects
2. Defining the reference structures (times, workloads, etc.) required by each family
3. Defining the project portfolio, on the grounds of the company's objectives, and mapping the competencies and financial resources needed
4. Analysing and managing risk
5. Inter-project organization, appointment of a multi-project manager and identification of critical resources/bottlenecks
6. Defining a system for managing the projects, with common routine specifications and integrated planning of the projects
7. Defining the priorities and allocating the available resources, taking into account the interdependencies existing among the projects

Innovation Index and Ready Plan methods are particularly useful for determining the reference structures for each family. Defining on one hand the complexity of the product structure and on the other the number of families in the project, the Innovation Index method can be effectively used in the presence of high levels of product complexity and limited family extension, whereas Ready Plan is indicated when the families are large, but product complexity is rather limited.

According to the Innovation Index method, the product is divided into functional groups, for each of which the index is calculated as the percentage of planning required as compared to that needed to design it de novo; the reference project family is then identified. Each family consists of a common part (the macro-activities) and a variable one (the duration of the activities and workloads on the resources). Hence, the projects listed in a decreasing order of innovativeness can deliver a new product, restyle it, give it a facelift or simply customize it, drastically or slightly.

The Ready Plan method, on the other hand, classifies interventions into standard, first-level interventions (e.g. a change of push-button panels) requiring a certain family of projects (in the case of push-button panels: functional aesthetics and ergonomics), which in turn determine standard second-level interventions (a change in the shape of the keys, changes in the disposition of electrical contacts, etc.) and relative ready-use plans.

Each project of the portfolio should have a standard reference form, easy to consult and compare with that of the other projects; the form should list the following:

- Type/class of project
- Client/internal sponsor
- Person in charge/project manager
- Allocated budget and resources
- Specifications and scope
- General and detailed technical programme (project plans)

- Start, interim for the milestones and final technical documentation
- Documents stating formal approvals, the minutes of the meetings and the lists of official external contacts (with suppliers, customers, etc.)

According to the MPM approach, organizational interventions should be carried out, focusing on the following:

- Organizational mechanisms, from a simple charismatic control carried out by the head of the department to the creation of committees coordinating the activities of the project managers
- Organizational structures, where each department is in charge of a responsibility and there is a further office responsible for multi-project planning
- The organizational figures, introducing one or more levels of multi-project managers, positioned either at a higher hierarchical level than that of project managers or in an intermediate, transversal position, where they act as connectors

Once a project management system is defined, establishing common routines (so as to seek efficiency in the planning process) or sets of repetitive, clearly defined activities, and having made an integrated project plan (scheduling the activities and use of resources), it is necessary to assign the priorities of the projects, fundamental when conflicts arise for the exploitation of the available resources.

Keeping in mind the interdependencies among projects, the definition of the priorities can be based on different criteria, such as technical difficulty (so the management can decide to give priority to the most expensive projects, those requiring greater resources and/or those that are considered more risky), commercial opportunities (success rate, outcome in terms of payoff and image, opportunity costs in the event of exclusion or demotion, importance of the customer), time criticalness (compulsory time-to-market stated by contract or established by competition, the penalty due in the event of delays, number of critical activities having no margin of flexibility), etc.

The definition of priorities requires a clear and univocal vision of the projects, their objectives and the technical–managerial aspects: it postulates a clear view of the interdependencies existing among the projects and a precise definition of owner-ships, as well as the mechanisms for the periodical revision of priorities. Moreover, it is important to keep in mind all the insurmountable constraints that cannot be levelled out (such as a sufficiently long test period).

## **II.5 Strategic Planning**

Strategy can be considered in terms of content and process. The content refers to both competitive priorities (performance-related macro-objectives that can become Critical Success Factors – CSF) and the interventions made to achieve them. The latter can deal with technological levers (relative to the product/process and to information/communication), internal organisational choices and those to interface with suppliers/customers, and managerial levers (for example, Just-in-Time, Total Quality Management and Concurrent Engineering). The process, on the other hand, refers to the formulation and implementation of the strategy.

Traditionally, corporate strategy relies on three options: cost leadership, differentiation and segmentation. The current trend of overcoming performance trade-offs questions this distinction:

the aim is the joint achievement of multiple performances, giving them different importance throughout time.

Nowadays, strategy is mostly about defining priorities, which are not standard, but more of an order-winning and qualifying type: the former ones make it possible to steal customers from the competitors; the latter simply allow the company to enter into a certain competitive arena. Both are equally important, and when analysing the scenario, a company must decide whether to invest in one or the other type of strategy.

The Industrial Organisation scheme has been hugely criticised because of the differences in profitability found between companies operating in the same industry/sector; furthermore, the classic five factors (intensity of competition, potential new entries into the industry, threats deriving from substitute products, contractual power of the suppliers and the customers) have often failed to explain the sustainability of the competitive advantage.

The criticism is moved by supporters of the theory according to which resources and competencies are the real source of advantage for a company (and not an adequate strategic behaviour for the industry, as maintained by the traditional theory of the Industrial Organisation). Theories such as Resource-Based View and Competence-Based Competition – which share some of the concepts expressed in the Enterprise Evolutionary Theory and Organisational Behaviour Theory – are approaches that have many features and principles in common, so that it is possible to speak of a Competency Theory.

According to the Competency Theory strategic analysis can be schematically described by the sequence: analysis of the resources/competencies possessed, assessment of their profitability potential, consequent definition of a suitable strategy for exploiting, valorising and consolidating them and strategy implementation by means of appropriate policies of resources management.

Hence, the process of strategic planning should take into account both the sequence of the analysis typical of the Industrial Organisation, and that characterising the Competency Theory, identifying the principal point of contact when comparing competitive priorities on one hand and resources/competencies on the other (shaded in Fig. II.4 to highlight this link). Competitive priorities emerging from an analysis of the industry are insufficient: the resources/competencies possessed must also be taken into account, after analysing their potential of profitability. Moreover, it must be kept in mind that the typical resources/competencies of a company have a value in se, when compared to the outside world (the environment and the industry, this latter sector being increasingly difficult to identify with precision nowadays), but also in relation to the company's competitive priorities.

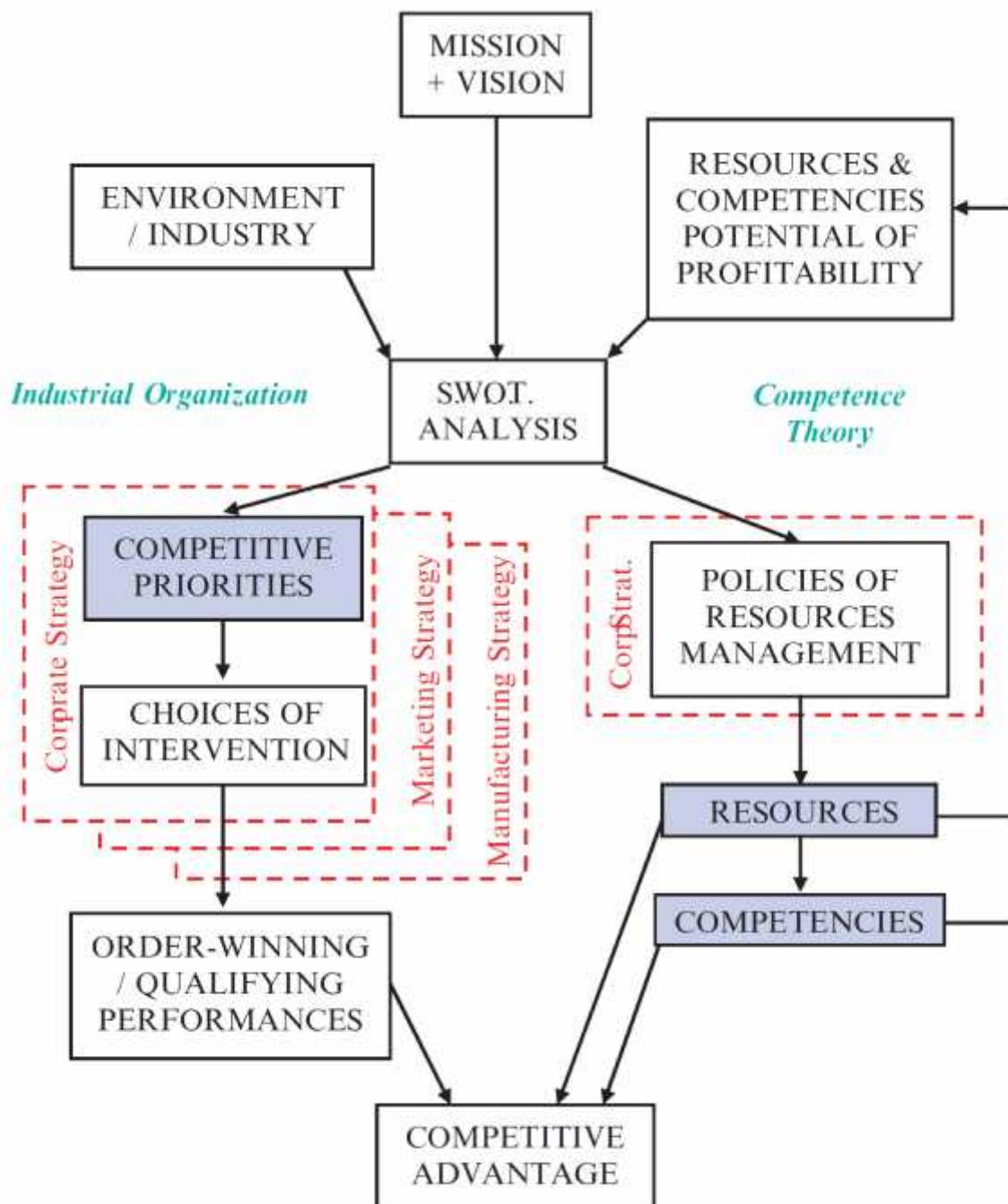
The link between the internal perspective, typical of the Competency Theory (inside-out approach), and the external one (i.e. the market/competitors), typical of the Industrial Organisation (outside-in approach), can be summarised by the so-called SWOT analysis (analysis of Strengths and Weaknesses + Opportunities and Threats).

SWOT analysis is usually carried out after the management has made its mission and vision clear. A company's mission is the answer to the questions: Who are we? What do we do? How? Why and for whom? Conversely, the company's vision answers questions regarding the future: Where will we be? What will we be? Mission and vision should be communicated both inside and outside the company.

Mission, vision and SWOT analysis lead to the definition of a strategy (depicted in Fig. II.4 by dashed lines), in terms of competitive priorities, intervention levers and resource management policies. The latter policies affect the competencies, which are placed at a higher level of

aggregation than the resources, and assess the capacity of an appropriately managed set of resources to carry out an activity or pursue an objective: competencies can explain how two companies, having the same aims and resources, can perform differently, or have the same performances when possessing different resources.

The strategic decisions concerning competitive priorities, interventions and resources management are made at a corporate level (corporate strategy), but are then further detailed for business units and departments, usually proceeding from the trading area (marketing strategy) to the operational functions: manufacturing strategy and design strategy. In the latter case, specific project management (design) strategies should be developed.

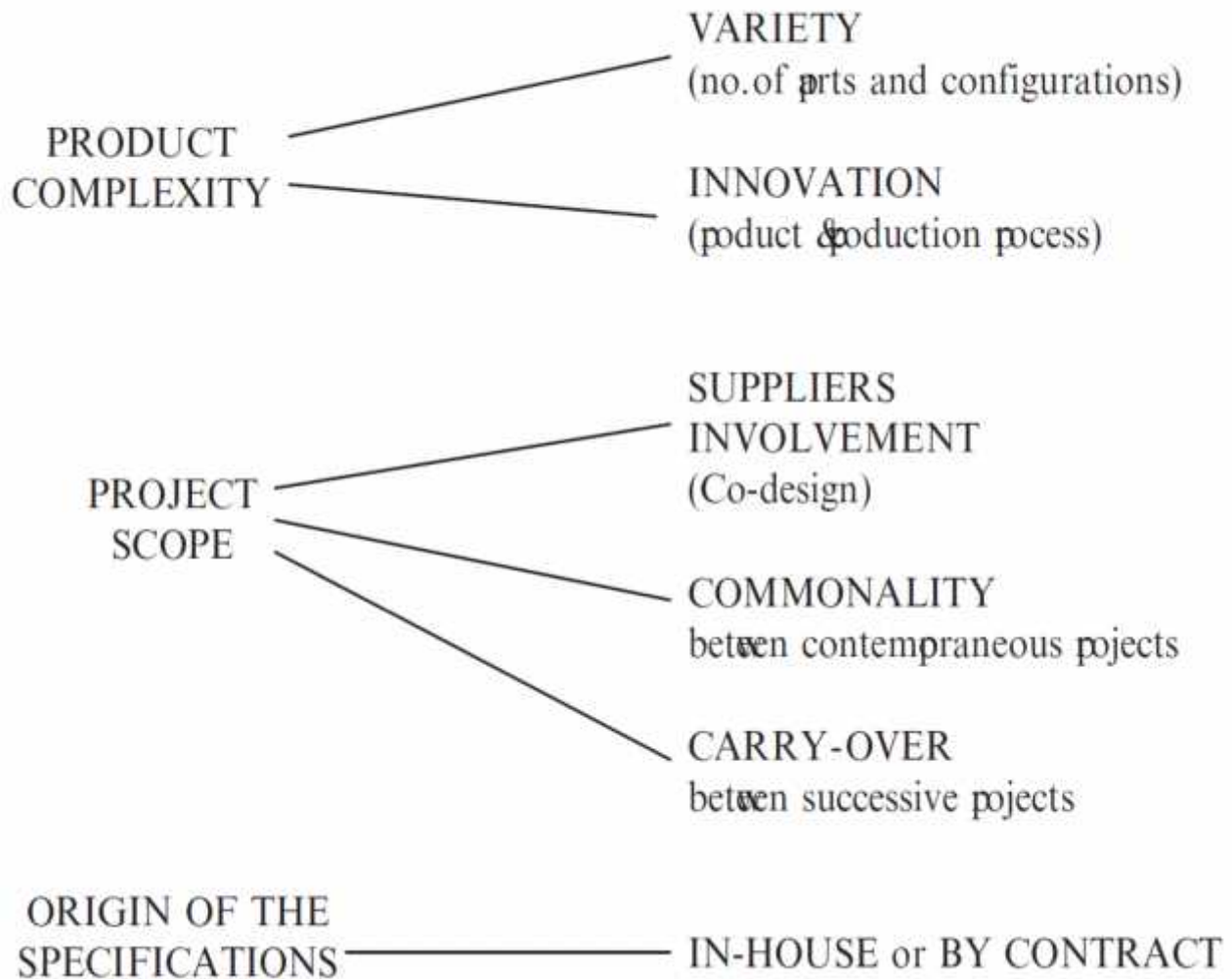


**Fig. II.4** Strategic planning according to Industrial Organisation and Competence Theory

## II.6 Project Management Strategies

We can identify three types of strategic decisions regarding projects (Fig. II.5).

First of all, it is necessary to define the degree of complexity to be assigned to the project, and reduce it if the analyses performed – using, for example, break-down structures – reveal a complexity that cannot be dealt with and managed with the available means.



**Fig. II.5** Preliminary strategic decisions regarding projects

The degree of complexity depends on two factors: (1) the variety of the project, namely the number of parts forming it and its various configurations, (2) the level of innovation required to develop these parts or carry out the necessary manufacturing/ production processes needed to deliver the project.

Both factors concur in making a project more or less complex: a project cannot be considered complex only because it consists of numerous, variable parts, but innovation must also be taken into account, in other words the novelties (with relative costs and risks) featuring in the project. The difference between large and small projects, or more or less complex ones, can be compared to that

existing between an orchestra and a string quartet: both aim at performing well, but the specialisation, coordination, communication and direction needed are utterly different.

A second type of decisions concerns the size (scope) of the project and possible ways to reduce/limit it. A project's size is defined by the amount of work, effort and money put into it. Size also depends on other factors, such as (1) the involvement of suppliers during the stages of design (in this case, co-design), (2) commonality, i.e. the design parts shared by various projects carried out at the same time by the company, (3) the carry-over, namely the number of parts that are inherited from pre-existing projects.

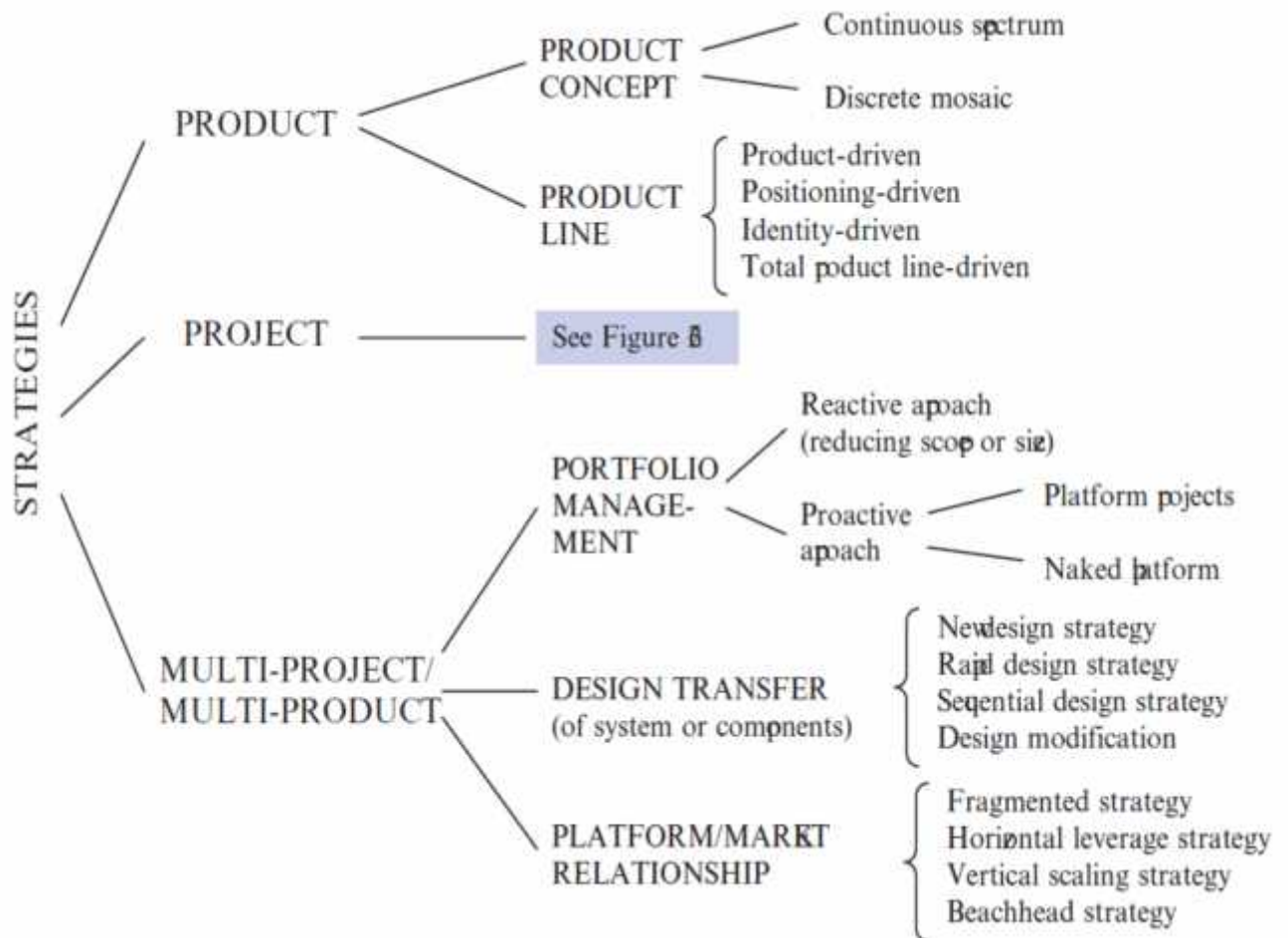
The involvement of the suppliers, not only in terms of delivery of materials, parts and sub-assemblies, but also as regards cooperative design, especially of those parts that are not considered strategic and for which the company does not possess the necessary competency, ensures a remarkable reduction in the size of the project. This may mean that the supplier establishes a stronger link and a more stable, long-term relationship with the customer, as well as spreading design costs over a larger pool of customers. Moreover, the skills of the supplier can certainly improve the quality of the product.

Commonality on the other hand ensures that, for the same investment, a wider range of products can be placed on the market: a core project termed platform is used as a starting point for responding to all specific demands – including customisation. Consequently, the break-even point for the sale of a certain product is lower, risks are smaller and the consequences of a wrong prediction of sales (unsold stock, costs related to production under- or over-capacity, etc.) are reduced.

Carry-over enables new products to be launched on the market with limited investments and risks. Only marginal innovations are introduced, chiefly of an aesthetic or modular nature (additional functions or replacement of certain parts/sub-assemblies), but these can have a remarkable impact on how the customer perceives the product, which is often more than proportional to the actual degree of innovation. Moreover, it is also possible to prolong the life cycle of a product, delaying investments for newer products, increasing flexibility and waiting for the competitors' moves or new technological developments. Not always are the pioneers more successful than the followers.

A third type of decision concerns the origin of project specifications, which may be internal (as often is the case in product development), or receive indications from a certain client of the company: in the latter case, design and production are made to order, or better, Engineered-to-Order (ETO). The client may list and define requirement in a more or less detailed manner.

The earlier macro decisions concerning strategies for a (single) project and linked to its complexity, size and specification occupy an intermediate level between strategies for a (single) product and multi-project, multi-product ones (Fig. II.6).



**Fig. II.6** Product, project, and multi-project/product strategies

Product strategies can be placed within the wider framework of marketing strategies. They also include the concept ideas defined when planning product development, and the product lines definition.

The decisions concerning product concept are affected by the relative position of each product on the market and their sequence of introduction (and for this reason, they are linked to multi-project strategies). Two alternative strategies may be adopted: continuous spectrum, which views the market as a set of stratified, continuous segments, a view that is reflected by the products of a certain line (hence the customer is tempted to pass from a basic model to a superior one), and discrete mosaic, where the market is considered as a multiple set of unrelated, discrete segments: in this case, the models are uniquely differentiated and are characterised by a very focused product concept (this is the strategy used by producers who want to compete against leading firms).

To design a product line, it is essential to first define the differences between products as well as the identity of the line, in other words the common features possessed by the various products. Also, in this case there are different strategies that can be adopted, according to the identity of the line and the importance of product-positioning within the line.

Multi-project, multi-product strategies mostly focus on (1) the management of the project/product portfolio, (2) design transfer, (3) the relationship between platform and market.

Portfolio management can be either reactive or proactive. Traditional policies are based on a reactive approach, exploiting commonality and carry-over. When starting a project, an attempt is made to identify the inter-dependence existing with past or current projects, and where possible, ready-developed solutions are adopted. A proactive approach, on the other hand, is linked to the concept of platform and can offer two alternatives: either develop a new core design when preparing a new product, or work in order to set up a platform without, for the time being, launching any product (naked projects such as the concept cars in the automobile sector that have no immediate commercial aim but in a later stage may also benefit from off-the-shelf parts, namely parts taken from the shelf of innovation).

Design transfer, namely the transferral of designs and core technologies among projects, requires a three-dimensional analysis, focusing on the type of transfer, the transfer process and the coding of technology. The knowledge transferred can be that relative to the parts or to the entire system. Strategies that provide for the development of a new product with a core design that has no significant interaction with other projects developed by the company (a particularly suitable strategy for incorporating state-of-the art design and technological solutions) are defined as new design strategy. There are also other strategies that can be used to transfer knowledge to other projects: (1) in rapid design transfer, the base project starts to transfer its core to a new project before it is fully completed, hence great coordination is required, and probably adjustments must be made on both projects; (2) in sequential design transfer, the transfer occurs when the base project is completed and the links with the new project are more relevant. There is also another strategy, termed design modification, according to which the design of a new product is based on the core design of its predecessor.

If on one hand new design is the best strategy in terms of expanding the company's market share, on the other it requires longer development times and considerable resources. The best compromise is a strategy of rapid design transfer, which ensures rapid access to the market and a satisfactory productivity of the resources. The time interval between the start of the original project and that of the new one the rapid transfer time is known as platform design age. Experimental results show that dominant positions on the market are obtained by the frequent introduction of new products, exploiting young platforms: the renewal of platforms is a vital issue for today's companies.

Platform development can be depicted as a grid whose rows report the levels of price/performances and the columns the market segments. As a consequence, there are four types of platform strategies: (1) a fragmented strategy if there is a specific platform for each cell (corresponding to a market niche): consequently, there are numerous families of products but also higher costs, because the concept of platform is poorly exploited; (2) a horizontal leverage strategy if one platform is exploited by various market niches sharing the same level of price/performance, thus along various segments of a certain row; (3) a vertical scaling strategy if one platform serves different levels of price/performance within a certain market segment, scaling either upwards or downwards; (4) a beachhead strategy if the firm prepares a platform for a specific, low-price segment and then extends it to other segments, at higher price levels.

Multi-project strategies based on platforms are part of a wider range of strategies that include joint ventures, globalisation and even the standardisation of platforms and/or architectures among various producers operating in a certain sector (this is often the case of electronic consumables).

Product, design, multi-product and multi-project strategies require the definition of the two factors that characterise all strategies: the scope (in term of quality, time and costs) and the necessary (technical) means to achieve it.

## II.7 Project Management Performances

It is first necessary to distinguish between the performances of a single project and those relative to the design process, i.e. all those activities that serve to deliver several projects in a certain period. In a company-wide framework, these activities (engineering, industrialisation, etc.) involve various departments (such as Marketing, Production, etc.), and therefore the performances should not only refer to Design function (technical office or similar units).

The performances of a project consider three aspects (Table II.1):

- The quality of the project (how it meets the client's expectations)
- Lead Time or time-to-market (duration of the project)
- Productivity cost (the amount of resources used to produce a certain output)

|               | (Single) project |                                               | Design process (multi-project) |                                                                                          |                     |
|---------------|------------------|-----------------------------------------------|--------------------------------|------------------------------------------------------------------------------------------|---------------------|
| Quality       | External         | Total design quality                          | Internal                       | Organisational learning                                                                  | Project Flexibility |
| Time          | Internal         | Lead time, time-to-market                     | External                       | Product replacement and range expansion rate                                             |                     |
| Costs         | Internal         | Project costs                                 | Internal                       | Costs of the Design Department and of the other resources involved in the design process |                     |
| Productivity  | Internal         | (Technical parameter)/(project costs)         | Internal                       | (No. of projects)/(cost of the design process)                                           |                     |
| Profitability | Internal         | (Net income from the project)/(project costs) | Internal                       | (Total revenues)/(cost of the design process)                                            |                     |

**Table II.1** Project and design process performances

The quality of a project depends on its output or deliverable. Quality is difficult to measure, both because its economic value cannot be immediately determined and because it is, by definition, a multi-dimensional parameter. One of the most popular methods to estimate the quality of a product – that considers eight dimensions: (1) key performances/features, (2) other performances/ features, (3) conformity with specifications, (4) reliability (the ability to carry out its function for a certain length of time without requiring repairs), (5) duration (linked both to technical obsolescence and economic aspects, i.e. if a certain product is still convenient), (6) aesthetics/design, (7) perceived quality (solidness, etc.) and image (including status symbol), (8) after-sale assistance and services.

The quality of a product, resulting from total design quality, can be considered good when (a) the product concept matches the requirements of the customer (customer concept matching) and (b) the product specifications meet the product concept (concept–design matching).

Project times are becoming increasingly important, especially in these days of Time-Based Competition, when projects are a key factor of success, especially in the case of premium price, usually resulting from being the first company to present a new product on the market.

The lead time or time-to-market of a project is an internal time performance; in other words, it cannot be directly perceived by the customer, who is only aware of the product replacement and the range expansion rates, namely the rates at which new products appear on the market (either to replace preexisting ones or to expand the range), or the ratio between the number of new products launched and the average number of products offered in a certain period of time (New Product Introduction Rate – NPIR).

Only in the case of ETO, the lead time of a project/contract job is an external performance, since it is perceived by the client, who knows when the project is due to start (usually when the contract is signed, although the company could have started work already, making surveys, preparing estimates, etc.).

The costs of a project refer to the resources (human, material and equipment) exploited for the various activities. Also productivity is an exclusively internal performance that cannot be perceived by the customer if not indirectly, when assessing the price. Productivity is the ratio between output and input, and with reference to specific standards is more accurately defined as efficiency (whereas efficacy is the ratio between actual output and targeted output, and is therefore independent of the input). Costs and productivity are thus closely linked, but despite this, they can give rise to discordant results: for example, there can be considerable expenses linked to the project but these may have a positive outcome in terms of productivity (with technical results well beyond expectations).

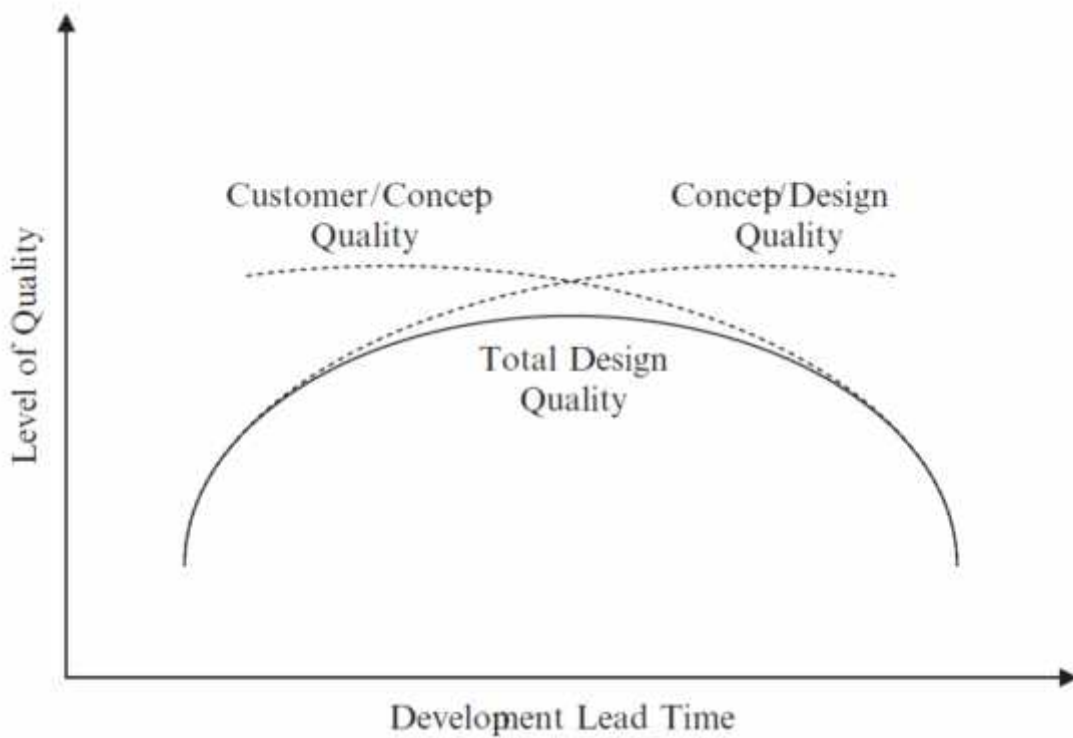
The output and input can be expressed either as amounts or in money value (in this case however there is the problem of price fluctuations, which can be solved by using deflators or the concept of equivalent units); generally, the productivity of a project is calculated as the ratio between output (a technical quality parameter) and input (the costs that can be ascribed to the project). When the project is considered as an investment also, the incoming cash flows generated by the project are taken into account, and the value of the numerator is equal to the sum of the profits that can be ascribed to that project. In this case, it would be more correct to describe this value as the profitability (or financial productivity) of the project, at a given level of cost.

Cost and productivity are considered as cost performances not only for the unit of measurement used to express them, but mostly because they are directly linked using specific formulas to the company's financial results; time and quality, on the other hand, are considered as non-cost performances because, although they affect these results, they are only indirectly linked to the costs.

Links can be established between product performances listed previously. It has been observed an inversely proportional relationship between customer concept matching and the time needed to develop a project, while there appears to be a directly proportional relationship between concept design matching and development time; hence, total design quality has an optimal development time, corresponding to the peak of the curve obtained by summing the curves of customer–concept quality and concept design quality (Fig. II.7).

There is also a relationship between (project) quality and productivity: when the latter increases, the quality of a specific project may decrease; on the other hand, greater productivity may determine a

greater variety, thus increasing quality in terms of customer satisfaction (fitness for use). Also, in this case, it is necessary to define an appropriate (minimum) level of productivity.



**Fig.II.7** The optimal development lead time is the maximum level of total design quality

In a multi-project framework, the overall design performances include time performances (corresponding to the product replacement and expansion rates), cost performances, which refer to the overall cost of the resources, without ascribing them to the single projects (thus without running the risk of a non-objective allocation), productivity performances, linked both to the number of projects carried out by the company (or other indicators such as patents, etc.) and their cost, and profitability performances, referring to the profits made by the company – thanks to the design activities; in this context, quality can be linked to learning (Table II.1).

When operating in a multi-project environment, it is fundamental to take into account the project's flexibility, in terms of easiness to modify both pre-existing products (product flexibility) and the manufacturing processes (process flexibility not to be confused with production flexibility, which refers to changes in the work programme, once the processes/production cycles have been defined). These performances although unperceived by the customer determine the range of products, as well as the times and costs needed to expand or replace them. A variation in pre-existing projects (namely, the deliverables of previous design cycles) implies a change in certain characteristics of the product (materials, parts, dimensions, etc) or its production, such as manufacturing stages and assembly: in other words, a change in quality requires a certain length of time and has a cost (Table II.1). The product and process flexibility is equal to the ratio between the extent of change (the numerator) and the time and costs required (the denominator).

Performances, both internal and external, of product development and more in general, of the design process, depend on (1) how the various stages of the process are managed, (2) the practices

used, (3) the strategic and organisational context. The most important drivers for these areas are as follows:

- The ability to understand in advance the customer's requirements and orient the designing activities so as to satisfy these demands
- Frequent contacts with the clients, so as to listen to the customer's voice during all stages of development
- Giving great importance to the first stages of concept definition and product planning; a partial overlapping of the various stages of development, with frequent exchange of information (and relative instruments), is a better alternative to the more traditional, sequential approach
- Frequent problem-solving feedback cycles
- The internal involvement of the stakeholders, namely the sponsors (commitment) and the management (leadership)
- A high level of integration among the functional units (including production, purchasing, trade and marketing, accounting, human resources management, etc.) and widespread team working
- A climate oriented towards innovation and learning, inspired by a specific, shared strategy
- Greater emphasis on the architectural and systemic aspects of the project, and on the involvement of suppliers and subcontractors
- The application of innovative techniques to manage variety, modularisation, integrated design, engineering, etc

# Chapter III

## Project Time Management / Project Organization and Resource Management

### III.1 Time Representation: Gantt Chart and Network Diagram

Time was the first variable in Project Management to be supported in a coherent manner by specific techniques. Thanks to the great repercussions caused by variations in the costs and delivery times for the high-profile military and civil orders made after the war. But while costs could be ascribed to a number of causes that, although often impossible to predict or control (as in the case of cost fluctuations), could be managed through various techniques, in the case of delays, management seemed less complex, and problems easier to solve.

The situation at the time is illustrated by two research projects dating back to the 1950s, one of which was carried out by the Rand Corporation and focused on military projects, whereas the other, on civil projects, was carried out by the Harvard Business School. The investigations reveal a cost factor (i.e. the ratio between actual and forecasted cost of the project) of 2.4 and 1.7, respectively, and a time factor (the ratio between actual and forecasted implementation times) of 1.5 and 1.4, respectively. Hence, although the delays were similar, there was a large gap between the two cost factors, which was ascribed to the greater degree of innovation characterising the military projects.

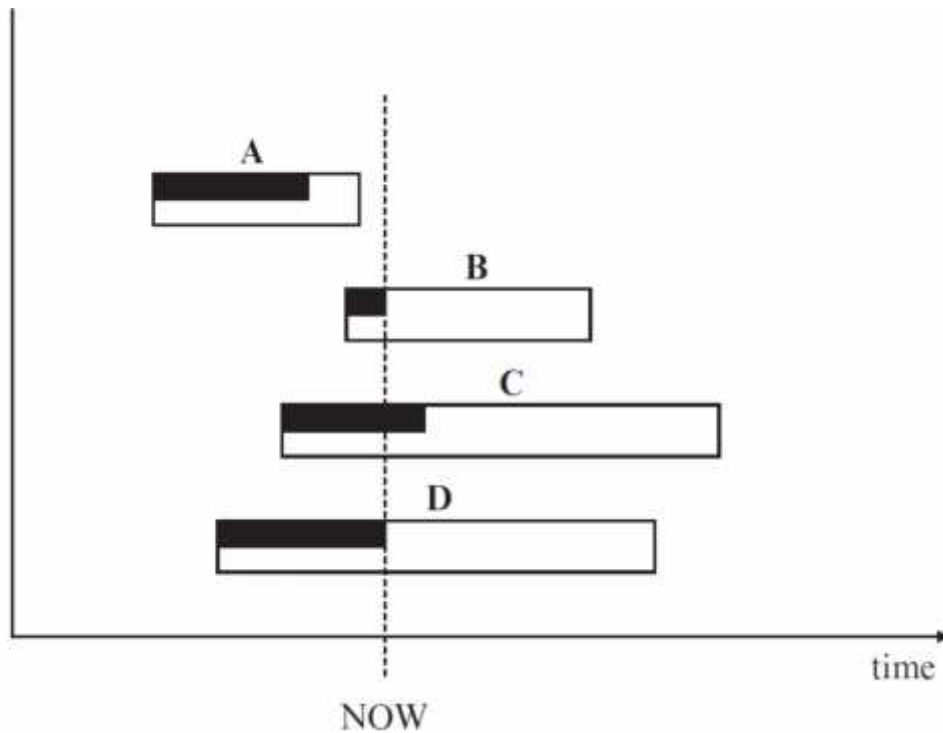
However, even before attempts had been made to improve project management, the first steps in this direction date back to 1911, when Frederick W. Taylor experimented on scientific production management (coinciding with today's times and methods) and Henry G. Gantt (1861–1919) was working for the US Army.

Gantt is the father of one of the two time representations still in use today: the activity bar on time axis or Gantt chart (the other being the network diagram).

Figure III.1 depicts a simple Gantt chart:

- The start date and end date for each activity (also known as task) are indicated on the horizontal time axis, while its duration is proportional to the length of the bar.
- The state of advancement of the tasks at a given time (usually coinciding with the present) is indicated by the blackening of the bar (in Fig. III.1, task A is late; B and D are on time; C is early).

The Gantt chart, although easy to read, has various drawbacks. It does not indicate priorities between the activities. The fact that task B starts when A ends does not necessarily imply that task A must be completed before carrying out B. For instance, when building a house, A could indicate plumbing and B wiring (two activities that could be carried out contemporaneously): the fact that one task is performed before the other does not indicate a priority, but could be due for example to the unavailability of the electrician.



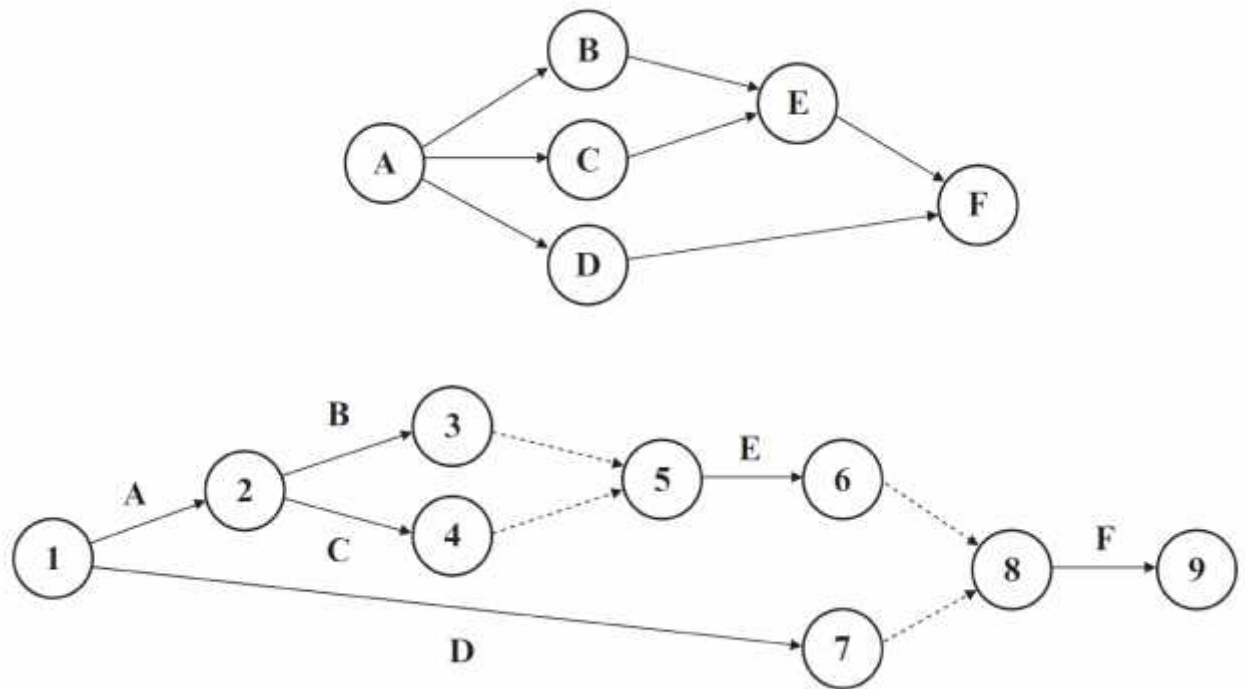
**Fig. III.1** Gantt chart

To visualise the actual priorities, the bars should be linked with arrows, but in the presence of numerous bars/activities, the complex network of arrows that would arise would make the chart difficult to read. In these cases, it is advisable to use network diagrams, which depict activities and their priorities with nodes and arrows.

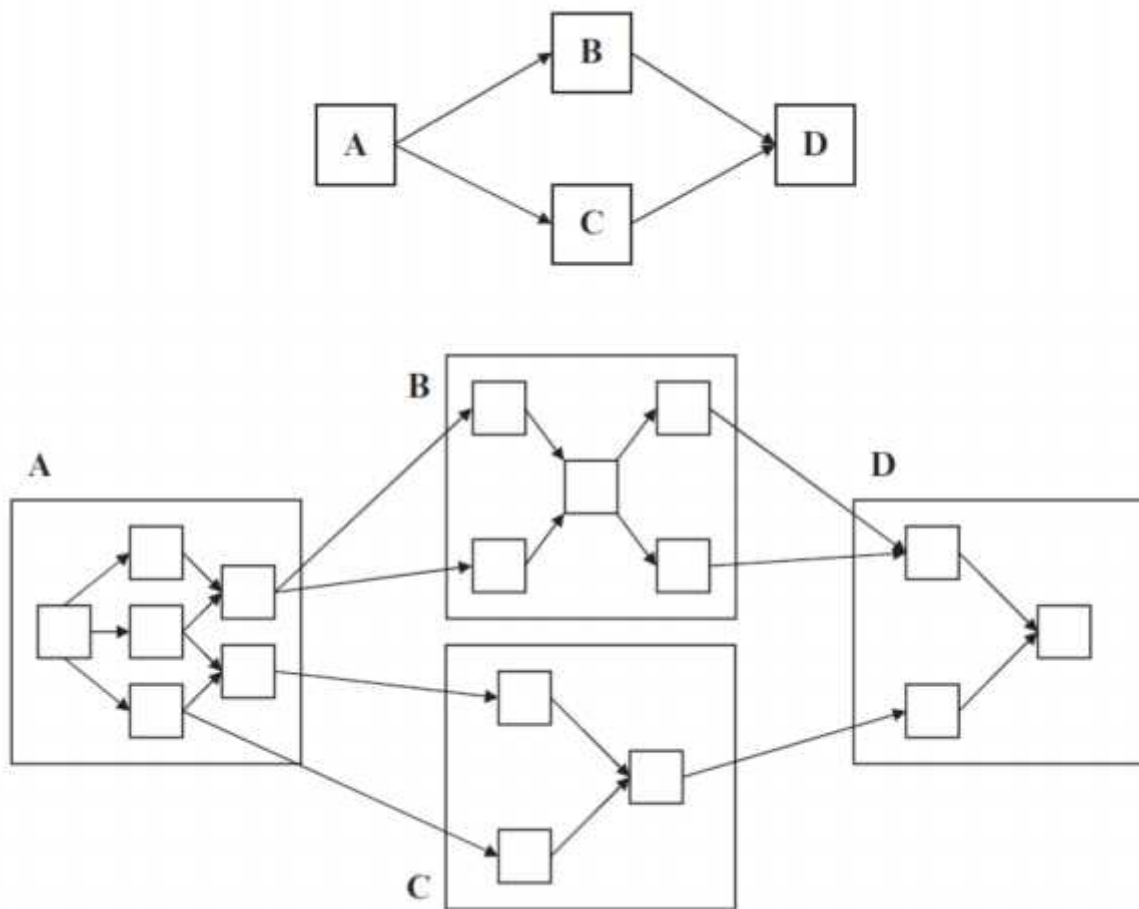
Typically, a given project can be described by two types of network diagrams (Fig. III.2), which are known as European and American. In the former diagram, the activities are depicted by nodes, in the latter by arrows. In the latter case, the nodes represent events: in Fig. III.2, node 1 is the event start of activity A and node 2 is end of activity A. Since the American representation makes the diagram more intricate (e.g. node 5 is necessary to signal the event activities B and D are concluded and is a so-called dummy node), this type of representation has been almost completely set aside.

Generally, a Project Management network consists of activities (the nodes) and links of precedence (the arcs or arrows). This network is a graph (a combination of nodes and lines) that is interconnected (there are no isolated nodes), oriented (the lines are arrows) and free of circuits (it is impossible to return to a node). To underline its field of application, it is also known as Critical Path Method (CPM) diagram or Program Evaluation and Review Technique (PERT) diagram, after the names of the main techniques exploiting it.

Network diagrams can also be hierarchical, according to the principle of Chinese boxes, as shown in Fig. III.3. It is possible to have either a general description (above), or a more detailed one (below), where all the links between micro-activities reflect those between macro-activities, and vice versa.



**Fig. III.2** Network diagrams according to the European (*above*) and the American (*below*) representation



**Fig. III.3** Overall (*above*) and detailed (*below*) network diagrams

Although the activities are connected to each other by links of precedence/sub-sequence, some may be concurrent; hence, a given task may start before the previous one is over. The degree of concurrency is measured by the so-called overlapping ratio, defined by the formula:

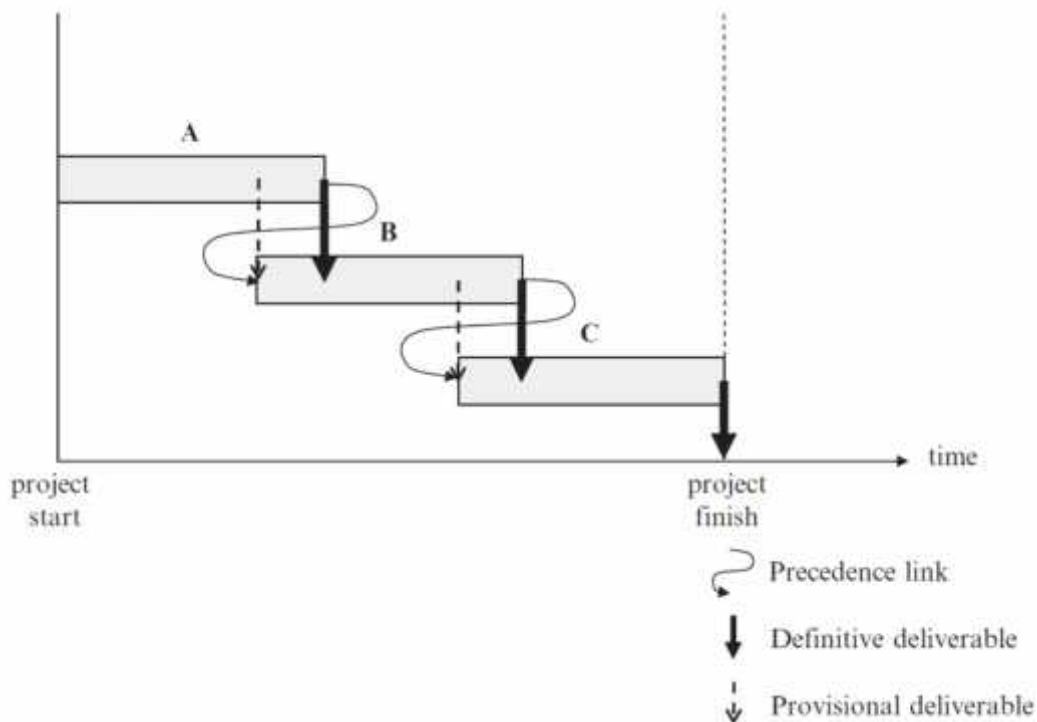
$$IS_i = \frac{\sum_{j=1}^N t_{ij}}{T_i}$$

where  $t_{ij}$  is the time required by task  $j$  of a project  $i$  consisting of  $N$  activities, and  $T_i$  is the overall duration of project  $i$ ; the total overlapping ratio is then calculated by summing the overlapping ratios for each project  $i$ .

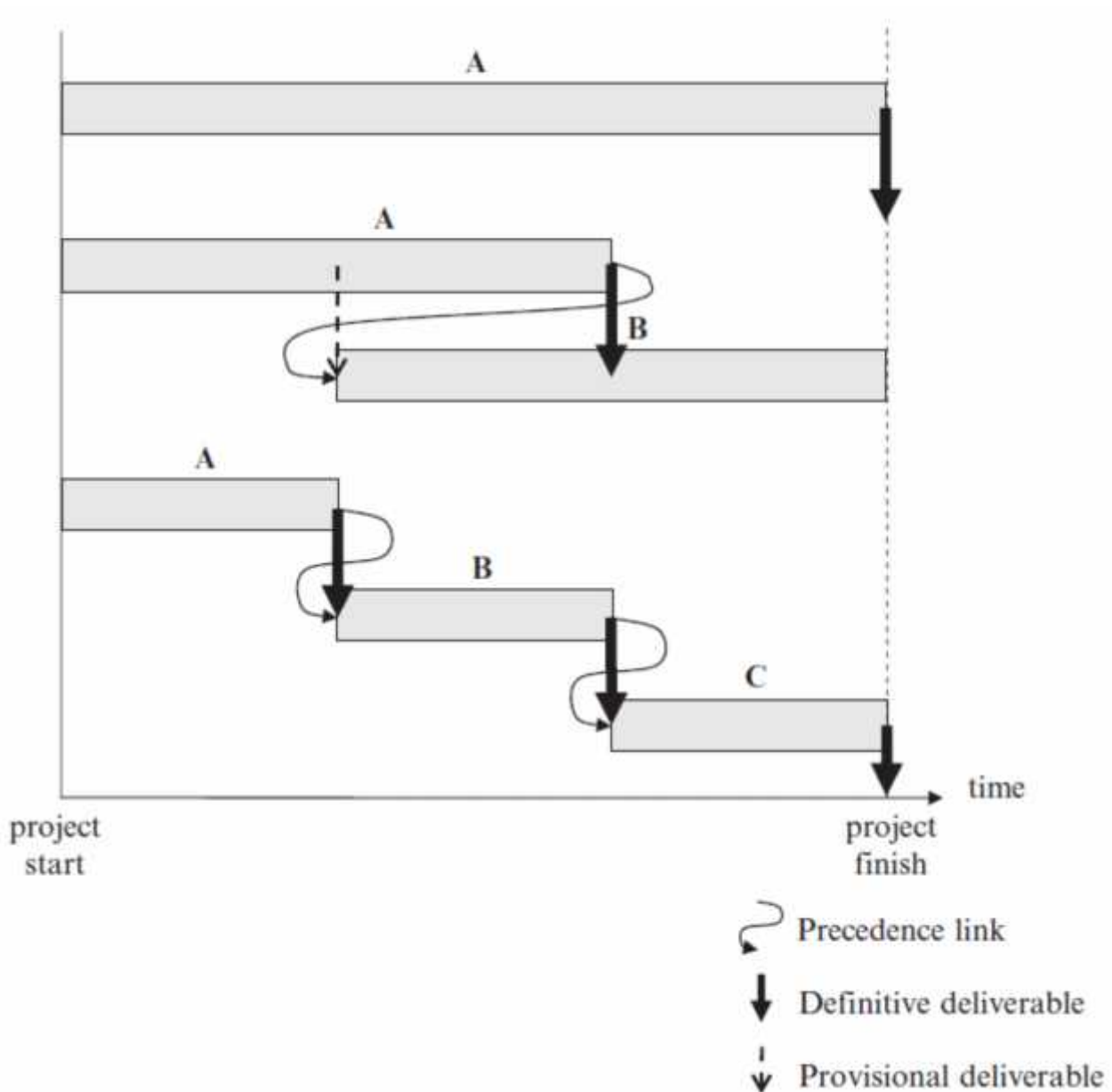
If, for instance, we consider, for the sake of simplicity, an identical duration  $d$  of the three activities forming a mini-project, and a link of precedence among them, the overlapping index is equal to 1 when all the activities are carried out in a rigid sequence ( $IS = (d + d + d)/3d = 1$ ), whereas it increases, reaching a maximum value of  $N = 3$ , when they can be carried out simultaneously ( $IS = (d + d + d)/d = 3$ ).

Figure III.4 illustrates the significance of precedence. A normal link of precedence between a certain activity  $A$  and the following one  $B$  indicates that  $A$  delivers an output that is an input for  $B$ . In the event of overlapping,  $A$  must be able to supply a provisional deliverable for  $B$  to start, and only when it delivers its final output, will activity  $A$  end.

Figure III.5 illustrates the meaning of activity splitting, and the difference that runs between having a large and a small number of activities. The splitting process must be such as to ensure that each sub-task produces a deliverable. If a project has only a small number of activities, there will be very few intermediate deliverables.



**Fig. III.4** Significance of the precedence link between activities



**Fig. III.5** Significance of activity splitting

### III.2 Network Techniques: CPM, MPM, PERT, GERT, VERT

Network techniques are used for managing time; they are called so because they are based on the network diagrams, in this case not intended to illustrate data but to elaborate them, so as to do the following:

- Schedule activities, namely define the start and end date of each activity and, consequently, the duration of the entire project
- Analyse allowable floats (or slacks) for non-critical activities that do not increase the duration of the project, which means identifying those activities that, if delayed, would prolong the duration of the project, and are therefore known as critical

There are three types of starting data:

- 1.The activities (task name or identification code)
- 2.Their duration
- 3.The links of precedence between the activities

The activities are those described in the Work Breakdown Structure (WBS), whereas duration and precedence are discussed and defined at meetings, and can be either deterministic (certain) or probable (estimated with a certain margin of risk).

There are therefore various network techniques:

- CPM, used when the duration of all the activities is considered fixed, and likewise the links of precedence, which are of the Finish-to-Start type (namely, the beginning of a certain activity is linked to the end of a previous one)
- MPM (Metra Potential Method): it is similar to CPM, but also includes three other types of relationship between the activities (namely, Start-to-Finish, Start to Start, Finish to Finish: e.g. it can sometimes be useful to have two activities finishing at the same time, and in this case a Finish-to-Finish link is established between them)
- PERT, namely a CPM having all durations expressed in a probabilistic manner
- GERT (Graphical Evaluation and Review Technique), namely a PERT that also has the precedence links expressed in a probabilistic manner (logical gates are therefore used to trace the paths, ensuring feedback among the activities and various types of conclusion)
- VERT (Venture Evaluation and Review Technique), which takes into account the time, cost, resources and risk variables contemporaneously, and is particularly suited in what-if scenario analyses and when evaluating and reviewing new businesses or strategic initiatives (as the name suggests)

CPM and MPM can thus be considered deterministic techniques, whereas PERT, GERT and VERT are probabilistic ones.

Defining the likely duration of the activities is not easy: it is insufficient to say that, for instance, in 80% of the cases a certain activity has duration  $d$ , since this statement does not explain how long it lasts in the remaining 20% of the cases. It is therefore necessary to consider the distribution of duration probability, using for example a Gaussian curve that not only indicates the average duration of a certain task, but also the variance (the distribution of values around the mean). However, a new problem arises, namely the huge amount of calculations required to define the overall duration of a project, which must take into account the sequence of probabilities. To simplify calculations, it is a common practice to use simulation methods (such as Monte Carlo) or a formula (derived from the Beta distribution) to estimate the duration of each activity.

In the first case, for each activity, a duration value is selected at random, using the Monte Carlo Method; the values thus picked are used to calculate the overall duration of the project. By repeating this procedure for a large number of times (generally, a few thousand), it is possible to obtain a significant sample of the time needed to complete the project, and this sample can be used to calculate distribution, mean value and variance.

Beta distribution can also be used to estimate the duration of a project. This function describes the distribution of duration probability, and intersects the x-axis in two points: the first one corresponds

to the times required in an optimistic scenario (i.e. the shortest duration), the second to those in a pessimistic one (i.e. the longest duration).

From a practical viewpoint, three types of duration are taken into account: low ( $d_{opt}$ ), base (i.e. the most likely,  $d_{ml}$ ) and high ( $d_{pess}$ ). The estimated duration is a weighed sum of the three, giving more weight to the most likely duration:

$$d = (d_{pess} + 4d_{ml} + d_{opt}) / 6$$

Thanks to these methods, it is possible to obtain deterministic values, and analyse them by CPM.

GERT, on the other hand, is even more complex, because not only is it necessary to calculate probabilities, but also determine the types of relationship. These can in fact change from AND/AND (when all the previous activities or predecessors trigger the following ones or successors) to OR/AND, AND/OR, OR/OR; moreover, the OR can be inclusive (the activity only starts if at least one of its predecessors starts) or exclusive (it starts when only one of the predecessors is carried out). For example, an inclusive OR/AND relationship must be thus interpreted: if at least one of the predecessor activities is executed, all the other subsequent ones can start.

The introduction of a risk variable and the contemporaneous consideration of all the other variables (times, costs and resources) makes VERT the most complex tool of all. It operates in a what-if scenario, and requires a certain amount of information before it can provide statistically significant solutions. The final result is given by a function or an index (Return On Investment, Net Present Value, etc.) representing the goals of the venture; each variable is weighed with the likelihood of its occurrence and the trend of the output is determined empirically, analysing the frequency curve obtained as the values of the variables change. The joint identification of the risk profiles makes this a very useful tool for decision-making purposes.

The complexity of PERT, and even more GERT and VERT, is such that in most cases an attempt is made to use CPM (or better, MPM, if there are various types of links): hence this method will be described in greater detail in the following section.

### **III.3 CPM: Activity Scheduling and Float Analysis**

The CPM was developed in 1957 in the United States by the Catalytic Construction Company, thanks to the efforts of Morgan Walker, who, when working on a construction project for the DuPont Corporation, devised a method to simulate various planning alternatives, all of which would have a fixed duration. Soon after, a more complex CPM, called PDM (Precedence Diagramming Method), was defined at the Stanford University. PDM also included start-to-start and finish-to-finish relation-ships, and can thus be considered the first MPM. The CPM/MPM was further developed and became increasingly popular thanks to the aid offered by calculators and computers.

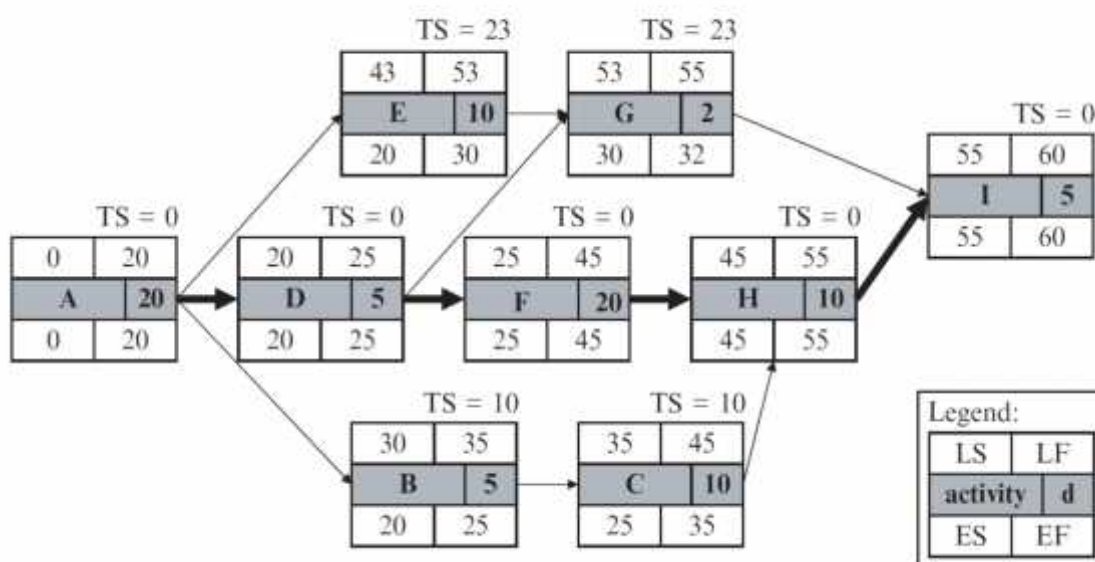
PERT, on the other hand, was defined about a year later in Lockheed, with the contribution of Booz, Allen and Hamilton, when designing and building atomic submarines armed with ballistic missiles for the Special Project Office of the US Navy. This was the Polaris project, involving over 250 contractors and 9,000 subcontractors. It was impossible to manage such a complex project using conventional methods, especially because of the cold war, which made the project a national priority (it was completed in a record time of 4 years).

GERT was created by NASA for the Apollo project, which brought man to the moon (1969). VERT, on the other hand, was only defined in the late 1970s and is still evolving.

These projects, formalising the various network techniques, were preceded by other ones, exploiting a series of more or less defined procedures that form the core of the theory and practice of Project Management. Among these is the Manhattan project, which led to the first A-bomb experiments in Los Alamos in 1943. Presumably however, some sort of management was required for other complex projects carried out in the past, such as the construction of the pyramids in ancient Egypt.

CPM considers a project as a set of activities, having a certain duration and clear links of precedence. Figure III.6 is an example, depicting the activities, the names and duration of which are indicated inside the rectangles, and the relationships, indicated by the arrows. Two questions arise: how much time passes from the start of the first activity (A) to the end of the last one (I), in other words what is the duration of the project? In addition, what is the schedule of each activity, namely its start and end date?

To answer the first question, we must verify all the possible paths leading from the first activity to the final one, and consider the (minimum) duration of the project as the time required to complete the longest path (in the example: A–D–F–H–I, for a total duration of 60 time units).



**Fig. III.6** CPM – in bold, the critical path, where TS = 0 (*d* activity duration, *ES* Early Start, *EF* Early Finish, *LS* Late Start, *LF* Late Finish, *TS* Total Slack)

This pathway, dictating the duration of the project, is the critical one, since a delay on this route determines a delay in the delivery time of the project. A certain slack can be tolerated in activities that are not on the critical path; for instance, both B and C (together) can slack up to a maximum of 10 time units, without causing any delay in the conclusion of the project (whose minimum duration is, as mentioned previously, of 60 time units).

We must then ask ourselves what are the start (and end) dates for each activity. Obviously, the end date depends both on the start date and on the duration of the activity.

In certain cases (i.e. for those activities that are outside the critical path) there is no definite start date, but there is instead a time interval given by the earliest and the latest date when the activity can start (Early Start date and Late Start date, respectively). For instance, activity B cannot start before time 20, or after time 30, else the project would not be completed in time.

This is obviously the maximum possible interval, and may not be completely available. The start date, for instance, may depend on that of the other activities that are directly linked to it; in the example, it is clear that C can start between time 25 and 35, but only if B starts between 20 and 30.

The CPM provides the algorithms to calculate these dates. By representing the Early and Late – Start and End dates, as shown in the caption of Fig. III.6, these algorithms help schedule the activities depicted in the figure on a clear background, and calculate the overall delay or Total Slack (TS), which is the difference between the earliest and latest date (it is indifferent if start or finish, since the latter date is equal to the former plus the duration of the activity).

All the critical activities (i.e. the activities on the critical path) have a  $TS = 0$ , whereas the others have a  $TS \neq 0$ . Therefore, all critical activities can be identified both by testing all possible paths as illustrated at the beginning of this section or by verifying whether early and late dates coincide. It is fundamental to calculate TS, since it identifies the criticalities (from a time viewpoint) for each activity: in the example, E and G are the less critical activities.

Given here are the formulas used for CPM algorithms (MPM formulas are more complex, since they must consider all types of relationship between any two activities: finish-to-start, start-to-finish, start-to-start, finish-to-finish):  $d$  is the duration of the activity, and activity  $j$  is preceded by  $i$  and followed by  $k$ :

#### (1) Initial activities

Early Start date  $ES(j) = 0$

Early Finish date  $EF(j) = ES(j) + d(j) = d(j)$

#### (2) Other activities (forward pass)

Early Start date  $ES(j) = \max_i EF(i)$

Early Finish date  $EF(j) = ES(j) + d(j) = d(j)$

#### (3) Final activities

Late Finish date  $LF(j) = \max_i EF(i) + d(j)$

Late Start date  $LS(j) = LF(j) - d(j) = \max_i EF(i)$

#### (4) Other activities (reverse pass)

Late Finish date  $LF(j) = \min_k LS(k)$

Late Start date  $LS(j) = LF(j) - d(j)$

Early and late dates are calculated using two separate processes (there are four variables, two of which however are not independent, because the end dates, as mentioned previously, are the sum of the start date and duration of the activities):

– The first step consists in calculating the early dates, starting from activity 1 (the first of the project) and trying to start all the subsequent activities as soon as possible (in other terms, we move forward – forward pass – along the network). When various activities flow into one, the beginning of this latter activity coincides with the latest (indicated as max) among the early finish dates of the previous activities (thus the rule is the latest among the earliest).

– Having reached the project's finish date (the end of the last activity), we can calculate the late dates, starting from the end of the network (therefore moving backwards – reverse pass). When

activities branch, the finish date of the predecessor activity is the earliest (indicated as min) among the late start dates (so the rule now is the earliest among the latest). The total slack must also be analysed, so as to verify how and to what extent it depends on upstream or downstream activities. There are various types of slack:

- Total Slack (TS) is the maximum slack allowable for an activity, when the established start and finish times of the project are respected (it is simply the difference between late and early start dates).
- Free Slack (FS) is the maximum amount of time for which a given activity, started on its earliest date, can postpone its finish date without causing delays in the early start of all the following activities (it is free in the sense that it does not create restraints downstream).
- Chained Slack (CS) is the difference between Total Slack and Free Slack.
- Independent Slack (IS) is the maximum possible slack for an activity carried out under the most unfavourable conditions, namely when all the previous activities are completed on their latest finish date and the following ones have started on their earliest possible date.

Obviously, if  $TS = 0$ , there can be nor FS neither IS. If  $FS \neq 0$ , IS is not necessarily  $\neq 0$ , because of the constraints present both upstream and downstream. In other words,  $TS \geq FS \geq IS$ .

Listed here are the formulas used for calculating slacks. The results of these calculations are one of the greatest practical implications of the CPM, because they help clarify the times needed to carry out each activity of a project, analysing in advance time criticalities and reducing the risk of organisational conflicts.

$$\text{Total Slack} = TS(j) = LF(j) - EF(j) = LS(j) - ES(j)$$

$$\text{Free Slack} = FS(j) = \min_k ES(k) - EF(j)$$

$$\text{Chained Slack} = CS(j) = TS(j) - FS(j)$$

$$\text{Independent Slack} = IS(j) = \max [0; \min_k ES(k) - \max_i LF(i) - d(j)]$$

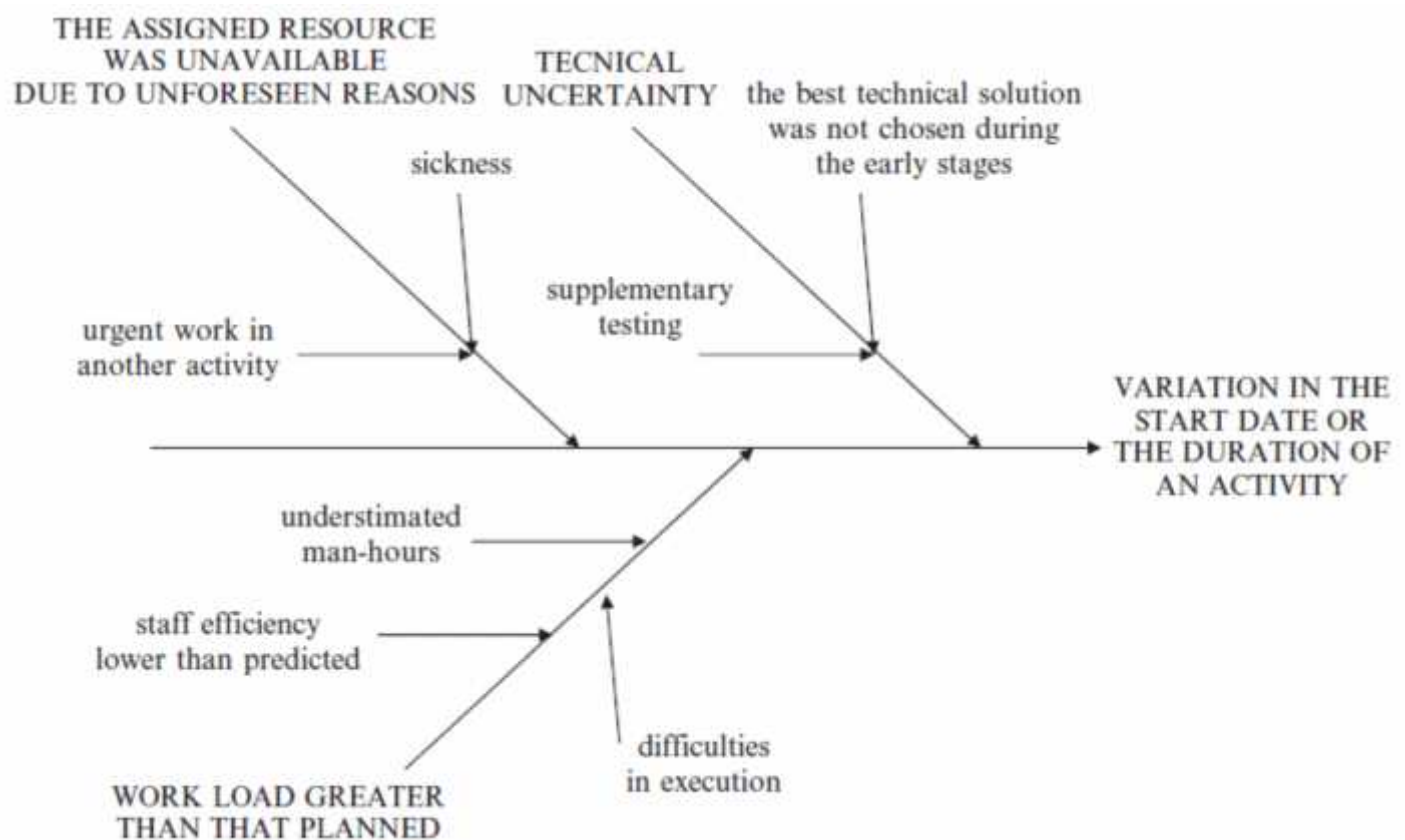
Table III.1 is an exercise on CPM: starting from the given data (the name and duration of the tasks, and their predecessors), calculate the schedule (thus, four dates per activity) and analyse possible slacks (TS, FS, CS and IS). Note that, in this exercise, there are three different initial activities and two different final activities (which could be, for example, a new product and the campaign to launch it). The solution is shown in Table III.1 from column ES to column IS.

Both activity scheduling and float analysis can be carried out before the project starts (i.e. planning the project). Once it has begun, it is necessary to control how the project proceeds, monitoring the differences with the scheduled times. These differences may refer to both start dates and duration of the activities, and may cause changes in the finish date of the project.

These variations can be analysed and discussed using various tools typical of quality control management – such as the fishbone or Ishikawa diagram. The main arrows point to a certain effect; on each of these arrows, there can be secondary ones that indicate the possible causes of that effect; these causes in turn will also have their upstream causes, so that a further arrow can be placed on the secondary one, and so forth (Fig. III.7). The causes can be evaluated in probabilistic terms and/or weighed according to the opinions of the persons involved in the project.

| Activity | Duration | Predecessor | ES | EF | LS | LF | TS | FS | CS | IS |
|----------|----------|-------------|----|----|----|----|----|----|----|----|
| A        | 9        | –           | 0  | 9  | 6  | 15 | 6  | 0  | 6  | 0  |
| B        | 3        | –           | 0  | 3  | 0  | 3  | 0  | 0  | 0  | 0  |
| C        | 7        | –           | 0  | 7  | 7  | 14 | 7  | 0  | 7  | 0  |
| D        | 10       | A           | 9  | 19 | 15 | 25 | 6  | 0  | 6  | 0  |
| E        | 1        | B           | 3  | 4  | 23 | 24 | 20 | 20 | 0  | 20 |
| F        | 21       | B           | 3  | 24 | 3  | 24 | 0  | 0  | 0  | 0  |
| G        | 1        | B           | 3  | 4  | 13 | 14 | 10 | 3  | 7  | 3  |
| H        | 5        | C, G        | 7  | 12 | 14 | 19 | 7  | 0  | 7  | 0  |
| I        | 6        | D           | 19 | 25 | 25 | 31 | 6  | 0  | 6  | 0  |
| L        | 3        | H           | 12 | 15 | 21 | 24 | 9  | 9  | 0  | 2  |
| M        | 11       | H           | 12 | 23 | 19 | 30 | 7  | 0  | 7  | 0  |
| N        | 8        | E, F, L     | 24 | 32 | 24 | 32 | 0  | 0  | 0  | 0  |
| O        | 1        | I           | 25 | 26 | 31 | 32 | 6  | 6  | 0  | 0  |
| P        | 2        | M           | 23 | 25 | 30 | 32 | 7  | 7  | 0  | 0  |
| Q        | 3        | M           | 23 | 26 | 31 | 34 | 8  | 8  | 0  | 0  |
| R        | 2        | O, N, P     | 32 | 34 | 32 | 34 | 0  | 0  | 0  | 0  |

**Table III.1** CPM exercise



**Fig. III.7** Cause–effect diagram for the analysis of the variation between estimated and actual times

### III.4 Company-Wide Project Management

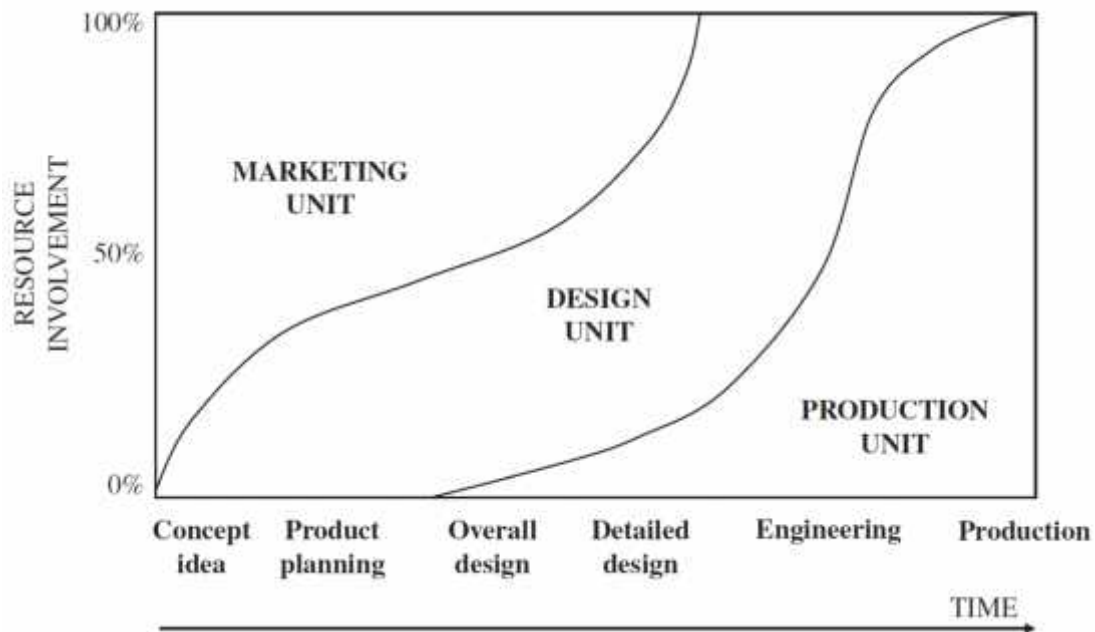
Projects, even the more conventional ones for new products, are created and developed thanks to the contribution of resources belonging to various departments (although Design department plays the principal role). In other words, even those functions whose tasks do not include the definition of project specification may and indeed must contribute to the project (the matrix structure typical of a project, as we shall see later has the objective of formalising this call for competencies).

Figure III.8 depicts the involvement of three specialisms in a project: Marketing (whose task is to ensure that the output of the project appeals to the market, thus justifying the investments made), Design (whose specific task is to develop and implement the project) and Production/Delivery (in charge of delivering the product/service specified in the project in an efficient manner and with a high level of conformity). However, other functions can be involved, such as Purchasing, the Engineering or Technology Department, Quality Management, Machinery Maintenance, Technical Assistance, Customer Service, and so forth.

Their contribution to a project is not constant throughout time, but varies according to the stage reached by the project, as illustrated in Fig. III.8. By tracing an upright line, it is possible to see the percentage of involvement of the various functional units at a given time.

Every project has its stakeholders, whose interest goes beyond technical and economic issues, and may include personal satisfaction as well as that of the entire company, a factor that contributes to making a serene working environment. The field of interest can also stretch beyond the boundaries of the firm, to include customer satisfaction, that of the suppliers, who preserve a market outlet, and even of the entire community, when themes of social utility and eco-compatibility are at stake.

Company-Wide Project Management requires integration between functional units, but also between the tasks assigned to single persons. Two types of integration are possible: horizontal (or job enlargement, with a larger number of tasks being carried out by one person) and vertical (or job enrichment, with greater responsibilities, including decision-making). In the former case, the employees become more skilled in a variety of activities, and are therefore able to carry out a wider range of operations, either sequential or similar, to the advantage of coordination and flexibility; motivation and a bent for learning is required, as well as a solid background of knowledge. In the latter case, the employees are encouraged to control and monitor the activities autonomously and solve problems independently, at least those of minor relevance. Job enrichment is linked to delegation and empowerment, two factors that spur the staff to improve and take on greater responsibilities, to understand more clearly the effect of their actions on the overall performances and constantly seek new solutions.



**Fig. III.8** Involvement (percentage) of the organizational units in relation to the project stages

### III.5 Organizational Structures for Project Management

Typically, companies are organized by functional units, i.e. hierarchies of various specialisms, and the human and technical resources are divided among them. The principle of dividing work to obtain efficiency used in this type of organizational structure is however inadequate for managing projects.

Project management requires resources and competencies that belong to different functions (not only Design, but also Marketing, Manufacturing, Purchasing, etc.); hence, when working to achieve certain goals (those of the project) instead of merely following specific procedures (those of the department), the available resources must be reorganized.

The typical organizational structure adopted in Project Management is the so-called matrix structure, which combines the conventional division by functions with structures that are specifically set up for every project.

There are therefore two dimensions and two different types of managers: the line manager (i.e. the head of the function) and the project manager (i.e. the owner of the process). The task of the former manager is to preserve the standards of efficiency/efficacy characterising a given functional unit, as well as managing, preserving and cultivating similar resources and competencies, and making them available for a variety of projects within the firm. The task of the latter manager is to exploit all available resources in the best possible way, allocating them so as to achieve the goals of the project, and manage extra resources brought in if needed.

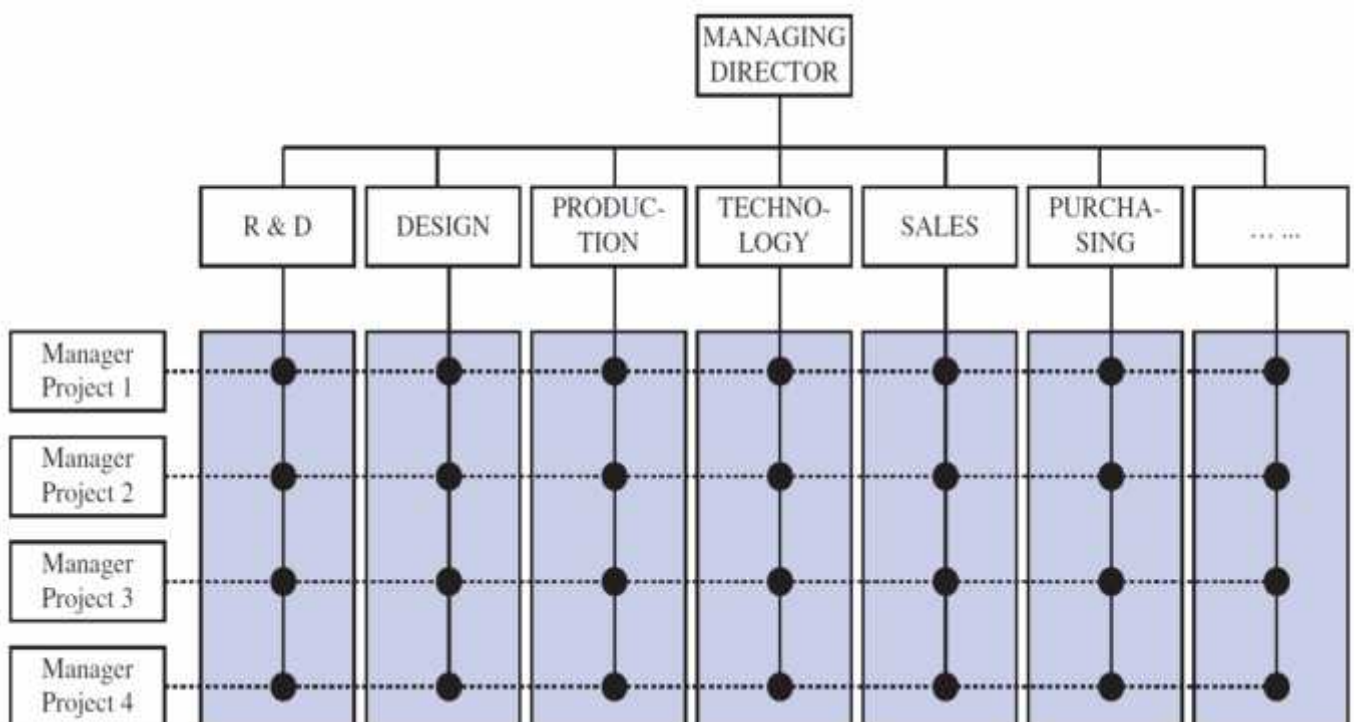
Inevitably, this two-dimensional structure is anything but simple to achieve in practice, since it goes against the Taylor principle of uniqueness of command. In the presence of limited resources and when there are conflicting demands made by the various managers, who has priority and decisional power? There are two alternatives – two organizational structures that differ according to where authority (i.e. the power to reward and punish the resources) resides, either in the function or in the project. The structures are as follows:

- The lightweight matrix, where authority is still retained by the line manager, whereas the project manager plays a side role, coordinating, allocating, using and managing the resources for the project (lightweight project manager)
- The heavyweight matrix, where authority is in the hands of the project manager (who in this case becomes heavyweight), and the line managers are in charge of supplying the resources to the project, while preserving a minimum of performances in the line function (productivity, technical updates, etc.)

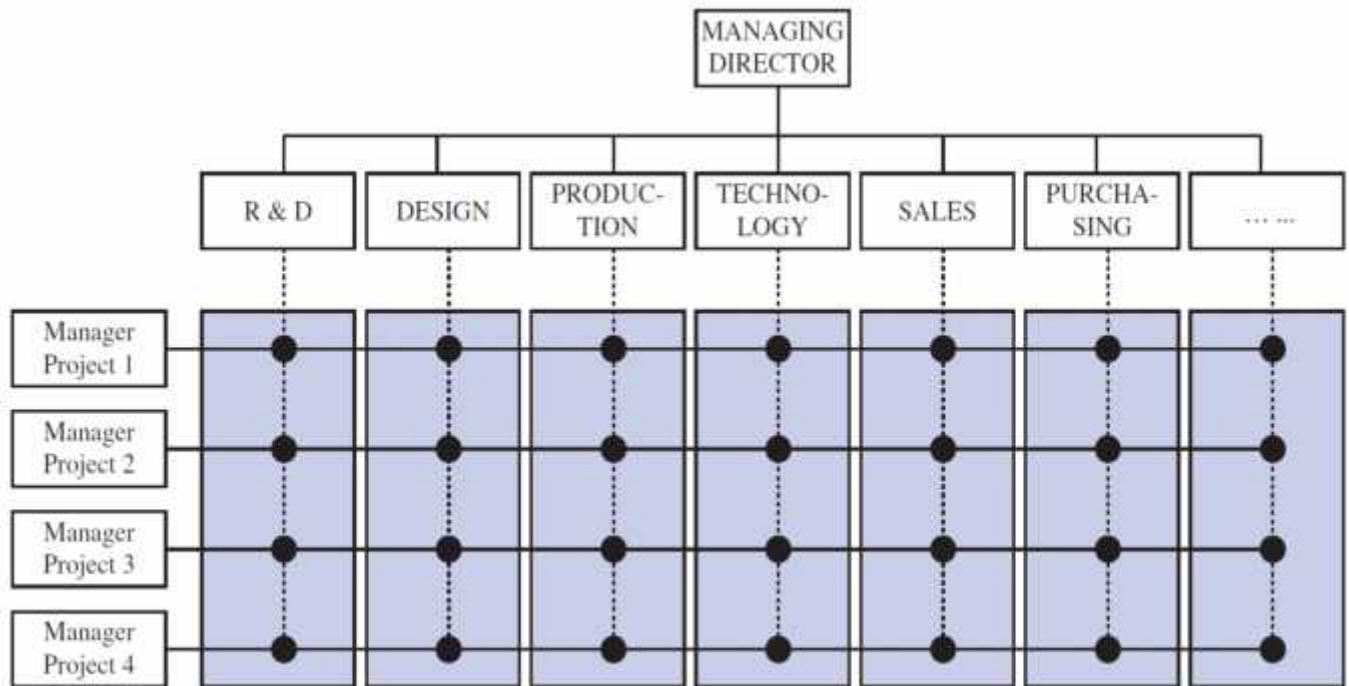
Clearly, in the latter case, many problems still exist and there is a greater likelihood of conflicts arising from competition among projects: to avoid this risk, the board of directors should appoint a multi-project manager to coordinate the various projects and their managers (Multi-Project Management – MPM).

On the other hand, even the first solution has some drawbacks that can be ascribed to the role of the project manager, who is responsible for the resources (used for the project) without having the authority to do so, and therefore risks becoming a mere coordinator/facilitator. For this reason when deciding to adopt this type of solution the project manager must have great leadership, competency and experience, since his/her role does not rely on any concrete power.

Figures III.9 and III.10 illustrate the two types of matrix structures, and indicate the position held by the project manager. In other cases, when the project is of the utmost strategic importance, the resources are asked to form a task force that is independent of the original functions. This task force is at the opposite side of the steering committee, in which the percentage of individuals involved in the project is close to zero.



**Fig. III.9** Lightweight organizational matrix of the project (continuous line = hierarchical power; dotted line = coordination only)

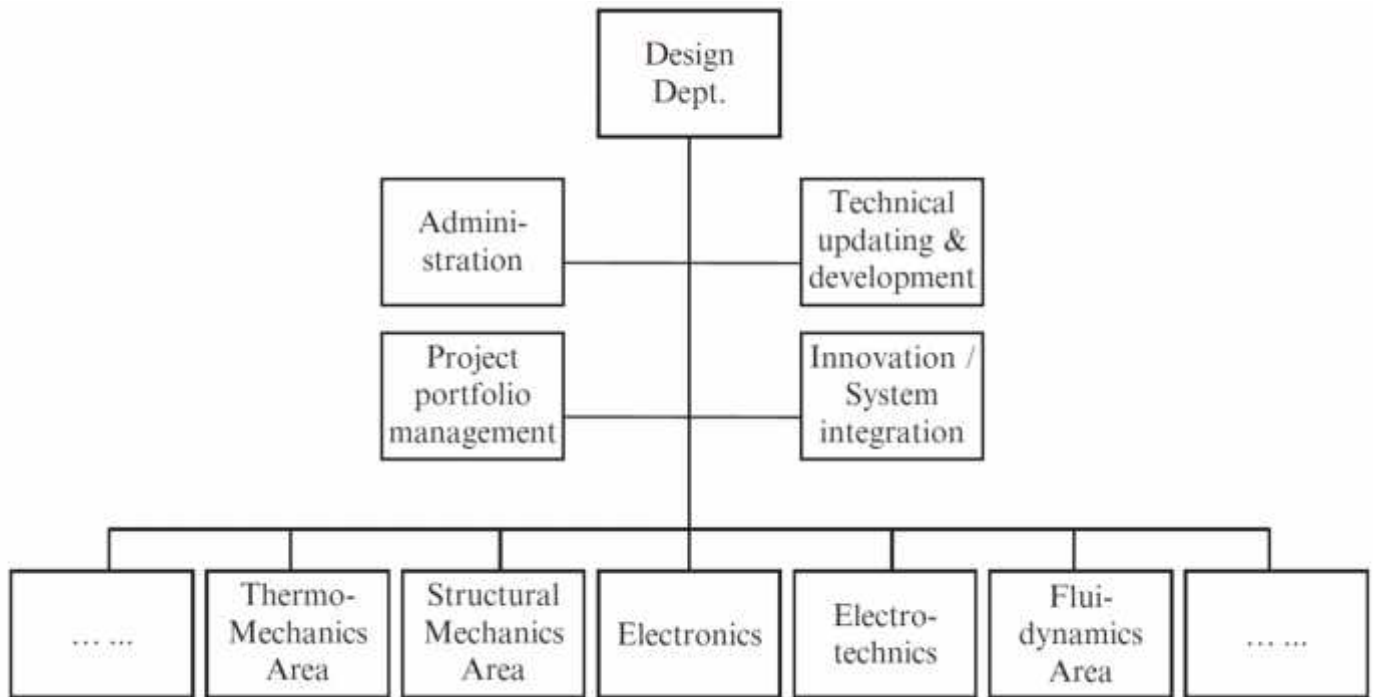


**Fig. III.10** Heavyweight organizational matrix of the project (continuous line = hierarchical power; dotted line = coordination only)

Usually, in order to be effective, matrix management requires certain social and organizational conditions, such as the following:

- A high level of communication, because of the notable amount of dependency and the need to establish relationships.
- A predisposition for teamwork, given the presence of individuals with different competencies and backgrounds.
- The ability to operate by objectives, because the teams are working on projects, and consequently an adequate system of reward should be established to encourage the teams to achieve these goals.
- Since projects are not routine activities, delegation of power should be more widespread, so as to ensure significant margins of individual autonomy.
- A proactive approach leaning towards innovation and change, with the acceptance of the consequent margins of risk; independent quest for information and availability to listen.

Independently of the matrix structure (and therefore of the existence of the project manager, with or without hierarchical power), the fact that most resources used in a project belong to the Design department/unit implies that the latter must possess a specific internal organization. An example of this is shown in Fig. III.11: the offices of the technical line (including, for example, designers specialized in the field of thermo-mechanics, structural mechanics, electronics, electro-techniques, aerodynamics, etc.) are supported by the staff in charge of administration/contract management, project portfolio, technical updates, system innovation/integration.



**Fig. III.11** Internal organization of the Design department

MPM has important consequences at an organizational level.

There are four steps in the evolution of organizational strategies that lead towards a more modern organisation-by-projects and that however can co-exist:

1. Separate functional units and sequential development stages
2. Integrated and overlapping functions and development stages, coordinated by a lightweight project manager, who may also become chief director if the events require so (heavyweight project manager)
3. Integrated and parallel functions and projects, coordinated by a multi-project manager, with a possible involvement of chief executives (such as the platform managers)
4. Intra- and inter-firm design teams (joint project management)

As a consequence, there are different types of organization that classifies according to inter-project learning (which is linked to the transfer of knowledge among projects) and the project's focus (on the single components or on the system and its connections), as shown in Fig. III.12.

It is possible to create differentiated matrices (Fig. III.13), where, according to the case, the line and the project managers are either heavyweight or lightweight (in Fig. III.13, the overlapping area indicates an authority over the underlying area), while the functions can serve various projects at different levels of intensity, distributing their resources among them.

The case of product platforms should be analysed separately, these serve to develop a core sub-system. Other modular sub-systems are then attached to it, and the combination of different modules gives rise to a family of products. Product platforms require a specific form of organization, which consists of the following:

-A platform team (which must not be too numerous the Renault Mégane platform was managed by 15 persons only), coordinated by a platform manager

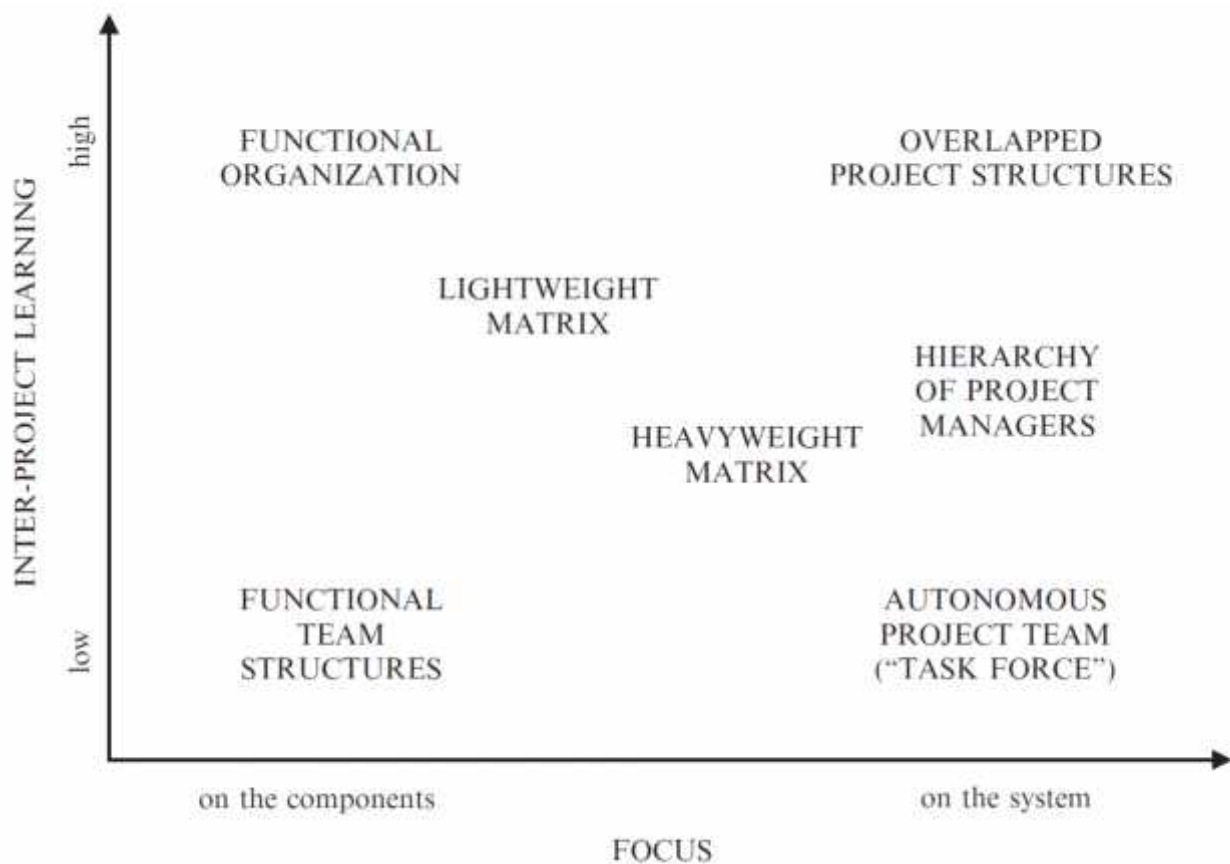
-Module teams in charge of developing the single modules

-Product teams in charge of producing the derivatives, starting from the platform and its interchangeable modules

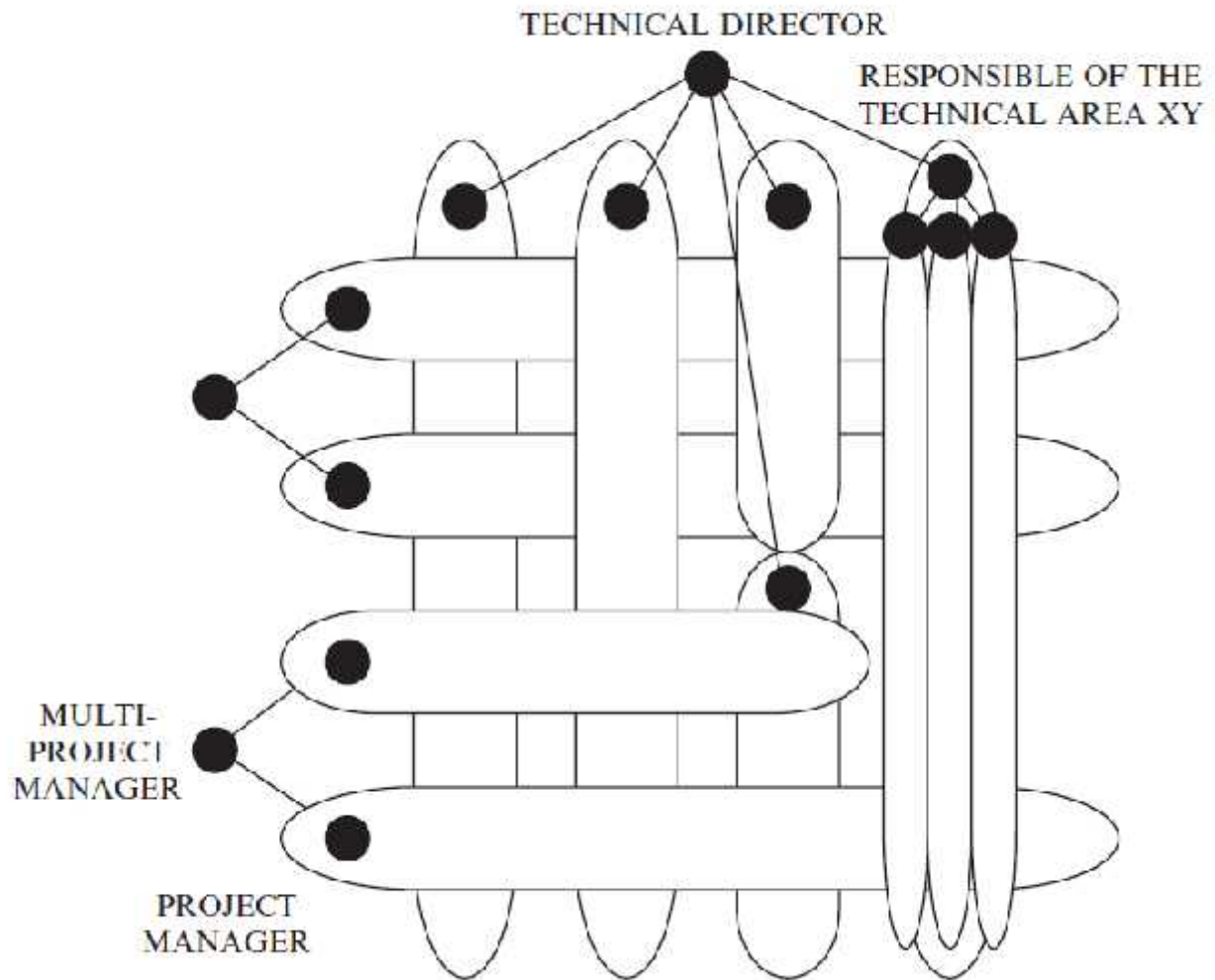
-An informal network of experts and designers that can include even a hundred persons or more, etc.

The multi-project organizational structures can also differ extensively according to the strategies adopted by the firm. In the automotive sector, for example: the following in the case of Design (not including Research & Development or similar departments, which are usually external):

- Rather classical matrix structures, as in BMW, Mercedes and Volvo (i.e. companies that focus more on strategies for product lines than on platforms)
- Matrix structures featuring a platform manager (but without establishing a centre for each platform), as in Fiat and Renault
- An organization totally divided into platform centres, each of which features a platform manager who coordinates the project managers, as in Ford and Toyota
- An organization partially divided into (semi-centred) platforms, sharing certain engineering functions, as in the case of General Motors and Nissan.



**Fig. III.12** Multi-project organizations



**Fig. III.13** Differentiated matrix organizational structure

### III.6 The Role of the Project Manager

As the name suggests, the project manager is in charge of managing the project, identifying, allocating and coordinating the resources to achieve the objectives of quality, costs and time specified by the project itself.

As we have seen, the project manager may or may not have a hierarchical authority over the resources, depending on the type of organizational structure (heavyweight or lightweight, respectively) that exists in the company. This person however is responsible for the project and the entire Project Organizational Breakdown Structure (POBS).

The project manager must therefore possess the indispensable technical knowledge to understand and carry out the various tasks, and because projects are usually complex and strategically important, also remarkable managerial and relational skills.

Often these abilities are more important than the know-how, because the technical aspects of a project can be manifold and different, so it would be impossible to know all of them in depth. It

helps however to have a complete and ample knowledge of the process rather than a more detailed one focusing only on certain, specific aspects. Usually in the case of high-profile projects, the persons chosen are those who have gathered great experience over the years in different disciplines, who then consult the specialists in the different sectors and it is these individuals who will update the single technologies.

The most important thing for project managers is to possess great organizational, managerial and relational skills. In particular:

- They must have a global vision of the project, and be capable of planning it and breaking it down into clear chunks, defining all the parameters and controlling the progress of the project right to its conclusion.
- They must sense and anticipate both market/customer demands and the possible technical problems linked to the various solutions, identify the persons who can help them make the best decisions and establish a constant dialogue with them.
- They must be capable of coordinating a multitude of heterogeneous persons, creating an environment that will promote constructive work and communication, overcoming the intrinsic obstacles deriving from different languages, cultures and work styles.
- Their leadership must be universally recognized, so that they can converse with different persons, motivate them and delegate responsibilities while still maintaining a not too onerous control.
- They must possess the ability to negotiate, but at the same time be able to make decisions and solve the conflicts that naturally arise when dealing with different persons and when there are various, competing projects.

Hence, the various skills of a project manager must also include the ability to manage interpersonal relationships. Various principles must be kept in mind for this purpose:

1. The persons must be treated as individuals, as well as members of a team. It is not enough to manage a team, since a lack of motivation can arise because an individual's objectives do not match those of the team, i.e. of the project.
2. Increase and stimulate the efforts of the team members for the project. One of the keys to success is to involve team members in the decision-making processes, so that they can play a more active role, and not feel that they are mere suppliers of competencies or the mechanical performers of tasks. The responsibility entrusted to them stimulates them to make a greater effort. It is also advisable to supply incentives, not only in terms of money, but also, for example, making them more visible inside the company or allowing them to attend training courses.
3. Inform the collaborators about all that occurs during the project. In order to do so, willingness is not enough, because the team members come from various functional units, and may have different backgrounds, objectives, habits – all elements that hinder communication. It is therefore necessary to establish a common language, which can be consolidated by using standard documents. As well as promoting communication, the project managers must also be able to listen, and so become aware of any conflict brewing.
4. Build consensus to channel conflicts. Conflicts are inevitable in any project and a good part of the project manager's task is to manage diverging opinions and behaviour. Conflict however can also become an opportunity to develop new ideas and solutions for the project. Ideally, they should be channelled, so that they may become a tool for promoting creativeness and proactivity.

5. Share informal authority with the collaborators. The best project managers accumulate an informal, transversal power inside the organization, which derives from their relational skills, their leadership and charisma, and then share this power with their collaborators, letting them perceive that the success of a project is also advantageous for them, because it can boost their informal authority. The team's success therefore becomes the success of its individual members; in this case, what is expected from a project manager is mainly honesty, competence, determination, drive and motivation.

6. Encourage creativity and propensity to risk. Being innovative and creative is mostly an innate aptitude, but it can be stimulated and rewarded; a similar definition can also be applied to risk propensity. Even though this subtracts time from management and control, the project manager should devote particular attention to these aspects.

Distinguish a project manager from a more technical one; the former manager in particular should do the following:

1. Find feasible solutions given the time, budget and resource constraints, rather than seek ideal, perfect ones
2. Aim at delivering the project, even to the detriment of technical perfection
3. Look at the overall results of the project instead of focusing only on the technical output
4. Despecialize in order to improve, and find new synergies and nourishment
5. Win together with the team

Project managers are pivotal for the project, because they are the driving force for the flow of information that is established with the following people:

- The board of directors (from whom they receive the indication of the company's policies and to whom they must report the progress of the project)
- The customer/purchaser (from whom they receive indications and/or specifications and to whom they must report the progress of the project)
- The line managers (whom they direct/coordinate and from whom they receive reports)
- The personnel allocated to the project (whom they direct and from whom they receive interim reports)

Project managers therefore play a variety of roles:

- A borderline role between the organization of the project and the external environment (either inside or outside the company).
- They act as interface in the exchange of information, both inside and outside the team.
- They also act as intermediaries between higher hierarchical positions (board of directors) and the staff employed in the project.
- Finally, they are the agents of change and promoters of innovation, which is the essence and most typical feature of a project.

### **III.7 Definition of Responsibilities and Conflict Management**

The innovative characteristics of a project, the lack or limited amount of reference standards, the risks and uncertainty concerning decision-making, as well as the involvement of resources from different functional units determine a stronger chance of conflicts rising within the framework of projects, as compared to other routine activities performed in the company.

On one hand, conflict is an intrinsic and essential part of a project, because it ensures a source of confrontation and spurs the resolution of problems; on the other hand, conflicts may indicate (as well personal interests) that the members of the team are fighting for the project's success and to achieve their work tasks. Conflicts arise because different individuals come into contact with each other: where there is no contact and no relationship there is no conflict, and the likelihood of problems increases as the interdependence between the individuals grows.

Conflicts of a technical nature often give rise to non-technical ones that affect business organization and management, as well as interpersonal relationships; these can be mainly ascribed to the following:

- Limited resources, both human and financial, allocated to a single project, due to the contemporaneous presence of and competition with other projects (project priorities)
- Work overload borne by the human and technical resources involved in more than one project (conflicts with the persons in charge of the departments)
- The structure of the POBS and the assignment of sub-project responsibilities
- Underestimated costs or their inadequate partition among the various activities of the WBS
- Badly scheduled WBS activities and blaming each other for the delays
- Problems linked to the clashing personality of the individuals involved in the project

The classic solutions for managing conflicts can be summarised as follows: (1) renouncing, (2) attenuating (by avoiding the diverging topics and underlining the points of agreement), (3) compromise (in the event of standstills, be available to give something in order to obtain something else), (4) pressure (trying to prevail, even if there is the risk of losing), (5) confrontation (analysing the conflict in order to reach an agreement).

The polarization of a team following internal conflicts, in other words having the members taking sides, only augments the conflict: polarization must therefore be avoided or restrained. It should also be kept in mind that often conflicts that apparently revolve around content conceal latent, but deeper and more pervasive issues regarding power, personality, etc.

The psychological and social approach to conflicts can be aided by the use of various techniques and tools, such as the following:

- MPM practices, objectively assessing the priorities of the various projects, monitoring in detail the workloads and resources and analysing their commitment over long periods of time
- Predictive tools such as baseline and techniques for analysing budget variances
- Anticipated formalisation of the assignment of external responsibilities, linked to the project, and internal ones (of sub-project), monitoring throughout time the workloads on all the resources in relation to all the activities

- Techniques, such as CPM, to determine the margins of flexibility and the causes of the delays

Among the techniques to reduce conflicts, the responsibility and relationship matrix deserves special mention: this structure formalises beforehand the responsibilities and relationships among the various managers (both company directors and managers who are directly involved in the project) during the different development stages of the project (Table III.2). It also specifies the types of responsibility and relationship, which can be summarised as follows:

- 1.General responsibility (concerning the relative deliverable)
- 2.Operational responsibility (being delegated to perform operative tasks)
- 3.Specific responsibility (tasks linked to the single activities in the WBS)
- 4.Necessary consultation (in order to make decisions that are relevant for a particular stage)
- 5.Possible consultation (not compulsory)
- 6.Compulsory communication (with a specified person)
- 7.Necessary approval (of the person involved)

A final observation – Responsibility is the authorization to carry out an activity aimed at achieving certain objectives, operating the necessary choices and being responsible for the results or deliverables. It does not necessarily imply changes in authority (the formal power to promote or punish). A delegation, on the other hand, is the formal assignment of one's tasks (deriving from one's position in the organizational chart) to someone placed at a hierarchically lower level.

Table 9.1 Responsibility and relationship matrix

| Stages                     | Chief Executive Officer | Managing Director | Project Manager | Project Engineer | Project Controller | Marketing Manager | Contract Manager | Technical Director | Contract Technical Resp. | System Engineer | Technical Area Managers | Procurement Manager | Field Manager | Production Manager | Production Coordinator |
|----------------------------|-------------------------|-------------------|-----------------|------------------|--------------------|-------------------|------------------|--------------------|--------------------------|-----------------|-------------------------|---------------------|---------------|--------------------|------------------------|
| Preparation of the offer   | F                       | A                 | B               | C                | C                  | D                 | D                | E                  | B                        |                 |                         |                     | E             | D                  | E                      |
| Offer                      | A                       | G                 | G               |                  |                    | D                 |                  |                    |                          |                 |                         |                     |               |                    |                        |
| Contract approval          |                         |                   |                 |                  |                    |                   |                  |                    |                          |                 |                         |                     |               |                    |                        |
| Contract bidding           |                         | A                 | B               | E                | E                  | E                 | C                |                    | E                        |                 |                         |                     |               |                    |                        |
| Contract signature         | B                       | D                 | E               |                  |                    |                   | D                |                    |                          |                 |                         |                     |               |                    |                        |
| Work order                 |                         |                   |                 |                  |                    |                   |                  |                    |                          |                 |                         |                     |               |                    |                        |
| planning                   |                         | A                 | B               | C                | C                  |                   | C                |                    | D                        |                 |                         | E                   | E             | D                  | E                      |
| Design                     |                         | A                 | B               | C                |                    |                   |                  | E                  | C                        | C               | C                       |                     |               |                    |                        |
| Checking of specifications |                         | E                 | A               | B                |                    |                   | D                |                    | D                        | E               |                         |                     |               | E                  |                        |
| Execution                  |                         | A                 | G               |                  | D                  |                   |                  | E                  | B                        | D               | D                       | C                   | C             | B                  | C                      |
| Evaluation                 |                         | A                 | B               | D                | D                  |                   | D                |                    | E                        | E               | E                       |                     | C             | D                  | E                      |
| meetings                   |                         |                   |                 |                  |                    |                   |                  |                    |                          |                 |                         |                     |               |                    |                        |
| Validation                 |                         | F                 | B               | C                | E                  |                   | E                |                    | E                        | E               |                         |                     | D             | E                  |                        |
| meetings                   |                         |                   |                 |                  |                    |                   |                  |                    |                          |                 |                         |                     |               |                    |                        |
| Customer relationships     |                         | E                 | B               | E                | F                  | D                 | C                |                    |                          |                 |                         |                     | E             |                    |                        |

A general responsibility, B operational responsibility, C specific responsibility, D necessary consultation, E possible consultation, F compulsory communication, G necessary approval

Table III.2 Responsibility and relationship matrix

# **Chapter IV**

## **Project Cost, Quality and Risk Management**

### **IV.1 Types of Project Costs**

Traditionally, Cost Accounting consists of three stages:

1. Collecting, classifying and recording all elements of cost
2. Allocating costs to cost centres (identified on the grounds of homogeneity, the existence of a person responsible for the costs, and of a certain budget calculated using prospective or standard costs)
3. Summarising and analysing costs to determine the selling price of the products

Costs are classified according to various criteria; the main ones are described in Fig. IV.1. All these costs must be considered in a project: the total cost of the project must therefore be analysed according to the nature and origin of the costs, and according to the project size (some costs are fixed; others vary according to the size of the project, whether small, medium or large); it is moreover essential to distinguish between costs that can be directly (= objectively) ascribed to a certain project and those that are indirectly (= using subjective parameters) ascribed “pro quota” to each project. Finally, a classification must also be made on a time basis, distinguishing between prospective, current and final costs.

Particular attention must be given to distinguish between variable and fixed costs on one hand, and direct and indirect costs on the other.

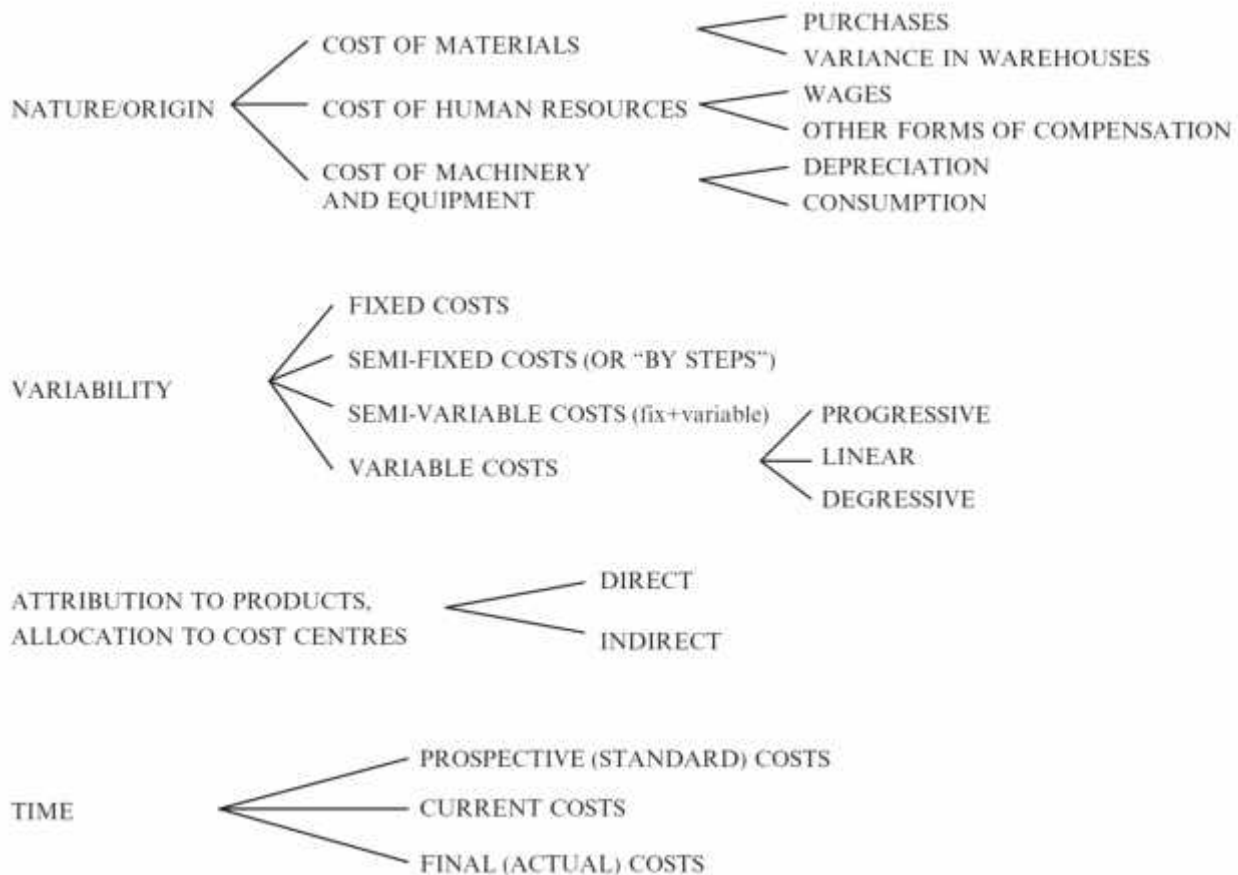
Since variable costs are often easy to ascribe to a product or a project (considering the materials used, the labour and power required by dedicated machinery or single-product lines, although also in the case of multi-product plants, it is possible to calculate them using the routing cycles), sometimes variable costs and direct costs are considered synonymous. It is easy to make this mistake because direct costing techniques, aimed at calculating the gross margin of contribution, consider this margin as the difference between profits and variable costs, a margin to cover fixed costs and, only in this case, direct coincides with variable.

In practice, there are also indirect variable costs (e.g. those relative to consumption that are not specified by any standard or any bill) and direct fixed costs (e.g. the depreciation cost of a single-product line, which can be directly i.e. objectively ascribed to that product).

### **IV.2 Cost Estimating and Project Budget Calculation**

According to the Project Management Institute (PMI), Cost Management can be divided into three stages, which will be described in detail in this section and the following two:

1. Cost Estimating, the stage during which the cost of the resources exploited for the project is forecasted, so as to estimate the overall cost of the project.



**Fig. IV.1** Criteria for cost classification

2. Cost Budgeting, the process of establishing a budget by summarising the estimated costs of the work packages (according to the Project Budget Breakdown Structure – PBBS), optimising this budget in relation to the available amount of money and finally defining the baseline (i.e. a curve describing expenditure throughout time).

3. Cost Control: once the project has started, the progress of expenditure is monitored, analysing the variances from the budget in real time.

Hence, Cost Estimating analyses the cost of the resources required for a certain project; the type and amount of necessary resources are identified taking into account the activities of the project, which are described in the Work Breakdown Structure (WBS).

In this section, we see how Cost Estimating in Project Management requires a different approach from that used in Cost Accounting procedures, typical of operations management, procedures based on the allocation of costs classified as direct or indirect to cost centres. The innovative approach of Cost Estimating in Project Management follows certain trends that are already present in advanced Cost Accounting, which in turn are based on Activity-Based Costing (ABC) techniques.

The difficulty of accurately and reliably calculating the full cost of a product/ project/work contract lies in the problems of allocating indirect costs, which by definition cannot be immediately ascribed to a certain product/project/work contract. Figure IV.2 illustrates the traditional passages from costs (classified as fixed/ variable and direct/indirect) to the cost centres (allocation) and the products (attribution).

ABC was created in response to the traditional technique used for calculating the full cost of a product (or project or work contract) and based on the division of indirect cost on a single base or multiple bases (bases, i.e. criteria, such as direct labour, cost of materials, number of machine-hours per product, etc.). When – like in today's world – variable costs decrease (in particular the percentage of labour), while indirect costs (i.e. those relative to technology, design, trade, etc.) increase (such as, for example, the depreciation costs of highly automated plants), allocating indirect costs on the grounds of direct variable costs (particularly on the traditional amount of direct man-hours or standard times) can cause consistent distortions in the calculation of the full cost.

Indirect costs are independent of production volumes but depend instead on various types of transactions:

- Logistical (such as those relative to customer orders)
- Balancing (namely, all those activities linked to the availability in space and time of the materials, labour and machinery needed to meet the demand)
- Quality (e.g. the quality control procedures)
- Change (as a consequence of starting new projects or modifying pre-existing ones)

Indirect costs are driven by complexity, whereas direct costs are mainly variable and are therefore driven by volumes; they distinguish between four types of cost-generating activities, each of which has different drivers:

- Manufacturing activities (direct labour, materials and power required, the driver being the production volume)
- Activities for running the production plants (such as maintenance)
- Production-supporting activities (such as machine tooling)
- Product-supporting activities (such as product development)

Except for manufacturing activities, in all the other cases there can be a variety of drivers: the number of customer orders, manufacturing orders and supplier orders, the number of lots, of items (common or special) and levels listed in the bill of materials, the amount of handling, tooling, the number of defects, complaints, etc.

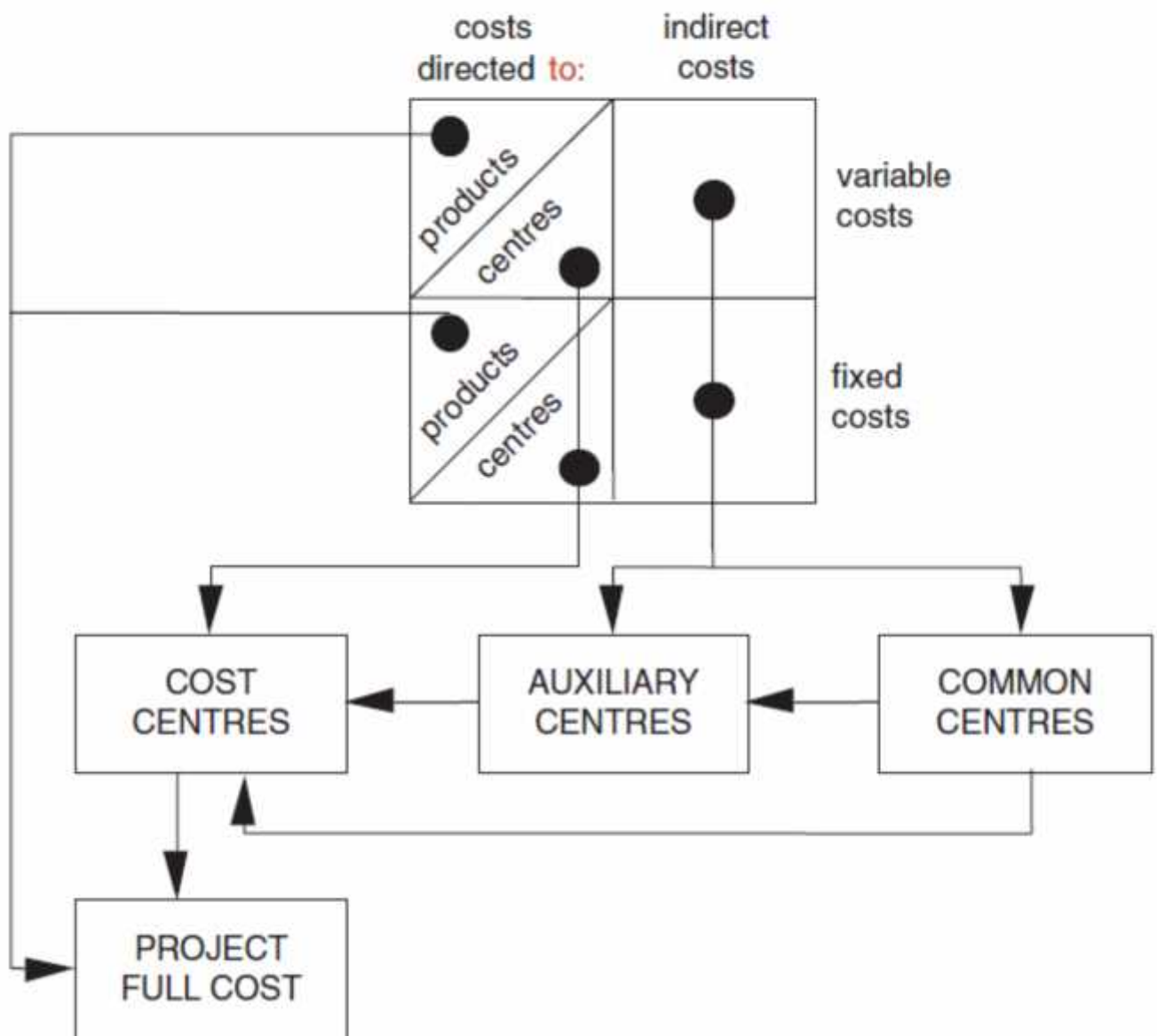
ABC is an innovative technique aimed at calculating the full cost of a product (or project or work contract) starting from the cost of the resources used. Assigning the cost of the resources to the single products does not occur through cost centres, as tradition dictates (Fig. IV.2), but occurs via the activities (Fig. IV.3): in other words, it is the activities that exploit the resources, whereas products do not use up resources, but activities.

There are therefore two stages:

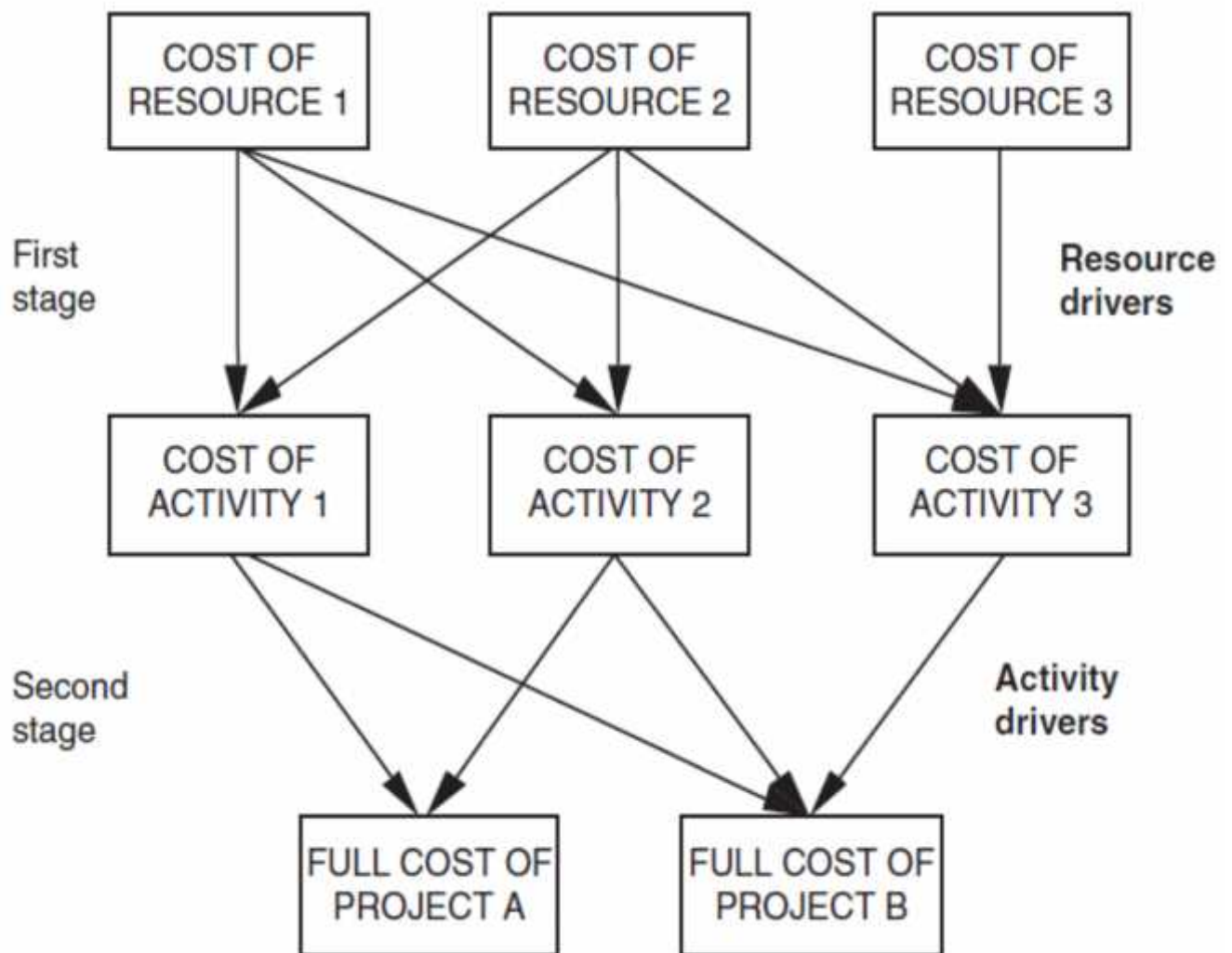
- During the first, the cost of the resources is assigned to the activities (by means of first-stage drivers, also known as cost drivers or resource drivers).
- During the second, the activities are linked to the products or projects (by means of second-stage drivers or activity drivers).

Cost Estimating in Project Management adopts the ABC approach to calculate the full cost of a project, but in this case the technique is used to estimate the costs of a project or a work order, and not of a product.

The starting point is represented by the activities needed to accomplish the project, which are described in the WBS. The second step is to link each activity (also called task) to the resources needed, which are organised and described in the POBS (which in turn is connected to the Organizational Breakdown Structure or OBS).



**Fig. IV.2** Traditional allocation of indirect costs through cost centres



**Fig. IV.3** Calculation of full product cost according to Activity-Based Costing (ABC)

This link is established by criteria that in practice coincide with the resource drivers found in ABC: for example, the allocation of the resources for the entire duration of the activity, either in proportion to its duration or as work hours required.

This allocation must be compatible with the calendars and the levels of saturation of the resources, which can be exploited by more than one project. When estimating the cost of human resources, it is necessary to include both the cost of calling or exploiting the persons for a certain activity (independently of the time required) and their cost per hour.

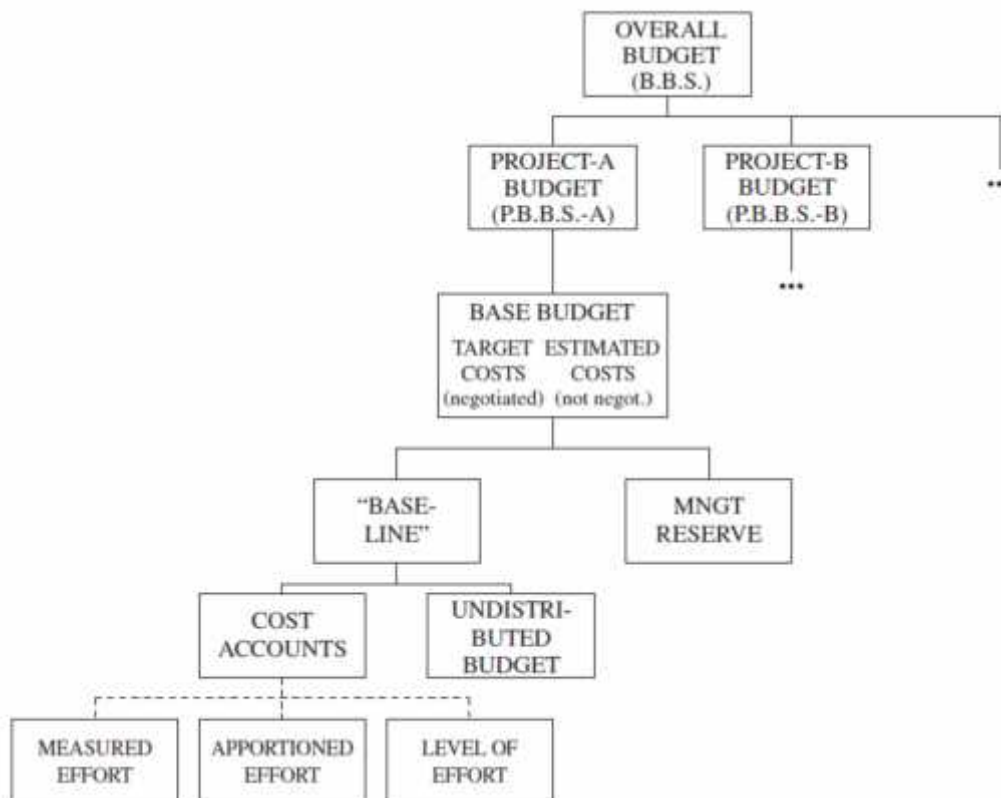
Finally, using criteria similar to the activity drivers of ABC (e.g. the duration of a certain activity in a project), it is possible on one hand to calculate the overall cost of the project so as verify if there are adequate funds (according to the company's overall budget breakdown structure – BBS) and, if necessary, revise the activities of the WBS, and, on the other, create and develop the PBBS of the project.

### IV.3 Cost Budgeting: Budget Breakdown Structure, Baseline, Cost Accounts

As described in the previous section, Cost Estimating allows the total budget for a given project to be defined. This budget is part of the overall budget of the company destined to projects (such as those for product development, work orders, improvement plans, etc.). The portion set apart for projects can coincide with the entire budget, in the case of ETO companies or in general, those working to order.

The budget of a project can be considered as a management tool: it is expressed in monetary terms and refers to a project that must be carried out (whereas in management control, it is considered a future accounting period). The budget takes into account all the necessary resources, unfolds in time according to a certain baseline (with interim checks, in the case of management control) and is articulated into cost accounts (while in management control, there is a profit and loss statement, the assets and liabilities sheet and estimates of the cash flow during the year). In both cases, the issues of leadership, confrontation, coordination and motivation are the same.

The budget of a project is structured according to the PBBS mentioned previously (Fig. IV.4). In the case of work orders, the expected margin of profit (return) must be detracted from the available amount (which can be the value of the contract or the starting price of a bid): the remaining amount is the base budget; this can include target costs and estimated costs: the former are those negotiated (e.g. x million euro per kilometre of motorway), whereas the others are not, and can only be predicted, a task that always hides a certain margin of risk (e.g. the cost of setting up a plant, before its turnkey delivery to the buyer).



**Fig. IV.4** Project Budget Breakdown Structure (PBBS)

The base budget is subdivided into two parts: the main one is the baseline, whereas a smaller amount is set aside for contingencies (management reserve). Management reserve is particularly important in the case of work orders, when the contract includes penalty clauses for late deliveries; considering the inevitable randomness of some variables, a certain budget percentage is necessary to reduce the risk of project delays.

The baseline on the other hand is the available sum that can be used to carry out the activities relative to the project. It is so called because its evolution in time can be depicted as a line. It usually has an S shape, since during the first stages expenditure is low, and then rises sharply, to finally decrease in the last stages of the project (Figs. III.6 and III.7). Therefore, in a cost/time Cartesian representation, the base-line curve starts at the origin of the axis to reach a final point, which indicates both the duration of the project and its overall cost (commonly known as budget), which corresponds to the maximum value of the baseline.

This sum includes the so-called Cost Accounts (CA) that are relative to the Work Packages (WP) carried out by well-established resources. The integration between costs and work schedule is termed as “Cost/Schedule Control System Criteria – C/S CSC” .

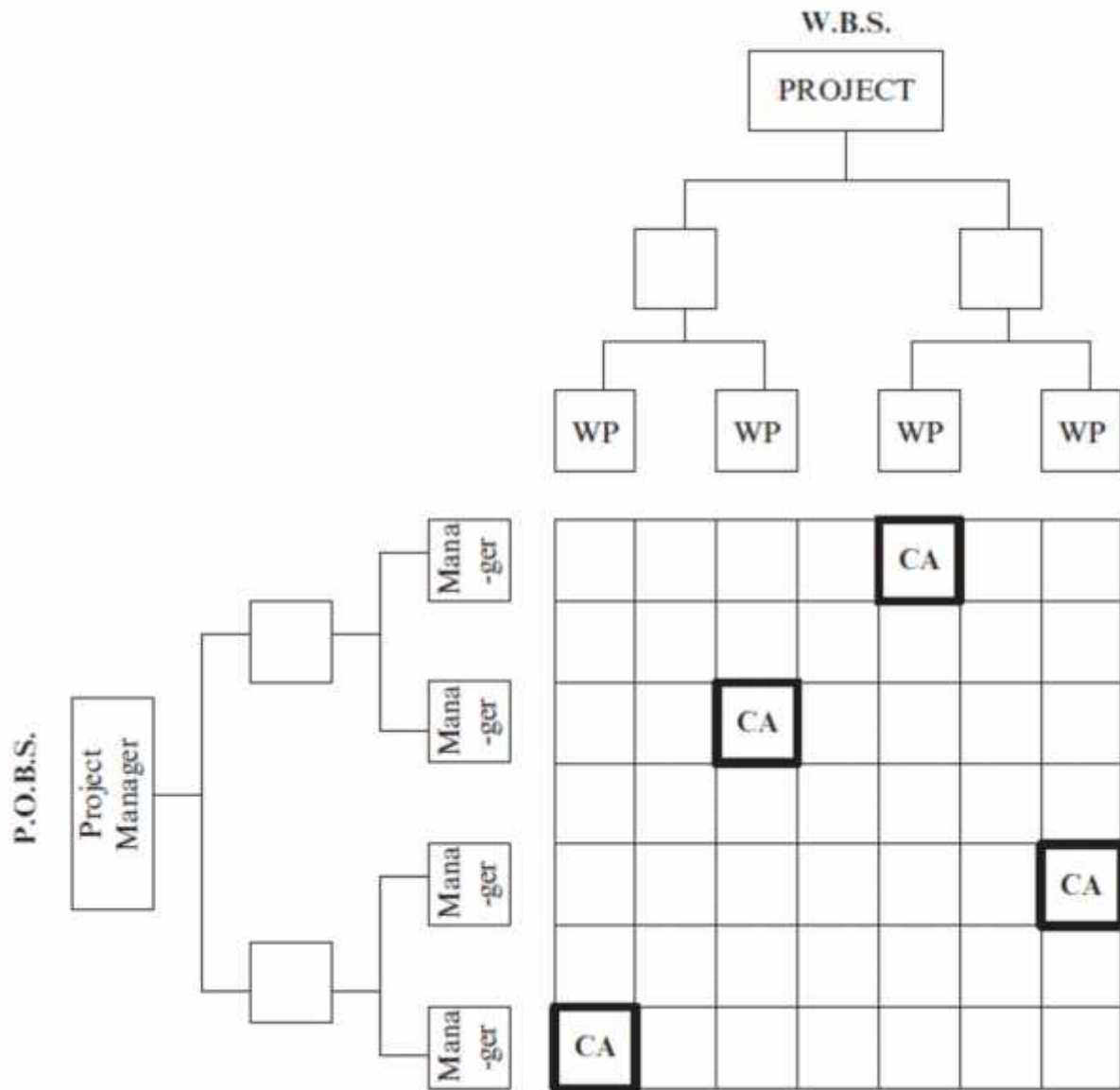
In other words, the CA are defined by combining the POBS with the WBS (who does what, respectively): the tasks described in the WBS are aggregated into work packages; organizational managers are responsible for these WP, and they have a certain CA at their disposal to pay for the necessary resources. Figure III.5 could also include a third dimension, rising up from the page, which structures the elementary units of the CA, to rebuild the PPBS.

Therefore, the project manager delegates technical and managerial responsibility for the various chunks of the WBS (i.e. the activities) to WP manager, who is also responsible for the CA. The project manager retains a part of the baseline for the direct, overall management of the project: this portion is known as undistributed budget (Fig. III.4).

The criteria used to define each CA must be based on the efforts needed to deliver the activities of the project; these efforts can be classified as follows:

- Measured Effort (ME) – an effort that can be divided into work packages (WP) Consisting of activities (30-40 at the most) of limited duration, and whose out-puts (deliverables) can be measured directly
- Apportioned Effort (AE) – an effort that by itself is not readily divisible into short-span work packages but that is directly proportional to the ME, and therefore to the WP (these are indirect activities, but the effort they require is linked to the amount of direct work expressed by the WP)
- Level of Effort (LE) – an effort of a general or supportive nature, which is not proportional to the ME and cannot be ascribed to the WP (fixed activities, independent of the size of the WP)

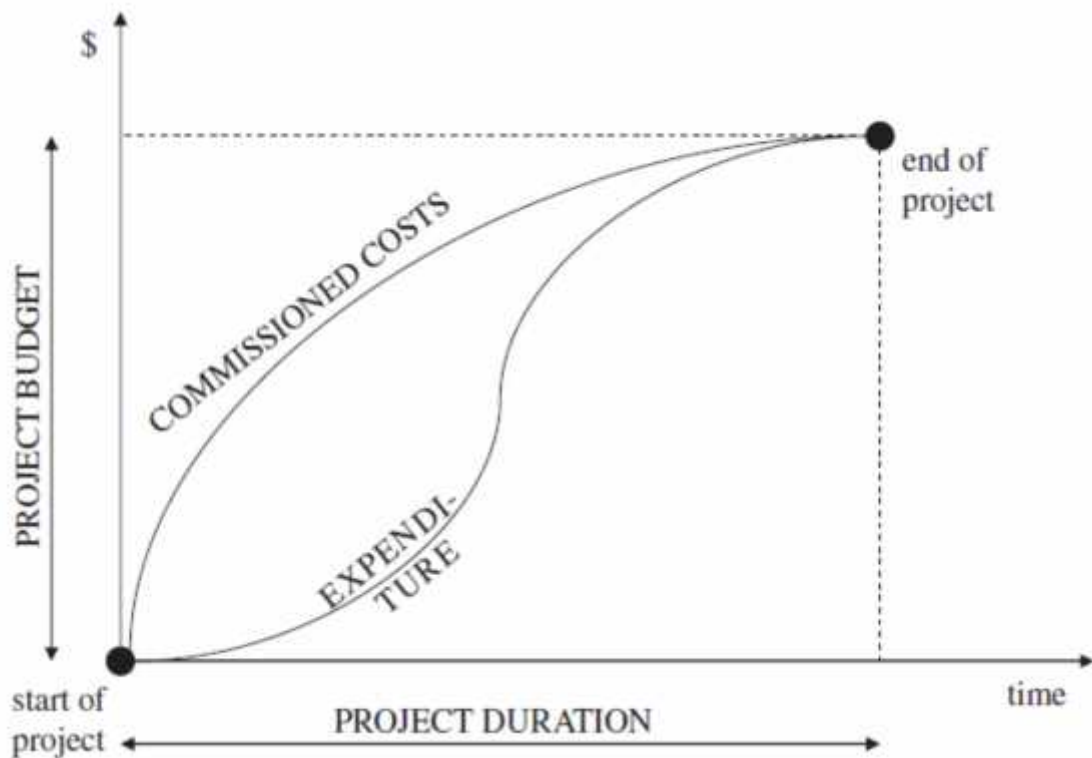
Hence, in order to carry out the operations described in the WP, it is necessary to have a CA that takes into account the ME, AE and LE; work packages deliver partial outputs known as deliverables, that document/concretise the work carried out, enable assessments to be made (checking whether the technical–qualitative goals have been achieved, and the times and costs conform to those established) and trigger the subsequent activities depicted in the network diagram of the project.



**Fig. IV.5** The origin of Cost Accounts

As shown in Fig. IV.6, all decisions concerning or affecting costs in other words, the commissioned costs are made a long time before paying the actual amounts: the decisions are made when defining the concept of the product and planning the project, therefore before the activities start. These first stages are crucial, and must be carefully managed, not only because of the technical repercussions on the product but also to determine its costs. The fact that it must be calculated so long beforehand is what makes cost management in a project so difficult. The curve of costs incurred in accomplishing work coincides with the planned baseline which in turn if the prediction is correct will also coincide with the ACWP.

It must be underlined that cost-related decisions made during the planning stage not only serve to estimate the cost of the project and therefore the necessary budget, but will also have a profound impact on the overall costs, once production has started. Planning plays a crucial role, even from an economic viewpoint; although it accounts for only 5% of the cost of the product, it can often be responsible for over 75% of the overall manufacturing costs.



**Fig. IV.6** Decisions affecting costs, and payment moments

As mentioned in the previous section, the baseline curve illustrates how the predicted costs relative to a project unfold throughout the duration of the project. Since it considers both costs and times before they actually occur, the baseline is also known as Budgeted Costs of Work Scheduled (BCWS).

Once the project has started, it is necessary to control its progress, not only in terms of work and technical performances, but also in terms of its cost, so as to intervene in time if the events require it. Cost control is carried out using, as well as the baseline, two other curves with acronyms similar to that used to indicate the baseline:

- The Actual Costs of Work Performed (ACWP) curve, namely that describing the work actually performed and its actual costs
- The Budgeted Costs of Work Performed (BCWP) curve, in other words, the curve describing the actual work performed but at the budgeted costs

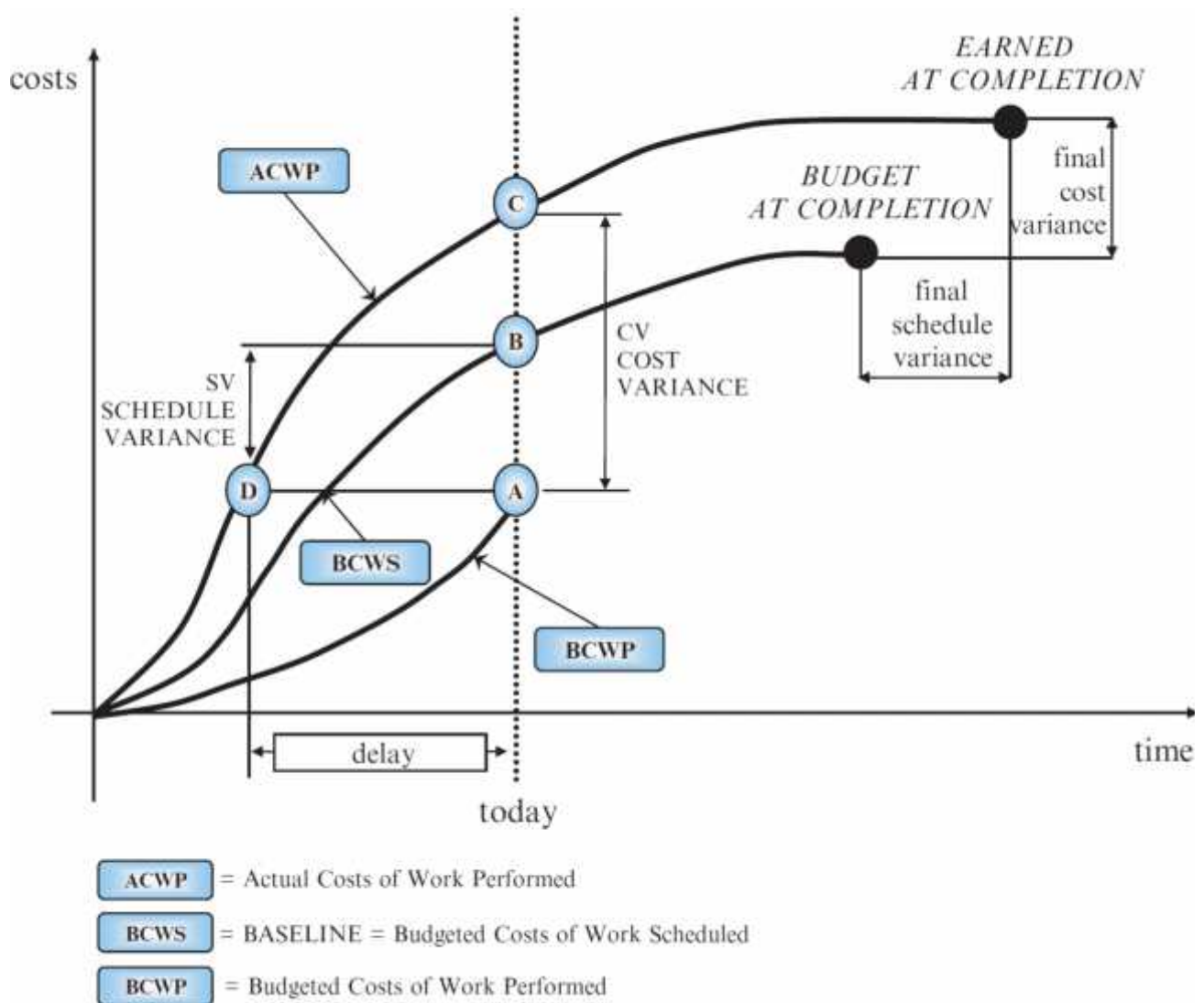
The ACWP curve, considering both the actual costs and times, is an ex-post curve and is therefore the opposite of the baseline (or BCWS).

However, the ACWP and BCWS curves alone are insufficient for analysing the budget variances for projects in progress. A third curve is necessary – BCWP – which is a hybrid of the previous two, considering the actual work performed but at the budgeted costs. A lower expenditure than that budgeted can reveal delays in the work in progress.

The need for the three curves to analyse budget variance when controlling progress is clearly shown in Fig. IV.7: at any given time (monitoring date), the future trend of the ACWP is unknown; moreover, a simple comparison between ACWP and the baseline would be insufficient, since it is

possible that by that date, the exact budgeted amount could have been spent (so ACWP and baseline would have the same value on the y-axis), but less work could have been carried out, at higher costs. Thus the need for the BCWP, since this curve shows how much should have been spent at the budgeted costs for the work that was actually carried out: if, for instance, on a given day the BCWP is below the baseline, it is clear that less work was done than that scheduled, since both curves refer to the budgeted costs.

Figure IV.7 shows a typical example of cost variance and a contemporary delay: the ACWP curve is above the baseline (BCWS) and the BCWP is below it. On the monitoring day, the difference on the y-axis between the value of ACWP and BCWP is the cost variance (CV), while the difference between baseline and BCWP indicates the schedule variance (SV), expressed in terms of costs. It would be a mistake to consider the CV as the sole difference between ACWP and baseline, since they would only coincide if the work progressed in perfect time. The SV gives an estimate of the cost variances during the progress of the project; the amount that has not yet been spent is simply due to the fact that certain expenses have not occurred because the respective activities have not yet started.



**Fig. IV.7** Curves used to monitor project costs with respect to the budget

It is therefore possible to calculate the percentage of cost and time variances at a given time  $t$  during the progress of the work, using the following formulas:

$$\% CV(t) = CV(t) / BCWS(t)$$

$$\% SV(t) = SV(t) / BCWS(t)$$

Only at the end of the project will it be possible to calculate cost and time variances in a different manner, measuring the differences of the final values of the ACWP curve and the baseline both on the y-axis (costs) and the x-axis (time).

The existence of the third curve, namely the BCWP, also gives the name to the method just described: Earned Value Method, defined as the value of the actual work according to the budget. Given the total value of the project, or Budget at Completion (BAC), and the percentage of work progress at a given time  $t$  (%L), the Earned Value (EV) can be calculated as shown here:

$$EV(t) = BAC * \%L$$

When controlling a project and comparing budgeted and actual costs, it is necessary to take into account the efficient use of the various resources.

With reference to Fig. IV.8, for every resource used to complete a work order, it is possible to calculate its predicted cost by multiplying the unitary cost or price of the resource (on the y-axis) by its use rate (on the x-axis), for example, in the case of designers:

$$(\text{€ per hour}) * (\text{hours per order}) = \text{€ for designing each work order.}$$

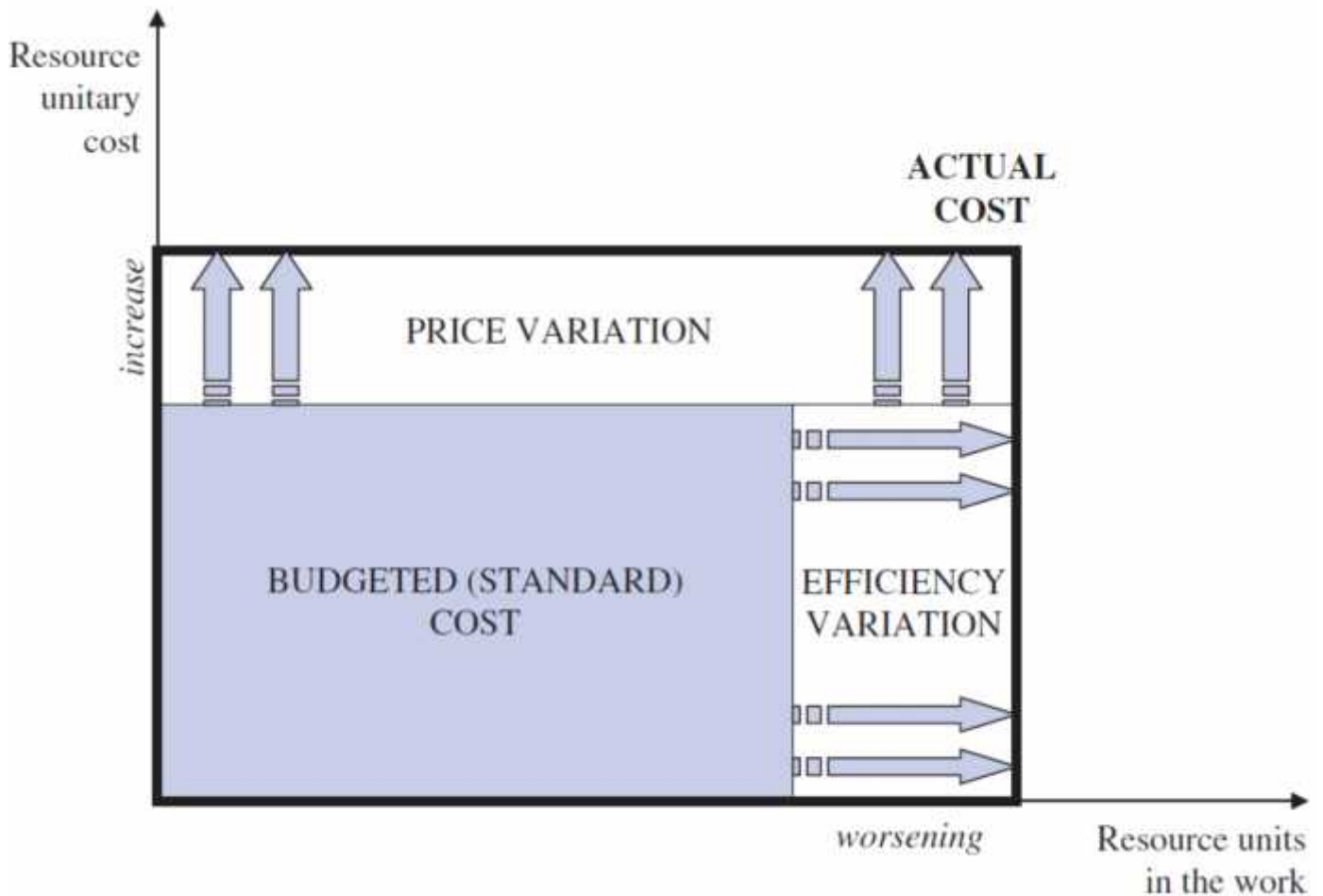
The total area of actual and final costs is equal to the algebraic sum of the three areas – budgeted cost, variances in the price of the resources (top part of the Fig. IV.8) and changes in operational efficiency (which decreases when moving towards the right hand side of the Fig. IV.8 and improves when moving to the left, because in this latter case less resource units are used for the job). It must be noted that the area corresponding to variances in the price of the resource takes into account both the budgeted costs and the increase (or decrease) in operational efficiency.

#### **IV.4 Capital Budgeting: Analysis and Evaluation of an Investment Project**

Cost management and its three stages described previously (Estimating, Budgeting and Control) are still insufficient to give a full view of the monetary situation: as well as an economic analysis, it is necessary to perform a financial analysis of the project, so as to take into account the time variable. A project is in fact a form of investment. The capital required for its delivery, and the expected gains, should therefore be allocated and considered throughout time (Capital Budgeting).

An investment, of any type, can be defined as a sequence of net monetary flows, structured so that at the beginning expenditures (costs) prevail, and only afterwards, the takings (gains or revenues).

Figure IV.9 shows two typical investment profiles relative to the launch of a new product, one of which is a pioneer (appearing for the first time on the market) and the other a follower (appearing later).

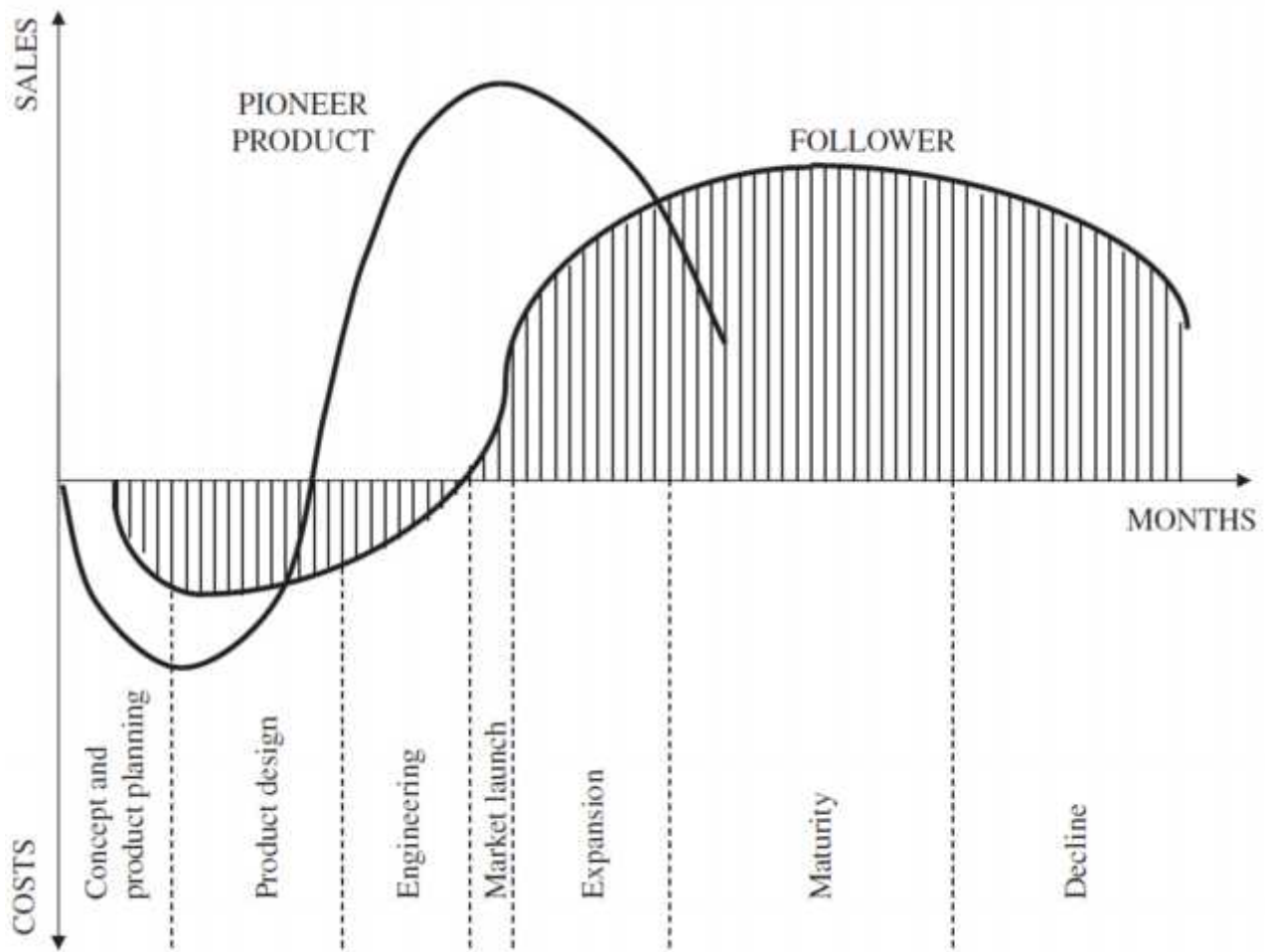


**Fig. IV.8** Variance Analysis between budgeted and actual costs due to variations in the price of the resources and in efficiency

These curves are extrapolated from cost and gain histograms relative to discrete periods, so the S-shaped curve of the baseline is the integral (i.e. the area bounded above by the graph of the function and below, by the x-axis) of this extrapolation curve: the value of the baseline on a given date is therefore equal to the sum of predicted costs incurred up to that day, and depicted as upright bars (histograms) of below-zero value (costs).

The moment of maximum slope for the baseline coincides with the bar having the greatest absolute value of cost, which occurs somewhere around the middle of the project's life cycle.

When taking into account the financial aspects of a project, it is necessary to define the monetary value throughout time as a cost (periodic percentage) sustained to anticipate a taking (e.g. the cash flow deriving from a loan received) or to delay an expenditure (e.g. when asking for a postponement of payment); in other words, profits are made by accepting to postpone an income or accelerate an expenditure.



**Fig. IV.9** Two typical investment profiles for the launch of new products (stages refer to the follower)

The transport of money throughout time requires correction factors: capitalising factor if moving from present to future, actualisation one if the other way round. As described in greater detail in any financial text, it is sufficient to multiply the amount to be moved as follows:  $(1+i)^n$  and  $(1+i)^{-n}$

where  $i$  is the interest rate for the period considered, and  $n$  is the number of periods through which transport occurs.

Any project, considered as an investment, must be subjected to two phases characterising the analysis and evaluation of a typical investment.

The stage of investment analysis includes the following:

- A quantification of the incoming and outbound cash flows that can be ascribed to the project, in other words, its estimated costs and the expected gains (arising from the sale of the product, the delivery of the order, etc.)
- The distribution of these flows in time
- Their monetary value in time, expressed by an interest rate
- The degree of risk, thus the uncertainty of all previous items

The following stage of investment evaluation includes the following:

- The identification, selection and application of one or more criteria to evaluate the investment profile calculated during the previous stage
- The definition of the acceptance criteria, which should take into account the company's strategies, its short-, medium- and long-term objectives, technical feasibility, exposure to risk, compatibility with current or future projects, etc.

While the stage of analysis strongly depends on the intrinsic nature of the project, the evaluation stage exploits a set of standard methods to assess the following aspects of a project/investment:

- Net income (the difference between revenues and costs)
- Profitability (the ratio between all the revenues occurred and the costs sustained)
- Risk (intended in this context in an economical, not a technical sense)

The most popular methods for evaluating the financial performances of a project are as follows:

- 1.Net Present Value (NPV) method for evaluating income
- 2.Profitability Index (PI), also known as Value Investment Ratio
- 3.Payback method for limiting risk when estimating cash flows
- 4.Internal Rate of Return (IRR) method for evaluating the level of risk when estimating the actualisation rate

In the following pages we will briefly describe these four methods, presenting at the end an example of a compared evaluation.

The Net Present Value (NPV) is the difference between positive (gains) and negative (costs) cash flows, both of which are actualised. This value is the net gain that can be ascribed to the project as if it were already available, in other words, at its present value. It therefore depends, as well as on the amount of forecasted profits and losses, also on the interest rate used to actualise the sum (since the coefficient is always lower than 1, actualisation detracts a certain amount of the future gain to its current value: for this reason, the flows obtained are discounted). A company will choose those projects having a positive NPV, taking however into account the links existing between the various projects (in order to avoid, for instance, product cannibalism), the consequences of path dependency (i.e. constraints on future choices brought about by the decisions made on current investments) and the limited availability of resources.

The Profitability Index (PI) measures the ratio between positive (gains) and negative (costs) cash flows, both of which are actualised, i.e. discounted; the negative cash flows (i.e. the denominator) often coincide with the initial investment, whereas successive costs are deducted from the gains at the numerator. It must be noted that a good PI does not necessarily imply a good NPV. Since  $PI = R/C = (C + NPV)/C = 1 + NPV/C$ , where R are the revenues and C the costs, there could be a modest value of NPV but an excellent PI if the costs sustained were very limited; on the other hand, a very high value of NPV could be obtained at remarkable costs, and therefore the PI would be low. When applying the PI, attention must be paid to the data considered: the value of the index changes if all the costs and revenues are considered, or the positive and negative periodic flows only (a periodic flow is the difference between revenues and costs in a certain period of time). The acceptance criterion for a project, according to this method, is that the PI value is greater than 1;

given a certain sum to invest (in the event of a limited capital), the project chosen is that with the greatest PI.

The payback considers the time needed to retrieve the investment made (in other words, the initial stage during which costs prevail) – thanks to the first gains. The fact that this period of time is short – considering that all cash flows are only estimated – reduces the economic risk of the project when income and profitability performances are equal. From a graphical viewpoint the payback is the value of the x-axis (time) when the positive area (indicating the proceeds) is equal to the negative one (the costs): all proceeds from that date on are pure profits. Obviously, both cost and revenue flows must be actualised.

There is another risk factor in the process of actualisation required by these three methods, as well as that concerning the amount and distribution of the flows, namely the value of the interest rate  $i$  (mean capital cost, opportunity cost, etc.). To solve this problem, it is necessary to calculate the Internal Rate of Return (IRR) of the investment project, namely the value of  $i$  that causes the NPV to be equal to 0. The NPV is a function of the interest rate  $i$  and follows an exponentially declining law: the value of NPV peaks when  $i = 0$ , then – as  $i$  grows – NPV decreases till it reaches negative values. To appeal, and therefore have a good NPV value, an investment must have a real  $i$  rate that is much lower than the IRR. With this method however, it is unnecessary to define a precise  $i$  value, but only a range of probable values, to be considered at a safe distance from IRR, which is calculated as the rate that would make NPV equal to 0.

Table IV.1 presents an example of a financial evaluation of three different investment projects using the above methods. The table illustrates a simplified estimate of a cash flow (the costs and revenues expected from the project), which is then actualised. It can be observed that, according to the method used, different projects are selected (those in grey) because different parameters are taken into account (income, profitability, risks concerning the estimated cash flows and the interest rate). It is therefore necessary to perform a comparative analysis of the projects, considering the various aspects here described.

|             |                                  | Cash flow      |                |                |                  |                |                 |
|-------------|----------------------------------|----------------|----------------|----------------|------------------|----------------|-----------------|
|             |                                  | Project A      |                | Project B      |                  | Project C      |                 |
|             | Actualisation rate ( $i = 6\%$ ) | Not discounted | Discounted     | Not discounted | Discounted       | Not discounted | Discounted      |
| First year  | 0.9434                           | -30,000        | -28,302        | -60,000        | -56,604          | -10,000        | -9,434          |
| Second year | 0.8900                           | 5,000          | 4,450          | -30,000        | -26,700          | 0              | 0               |
| Third year  | 0.8396                           | 10,000         | 8,396          | 20,000         | 16,792           | 10,000         | 8,396           |
| Fourth year | 0.7921                           | 20,000         | 15,842         | 50,000         | 39,605           | 20,000         | 15,842          |
| Fifth year  | 0.7473                           | 15,000         | 11,210         | 50,000         | 37,365           | 10,000         | 7,473           |
| Sixth year  | 0.7049                           | 10,000         | 7,049          | 40,000         | 28,196           | 0              | 0               |
| Net value   |                                  | 30,000         | –              | 70,000         | –                | 30,000         | –               |
| NPV         |                                  |                | 18,645         |                | 38,654           |                | 22,277          |
| PI          |                                  |                | 1.66           |                | 1.46             |                | 3.36            |
| Payback     |                                  |                | Nearly 4 years |                | 4 years 9 months |                | 3 years 1 month |
| IRR         |                                  |                | 25.1%          |                | 19.1%            |                | 61.8%           |

**Table IV.1** Evaluation and comparison of three investment projects

## IV.5 Project Financing

Project Financing is an alternative to the more conventional company financing, from which it differs in one important aspect. While the latter is aimed at evaluating the economic and financial statement of the company and the effects of new investment or new debts on this balance, Project Financing is aimed at evaluating the economic and financial statement of a specific project, linked to a certain investment, and in economic and legal terms it is independent of all other activities made by the company.

In the former case the underwriter, usually a bank, assesses the company requiring the funds and then, on the grounds of this evaluation, finances the enterprise, in exchange for concrete guarantees or bonds. In the latter case, the underwriter finances a single idea or project; the attention is focused on the prospects of the project and its ability to return the investment. If the project is unsuccessful, the underwriters can only make up for the loss with the goods of the project, and it is only possible to claim a limited recoup from its promoters.

Project Financing can be defined as an organisation formed by a plurality of subjects to finance the production and management of an economic good, giving rise to a cash flow that can pay back the initial investment at a market return rate. The aspect characterising Project Financing is the fact that the underwriters accept as a guarantee the cash flows generated by the management of the project, which are made as stable as possible by means of contractual terms defining how the risks are shared.

This definition underlines a typical feature of Project Financing, namely the need to identify the technical and economical risks linked to the project and define risk management procedures. Since usually Project Financing operations require large funds, but the assets of the company promoting the project are in most cases insufficient as a guarantee, the risks relative to the project and its estimated payoff are divided among all the members of the operation, by means of a harmonised system of contracts. It is the management of the financial risk linked to the operation that is the most typical and characteristic feature of Project Financing.

Project Financing is therefore an operation that occurs outside the budget of a specific company, which is independently assessed according to its ability to generate profit, and whose cash flows are considered as the main source of the capital invested. This type of logic focuses on the fact that the underwriters' expectations lie on the project's estimated profits and not (only) on the economic reliability of the companies, or their capital.

Consequently, the general goals of Project Financing are the financial support and the delivery of the project under conditions of great autonomy with respect to the underwriters who are its promoters. It is thanks to its – outside the budget financing logic that Project Financing ensures a financial leverage that is usually difficult to obtain.

When the project concerns technological innovation, Project Financing, rather than supplying resources in the form of medium–long term loans, is aimed at widening the ability to collect risk capital by releasing shares of the company. The technique of Project Financing, as well as responding to the need to finance autonomously the investment projects, can be included among the policies of Risk Management. Obviously, Project Financing is not the only solution to finance research and innovation projects: other opportunities also exist, such as the establishment of joint ventures, pools of enterprises, public research centres and venture capital.

## IV.6 Designing with the Customers

The most important design techniques aimed at satisfying customer requirements (i.e. the modern definition of quality) include Quality Function Deployment (QFD), Robust Design, Value Analysis and Value Engineering.

QFD, a method created in Japan in the 1960s, is aimed at translating the customer's desires into technical details, using a scale of priorities that is also dictated by comparison with similar products made by competitors. Applied for the first time at the Mitsubishi shipyards in Kobe (Japan) in 1972 and later in Toyota, it owes its formalisation to Professor Yoji Akao (who first described it in 1966, although his most famous and complete work is that published in 1990). QFD became popular in the Western world, thanks to Don Clausing, professor at the MIT in Boston, and was soon adopted by General Electric and Ford, where it is now one of the most used methods for product development ([www.qfdi.org](http://www.qfdi.org)).

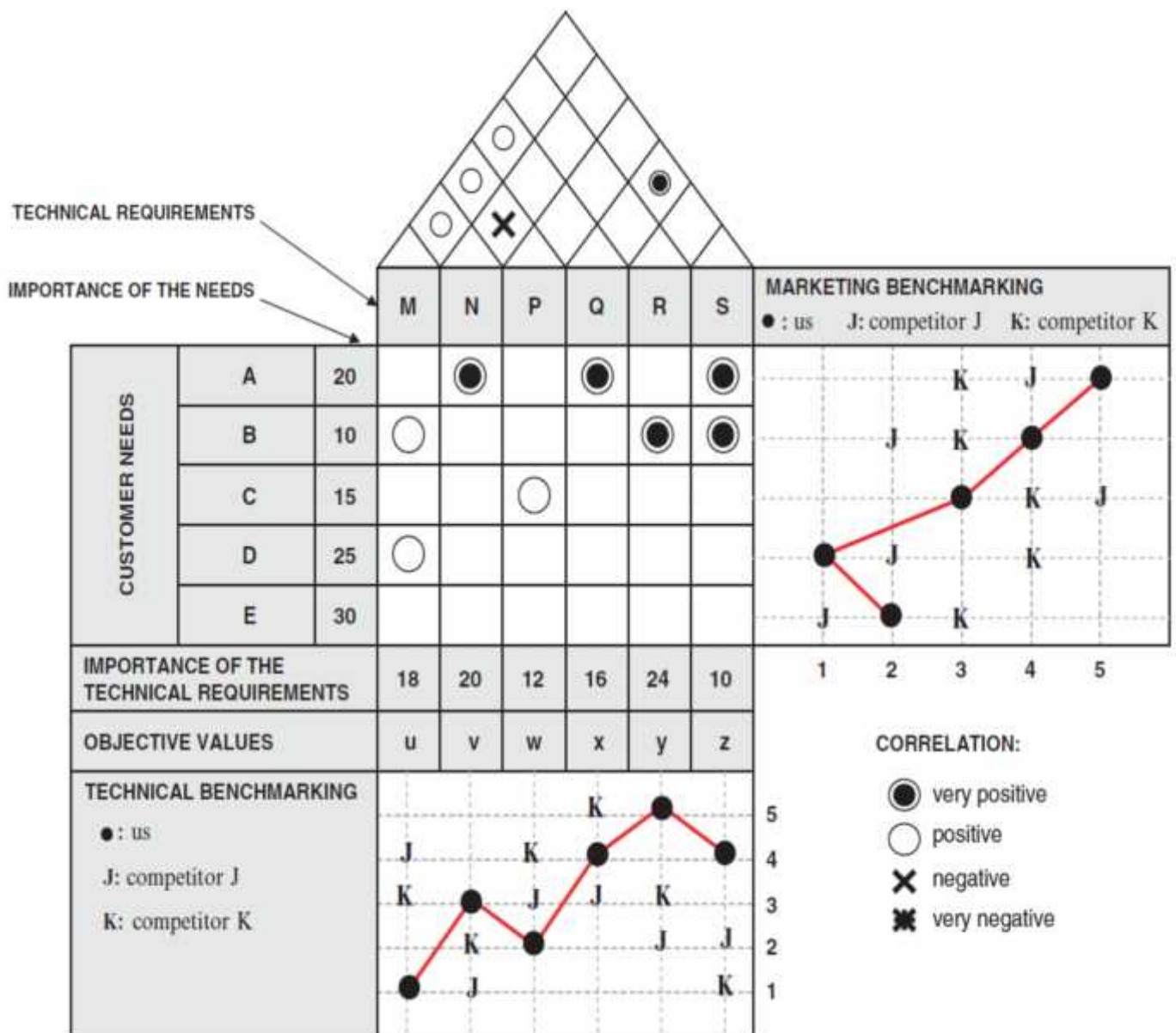
A first, partial presentation of QFD can be made through its what-how matrix, illustrating the following (Fig. IV.10):

- Customers' desires (the whats to produce) and their priorities, in the rows
- Technical-operational prerequisites (the hows, i.e. how to translate the customer's desires into practice) in the columns
- Customer needs versus Technical-operational prerequisites (inside the matrix) and a diagonal correlation between the hows.
- An assessment of the importance of the technical operational prerequisites and their objective numerical values, in the basement
- Evaluation of the competition, considering how the products respond to the demands of the customers (on the right, in the central matrix) and their technical level (at the bottom)

The customer's demands (on the rows) are established by marketing research (through interviews, questionnaires, etc.), and it is often necessary to group these requirements into categories, using techniques of Hierarchical Cluster Analysis.

In practice, a chart is made (the so-called Demanded Quality Deployment Chart), which is organized by rows and develops these demands horizontally by increasing levels of detail (generally, three): the most detailed level will be linked to the technical-operational prerequisites (described in the columns).

Also the Quality Pre-Plan has a matrix structure, with rows expressing customer needs and columns describing (1) the score given by the customers to the goods produced both by the company and its competitors, according to how these match their requirements, (2) the objective score that the company intends to achieve by developing the new product, (3) the improvement rate deriving from the comparison between past scores and the objective score, (4) the sales point scores, namely factors of 1.2 and 1.5, respectively, linked to requirements that, if satisfied, can make a difference in terms of image and sales success, (5) the overall score resulting from the score given by the customers, the rate of improvement and the sales point score, (6) the demanded quality weight or relative weight, namely the value of the previous score expressed as a percentage: this value is then written down in a column of the HoQ matrix (Fig. IV.10).



**Fig. IV.10** The whats–hows QFD (Quality Function Deployment) matrix

The technical operational prerequisites listed in the columns of the HoQ represent the technical features of the product and are also known as the voice of the engineer. These prerequisites indicated as  $w_j$  –are also weighed, using factors obtained by multiplying the demanded quality weight  $d_i$  (see earlier) by the crossed  $r_{ij}$  values of the matrix correlating the whats and the hows; the latter values are converted from rankings (like those shown in Fig. IV.10) into numerical values using techniques of Analytic Hierarchy Process: four alternative rankings usually become  $-2, -1, +1, +2$ ; three alternatives can become  $1, 3, 9$  (or  $1, 3, 5$  or even  $1, 5, 9$ ).

$$w_j = \sum_{i=1}^n d_i * r_{ij}$$

The relative importance of each technical feature (i.e. the columns in the HoQ) can then be determined, so as to obtain a list of priorities that the engineers must keep in mind when designing the product:

$$\tilde{w}_j = \frac{w_j}{\sum_{j=1}^m w_j}$$

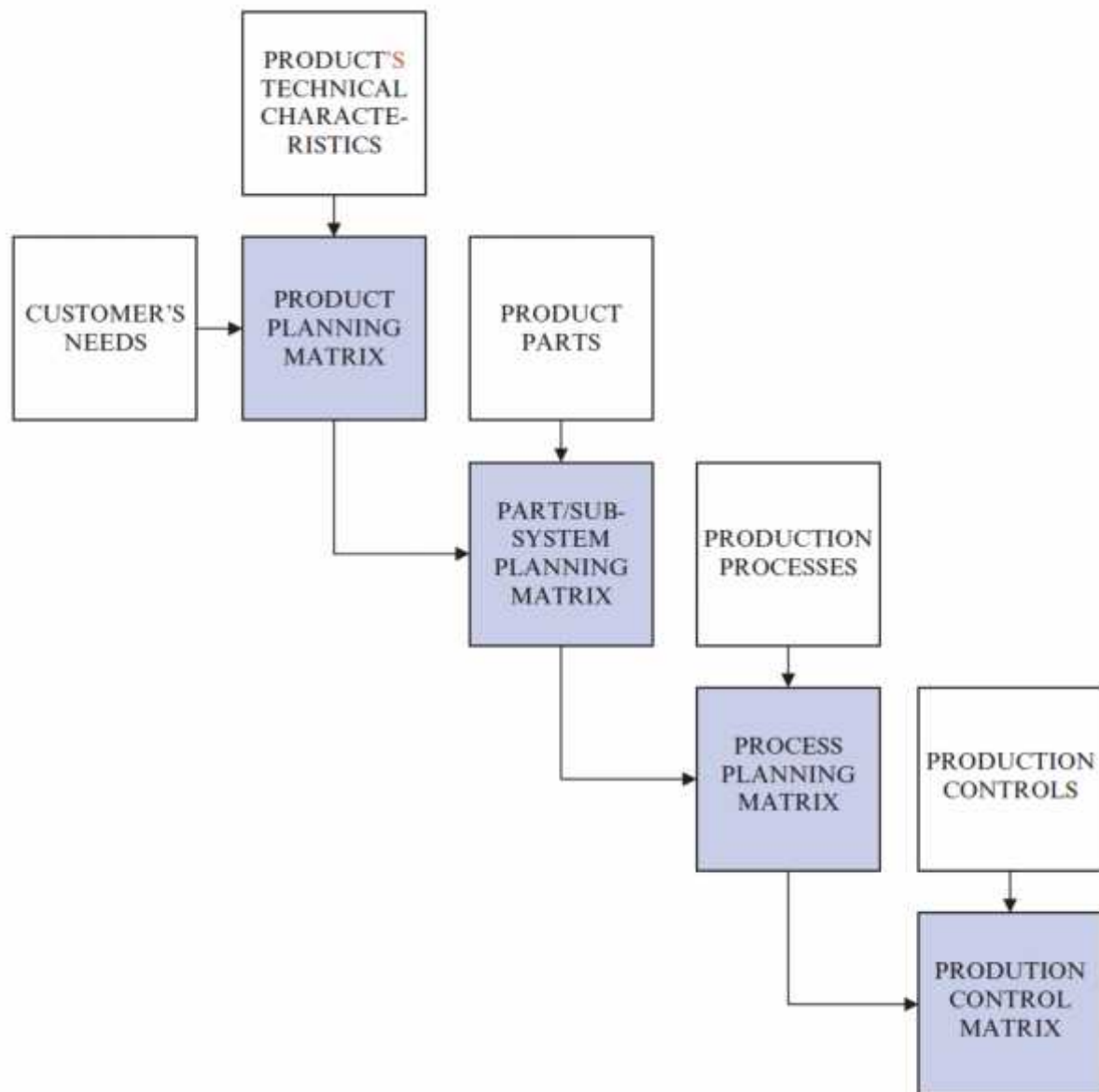
As well as the HoQ (or Product Planning matrix), the QFD method also includes other types of matrices, such as the Part/Sub-System Planning matrix, the Process Planning matrix and the Production Control matrix, which are linked to each other as shown in Fig. IV.11.

Moreover, by extending the method, it is also possible to prepare other charts for the deployment of various needs: the technology required (Technology Deployment Chart), the technical mechanisms/solutions to adopt (Mechanism Deployment Chart), product reliability (Reliability Deployment Chart) and costs (Cost Deployment Chart), the latter two being linked to FMEA and Value Analysis, respectively.

QFD has now become a common practice, linking design to quality management. The driving force is the customer, since quality – as established by norm ISO 8402 – is the satisfaction of market needs and desires. Quality therefore starts from the stage of design.

QFD can be successfully applied not only to the manufacturing industry but also to process industries, construction firms and software or service companies. There are also other approaches similar to QFD, such as FAST (Function Analysis and System Technique).

Robust Design (RD) is aimed at designing a product in such a way as to minimise loss of quality, which would mean failing to satisfy customer needs. Loss of quality is caused by a variance from the identified targets, and according to Professor Taguchi's "loss function", the failure to achieve these targets determines the onset of costs that are proportional to the squared value of the variance (Barkley and Saylor, 1994). Taguchi's approach considers three stages of design, relative to (1) the system, which defines the architecture of the parts, the shape of the product, the materials used, etc., (2) the parameters of the product, which must ensure that the performances are the least sensitive possible to variations from the target values, (3) the admitted tolerance.



**Fig. IV.11** The four QFD matrices

Value Analysis (VA) consists in studying the relationships between functions and performances on one hand, and the cost of the product on the other (an example is the classic quality/price ratio); the analysis, when referred to the product, determines an analysis of its parts and sub-assemblies. It is also known as Functional Cost Analysis.

The value is defined as the ratio between the weighed sum of benefits and costs:

$$\text{Value} = (\sum_i p_i B_i) / (\sum_i p_i C_i)$$

This value can be as follows:

- A use value or functional worth
- A cost value (summing the costs of materials, work and overheads)
- An esteem value (or prestige value, for which one is willing to pay an extra)
- An exchange value

The benefits considered to calculate this value can be functions, performances or both, and are ranked on different scales.

It is important to distinguish between primary functions (those responding to the primary scope for which the product is manufactured – e.g., in the case of a screwdriver, to transfer torsion) and secondary ones (referring for example to how the primary functions are carried out – in the earlier case, it could be to provide electric insulation).

It is also necessary to distinguish between (a) configuration parameters (e.g. the engine displacement in a car), (b) performance parameters (horsepower or fuel consumption), (c) performance indexes (the ratio between the earlier parameters, such as power/engine displacement and speed/fuel consumption).

VA considers all the primary and secondary functions of a product, assessing their usefulness and the level of appreciation by the customer. The key concept in this analysis is that the consumer is willing to pay an extra sum for some accessory functions. The scope is to create a product of lower price, supplied with all the functions appreciated by the customer and lacking all those that the customer is unwilling to pay for.

Value Engineering (VE) was applied for the first time in General Electric during World War II. It considers the materials and manufacturing processes needed for every function and component, selecting those that are both the cheapest and most efficient to perform the desired functions.

## **IV.7 Designing with the Suppliers**

The relationship with the suppliers has gained increasing importance over the last few years, as it became more evident that working together during the stages of product design/development and indeed during the entire production cycle could greatly improve time, cost and quality performances; another factor promoting collaboration is the increasing weight of purchase costs on the price of the end product.

The main novelties concerning the evolution of the customer–supplier bond refer to the models and types of relationship.

With reference to the models, these mainly consist in the following:

- Revising the traditional antagonistic model of the customer supplier relationship. The closer interdependence between the various units of the supply chain has transformed the transaction of goods into a relationship of cooperation, which has also become more exclusive, reducing the number of suppliers. The evolution of the relationship has led to single sourcing, dual sourcing and parallel sourcing, featuring, respectively, one supplier per component, two in competition with each other, or again, only one, but with the possibility of changing the supplier in favour of someone who produces a similar part and/or one that can be used for another model.

- A reconfiguration and integrated management of the supply chain. The broader area of customer–supplier interaction redefines the profile and role of the upstream interlocutor. In particular, privileged suppliers are those who provide sub-assemblies that are not critical for the purchasing company, thus allowing the latter to reduce the relational effort arising from a larger number of supplying interlocutors. In other words, the company interacts with a smaller number of suppliers than before; these are often tier-1 suppliers managing tier-2 and tier-3 suppliers, who in the past would have interacted directly with the purchasing company.

– An extension of the traditional geographical area for procurement. These changes arise from the world-wide competition that exists in certain sectors, and the need for a company to acquire distinctive features on the global market.

As regards the types of relationship with the suppliers, it is possible to distinguish between the following:

– A traditional relationship, featuring negotiation, inspections of the incoming products and safety stock

– An operational integration, with medium- or long-term relationships, the possibility of changing prices and volumes, guaranteed and certified quality, responsibility for the modules or sub-assemblies provided, frequent supplies in small lots (when operating in an open order mode) or according to the needs of the manufacturing departments (i.e. the pulled supply of Just-in-Time Purchasing), continuous quality improvement and cost reduction, offers of service packages, consultancy and training activities

– Partnership, which results in cooperation right from the stages of design, common investments in technology, research and development, a constant exchange of information, and in general, a coherence of strategies

Delegating the suppliers to partly or wholly design and develop the components is the last step towards establishing a partnership. While a medium- to long-term contract with an integrated supplier guarantees certified quality and just-in-time delivery (i.e. in small, frequent lots), a relationship with a partner also ensures cooperation in component design/development and, thanks to shared investments in research and technology, an innovation in the manufacturing/assembling processes. The companies can finally decide to establish solid builder/supplier groups that in Japan are known as keiretsu.

There are two types of involvement:

-Spot, when the supplier is occasionally invited to meetings with the engineering team of the company so as to discuss certain issues and design solutions

-Continuative, when the supplier's team works with the company for the entire duration of the designing activity

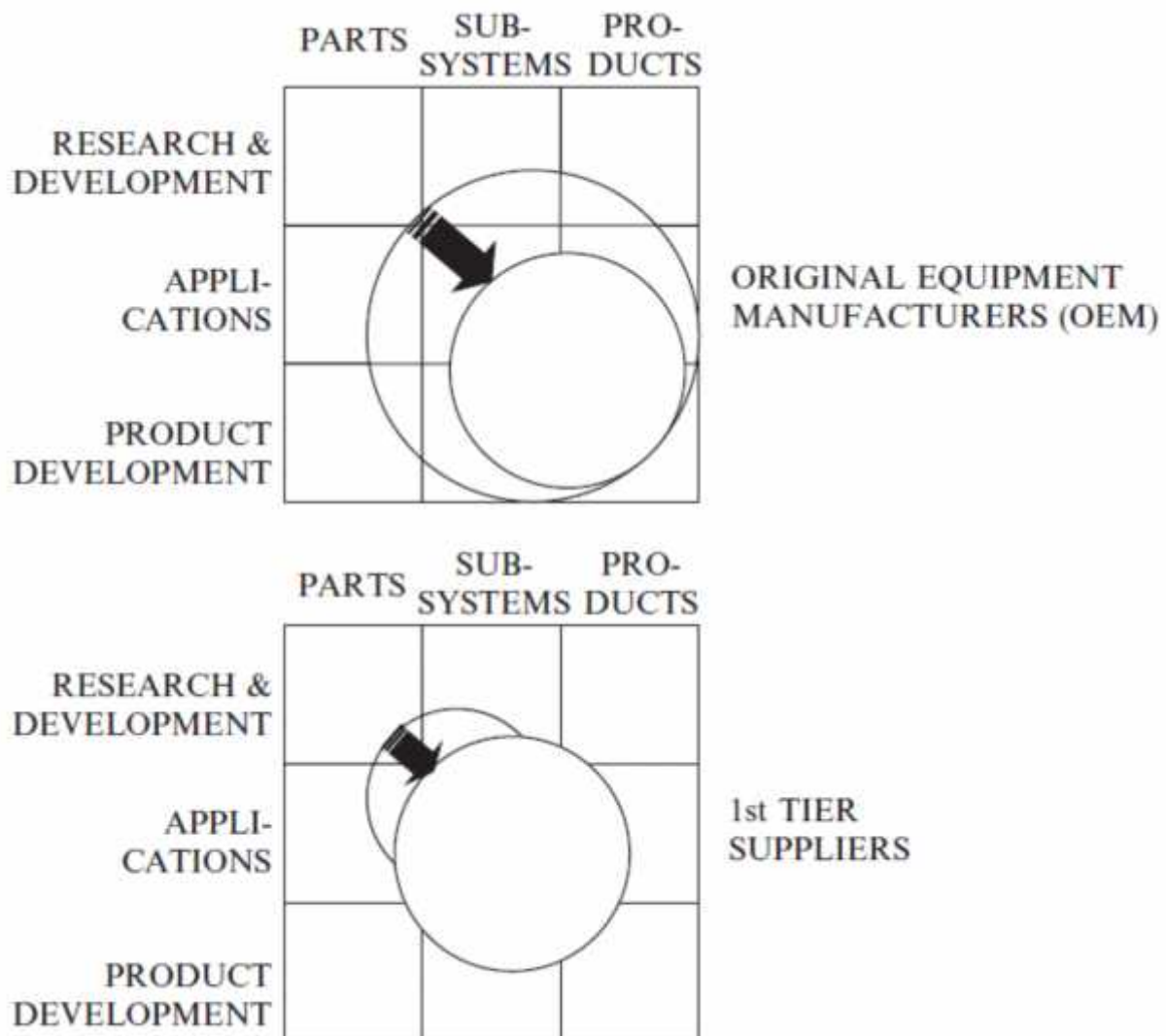
In the latter case, the involvement ranges from detailed controlled (when all specifications are provided by the customer, and the supplier must only carry out engineering and production) to black box (when the client specifies the basic features – performances, external shape, interface, and so forth, which arise from a rough, preliminary design – leaving the details to the supplier), to supplier proprietary (where the specifications, although congruent with the project of the client, are entirely defined by the supplier). The second case is becoming increasingly widespread, because the company can exploit the technical and engineering know-how of the supplier while preserving control of the product's architecture; the advantages are however counterbalanced by the risk of depending on one supplier only and being spied on by the competitors. Usually, the smaller the interdependence between product parts, the more the black box policy is used. The final drawings are either approved or consigned, according to whether the supplier keeps the property of the drawings (and therefore the client only approves their use) or not (usually when a large number of specifications, although not detailed, are defined by the customer).

The involvement of suppliers largely depends on their designing ability, and its two parameters: breadth, i.e. the number of black box transactions, and depth, namely the different types of design activities that the supplier can carry out (basic specifications, detailed design, assemblies,

prototypes, etc.). The criteria used to assess the supplier's designing capability consider various areas: (1) devising and designing the part and/or sub-assembly, (2) planning and engineering it, (3) planning and engineering its manufacturing process.

Nowadays it is a common practice to involve the suppliers in the design; in the automotive sector, for example, producers are reducing their design efforts and are moving towards the development of an overall design solution (modular platforms); at the same time, the suppliers of sub-assemblies or systems (first level suppliers) are gaining more space in designing activities (illustrated by the larger area in the lower part of Fig. IV.12), although they too are moving towards more systemic solutions.

The automotive group Fiat, for example, operates a strategic segmentation of the suppliers, grouping them into five categories: (1) co-design A (for parts that have a strong impact on the overall style and/or performance of the vehicle, hence the suppliers are involved from the stage of concept development), (2) co-design B (for components that are influenced by the style of the vehicle, such as the parts inserted into the dashboard or the wipers, supplier involvement occurs at a later stage), (3) simultaneous suppliers (who provide the major metal parts; simultaneousness is fundamental, given the long lead times), (4) detailed controlled (for smaller metal or plastic parts), (5) off-the-shelf or commodity suppliers (for other components such as sparking plugs).



**Fig. IV.12** Reconfiguration of the design activities of the OEM (above) and greater design activities by the first level suppliers (below)

## IV.8 Design for Manufacturability

Design for Manufacturability (DFM) considers the effects of the product's structure on manufacturing costs and, thanks to cooperation between the design and production units, aims at simplifying the manufacturing processes, while preserving the characteristics and performances of the product.

Lists a series of key points ensuring a good DFM, which include assessing the manufacturability of the various parts, so as to choose design solutions ensuring a high degree of conformity; evaluating the complexity of the manufacturing process required by certain design solutions and choosing the easiest ones among those ensuring the functionality of the project; assessing the variety of machinery setups required by a certain solution.

It is also possible to create two types of correlation matrices, known as Houses of Producibility: one correlates the design parameters of the product with the process, and the other the process design parameters with the production performances.

Like DFM, Design for Assembly (DFA) is aimed at limiting assembly costs while preserving a high level of quality, by choosing the most appropriate assembling methods, reducing handling and change of direction, inserting and connecting the components according to their shape, the material they are made of, technology, etc.

Since it considers the impact that certain choices of design have on production (manufacturing and assembling), DFM/DFA is also known as Design for Operations DFO. Given here is a list of the main rules of DFO:

- Limit the number of components
- Reduce component variety as much as possible
- Design components that can perform multiple functions
- Design components that are suitable for various uses
- Design components that are easy to manufacture
- Maximise conformity, so as to make it easier to comply with the specifications
- Reduce handling during production
- Design so as to make assembly and disassembly more simple
- Choose, if possible, only one direction for assembly, keeping in mind that top to bottom is better than vice versa
- Avoid separate fixing/connecting devices
- Eliminate or reduce changes while assembling

Applying these rules and keeping in mind past experiences simplifies the following stage of engineering, making it possible to limit the number of tests and trials (pilot runs or prototypes).

While DFM/DFA lists a series of principles that, if applied, should simplify manufacturability, Integrated Product–Process Design (IPPD) aims at integrating product design with production design. To do so, it is necessary to find points of similarity between product and process, on the grounds of the following:

- Product repetitiveness, which can be analysed by considering the production volume (i.e. the total number of items per their average volume)
- Process repetitiveness, which can be analysed by considering the production volume as the product of the number of families (i.e. a group of products characterised by similar component items produced by groups of similar machines – manufacturing cells), per the average number of items per family, and the average volume of each item

Interventions of IPPD, aimed at rationalising the product and simplifying the manufacturing processes, can occur at three different levels:

- 1.Level 1, the lowest (level of single component as regards the product, and single operation in the manufacturing process)
- 2.Level 2, intermediate (level of sub-assembly or functional group in the case of the product, and functional unit in that of the process)
- 3.Level 3, the top level (level of end product, and production process)

## IV.9 Reducing Variety

The Variety Reduction Program (VRP) is a technique, that is aimed at reducing the cost of design and product development by limiting the number of components and processes needed to manufacture a product, while responding at the same time to the market demand for an ample variety of products. It may seem a paradox to reduce variety when the market requires a wide range of models and customization: however, the technique ensures a reduction of internal variety (which, for a company, means costs), while preserving external variety and therefore the number of goods offered to the customers (it is this type of variety that contributes to customer satisfaction).

VRP considers three different types of costs, which differ extensively from the traditional ones examined in cost management: the latter costs can be easily classified according to their nature (e.g. those relative to the materials, machines/plants, staff, etc.), their variability (fixed costs, variable costs, semi-variable, etc.), their attribution to a cost centre or a product (direct/indirect) or in relation to time (predicted, actual, final), etc. The costs considered in the VRP are as follows:

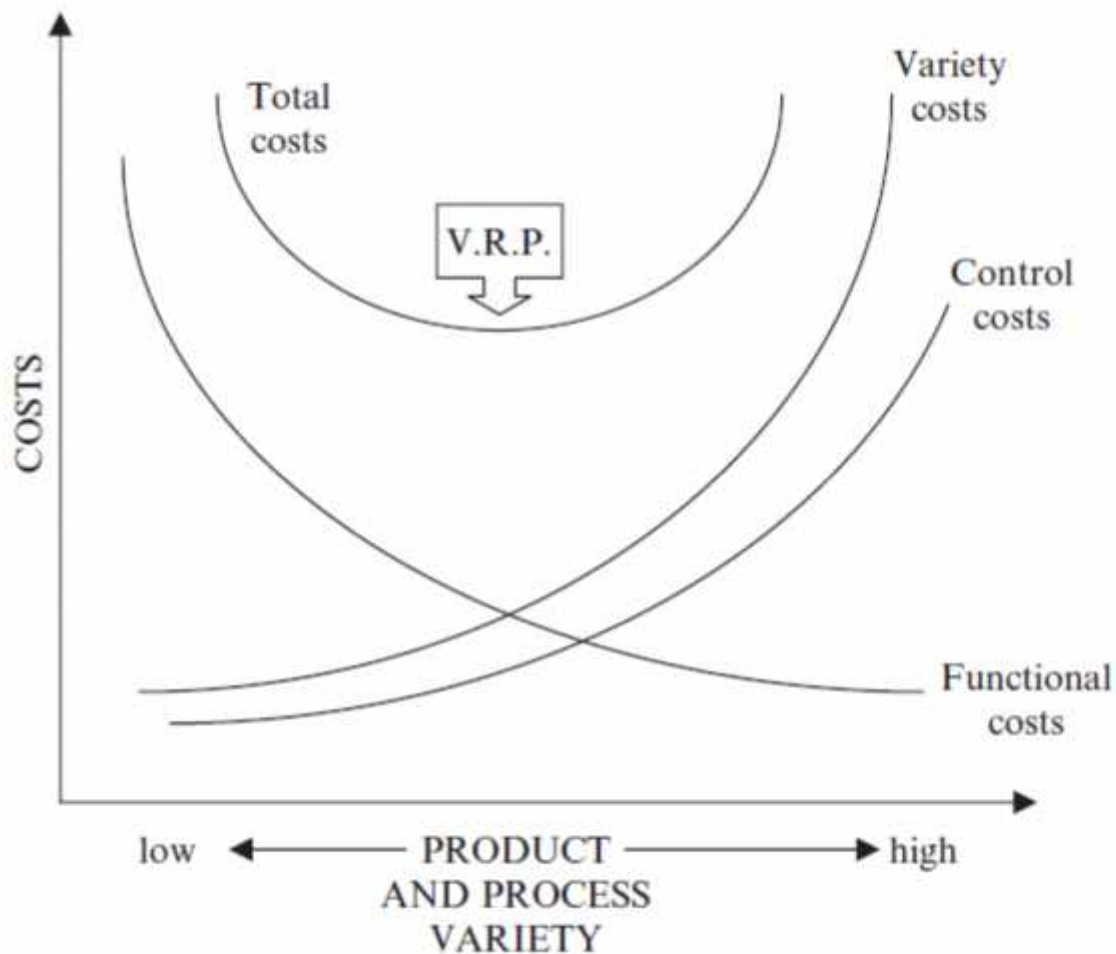
- 1.Functional costs, linked to specific performances/functions that the product must possess (they indicate the cost needed to ensure a certain performance of a given function added to the product, which implies additional materials, components, manufacturing processes, etc.). In other words, the focus is no longer on the traditional bill of materials (Product Breakdown Structure – PdBS) but on the product's functions (Product Function Structure – PFS). The relationship between performances/functions and costs is determined by its Value Analysis (VA).
- 2.The cost of variety, due to the fact that if a wide range of products is appreciated by the market, it requires different processes and therefore different types of machinery and equipment.
- 3.The cost of control, namely assessing the economic impact of complex management.

These costs evolve differently in relation to variety, with the latter two rising as product and process variety increase, whilst, under the same conditions, functional costs decrease (Fig. IV.13). A greater variety allows the latter costs to be distributed over a wider range of products: accessories, for instance, can be applied to different families of products. The VRP technique helps identify the level of variety needed to minimise the three types of cost. It is an innovative approach, differing extensively from the more conventional methods used to examine costs.

External variety coincides with the breadth of a given range of products, while the depth measures the number of options for a certain family (for instance, in a car: three or five doors, with or without air conditioning, etc.).

Internal variety can be assessed by means of various variety indexes, such as the following:

- The parts index, based on the type and number of parts forming a product
- The production process index, based on the different types of processes needed to manufacture a product and the number of machines involved in each process



**Fig. IV.13** The optimal degree of variety is the minimum of Variety Reduction Program (VRP) total costs.

An example of calculation used to determine the parts index is shown in Fig. IV.14: A, B and C are three different models, X, Y and Z are their respective components, which differ slightly in size, for instance and hence there are variants  $x'$ ,  $x''$ ,  $x'''$  for X, etc.;  $2^*$  and  $4^*$  are the use coefficients.

Figure IV.15 illustrates how the production process index is calculated: the circles are the departments and the triangles are the warehouses; the flows are not necessarily linked to production lines as shown in this example, but could be merely logistic, in other words calculated for executing production.

By using these indexes and the functional, variety and control costs mentioned previously, it is possible to define programmes aimed at reducing variety by combining the different parts and minimising the number of components needed to carry out a certain function. Cost evaluation will help define a level of variety close to the lowest point of the U-shaped curve obtained by adding up the three types of cost (Fig. IV.13).

The VRP technique also suggests ways to reduce (internal) variety by applying five principles:

1. Distinguish between fixed and variable parts. In any given project, a clear distinction must be made between these two types of parts (according to the customer's need), as well as semi-variable (or similar) ones, and only increase the number of variable parts that respond to the real needs of the customer, reducing superfluous accessories.
2. Use combinations of parts, both to amplify the range of products and create higher level functions by combining various lower level ones.
3. Apply multi-functionality/integration, so that only one part or sub-assembly performs various functions (e.g. using the engine shaft both to transmit motion and distribute oil or conditioned air), if necessary by integrating various parts into one.
4. Analyse the range of performances for a certain part, without having to substitute it with another, so as to reduce the number of parts that must be designed/ produced for the entire range of products.
5. Analyse the series, namely seek a constant ratio (different for each series) between two dimensions, or two performances, or between size and performance.

| models<br>parts | A                    | B                    | C                    | Type of parts |
|-----------------|----------------------|----------------------|----------------------|---------------|
| X               | $x'$                 | $2 \cdot x''$        | $x'''$               | 3             |
| Y               | $2 \cdot y'$         | $y'$                 | -                    | 1             |
| Z               | $4 \cdot (z' + z'')$ | $4 \cdot (z' + z'')$ | $4 \cdot (z' + z'')$ | 2             |
| No. of parts    | 7                    | 7                    | 5                    | 6<br>19       |

$$\text{"Part Index"} = 6 \cdot 19 = 114$$

**Fig. IV.14** Part Index calculation

| models<br>pro-<br>cesses  | A+B | C | No. of<br>lines                                                                                    |
|---------------------------|-----|---|----------------------------------------------------------------------------------------------------|
| BASIC<br>WORKS            |     |   | 2                                                                                                  |
| SPE-<br>CIAL<br>WORKS     |     |   | 2                                                                                                  |
| ASSEM-<br>BLY             |     |   | 1                                                                                                  |
| No. of<br>opera-<br>tions | 6   | 4 | <div style="display: flex; justify-content: space-between;"> <span>5</span> <span>10</span> </div> |

$$\text{"Production Process Index"} = 5 * 10 = 50$$

**Fig. IV.15** Production Process Index calculation

Internal variety should also be reduced so as to ensure low production process indexes, at least during the first stages of production. Thus, in order to preserve the same range of products, external variety must be created downstream, towards the end of the manufacturing process (usually when assembling). This, in short, is the mushroom concept illustrated in Fig. IV.16: differentiation only occurs during the last stages of production (i.e. the mushroom cap), while the former ones (the stem) remain few and standardised. Hence, according to the mushroom theory, internal variety can be reduced while external variety remains unchanged.

Among the programmes used to reduce variety, modularisation or modular design deserves special mention. It helps obtain sufficiently different products while economising on the activities of design, production and management of logistic flows, thanks to the repetitive use of standard modules and parts when designing the product.

Modularisation is performed on the bill of materials, and can be of two types, vertical and horizontal. In the former case (Fig. IV.17), there is a fixed part that is common to all products (thus known as core product), and variety originates when assembling variable parts (such as accessories) onto the core products. Thus, families of end products are created starting from different core products (depicted as a trapeze, rhombus and rectangle in Fig. IV.17). In the latter case (Fig. IV.18), variety originates from the combination of basic modules, leading to the production of intermediate ones (also known as functional groups, which in turn determine the end product); this type of modularization is defined as horizontal, since in the product there is no prevalence of a certain part (one of the geometrical shapes illustrated in Fig. IV.18).

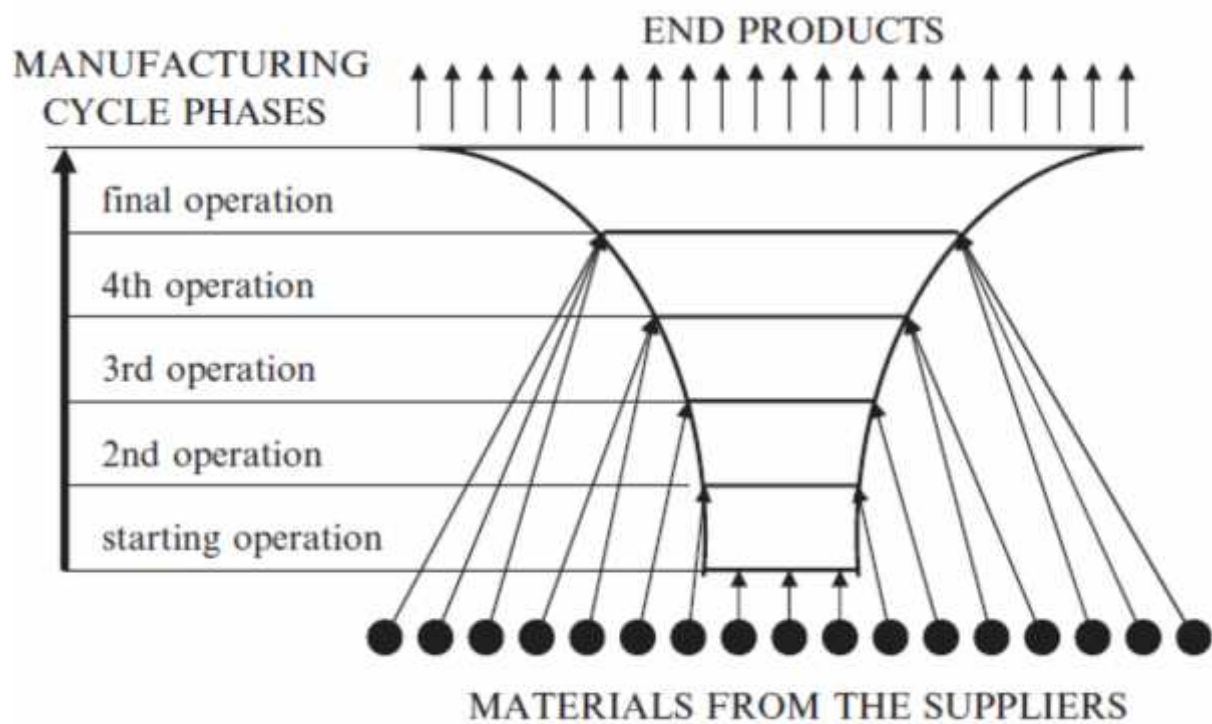


Fig. IV.16 Mushroom manufacturing cycle

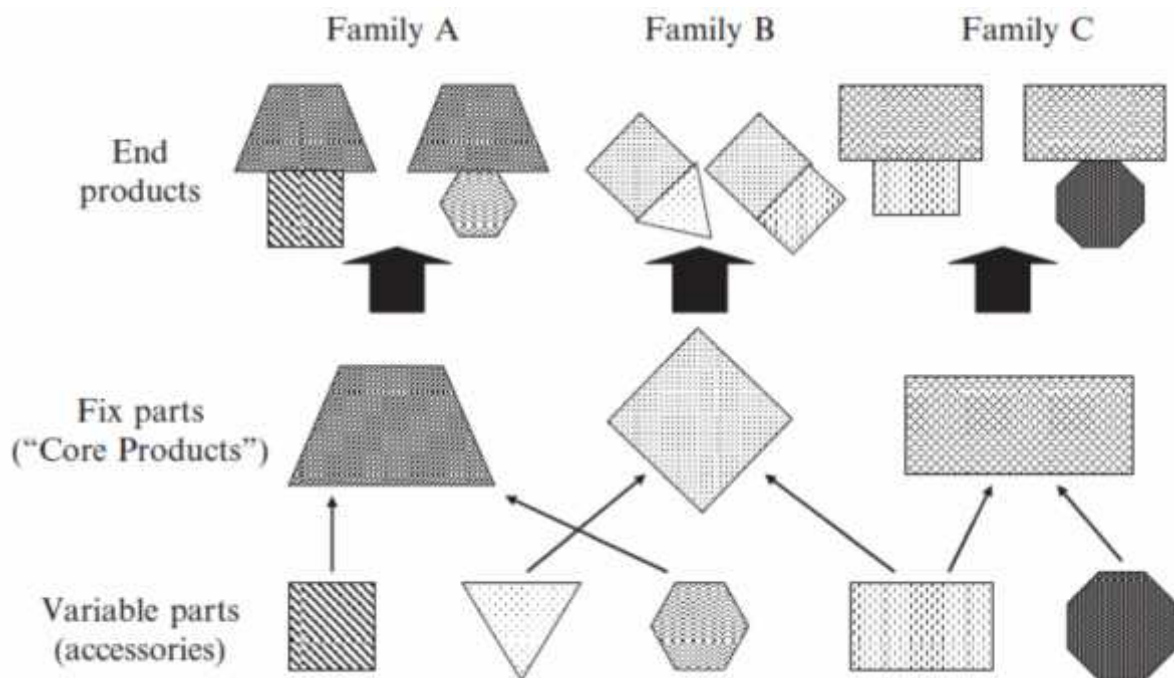
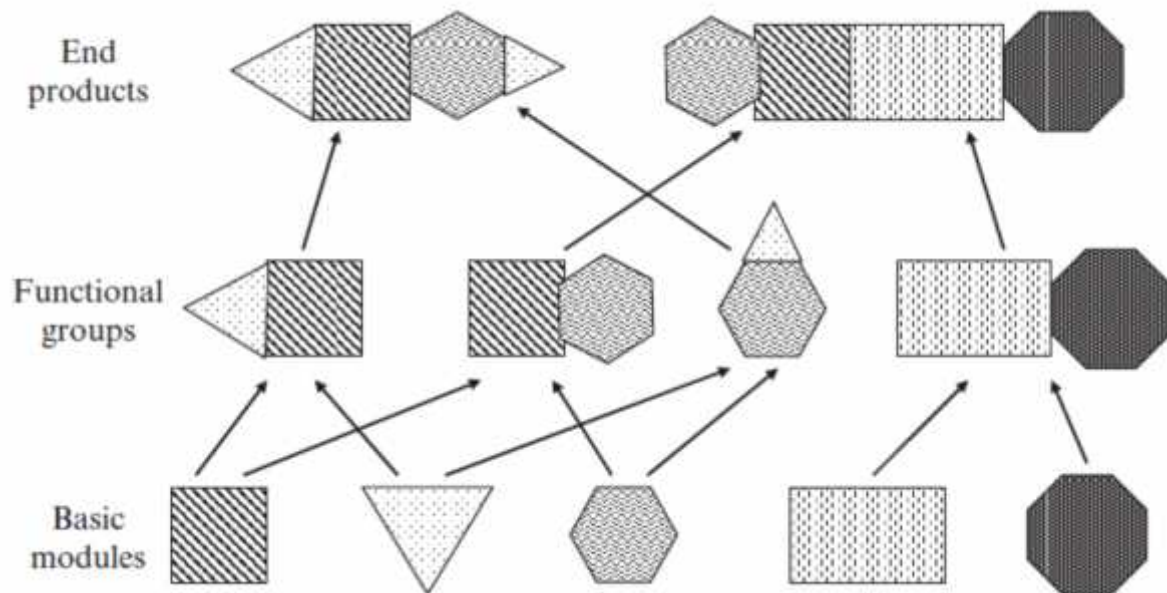


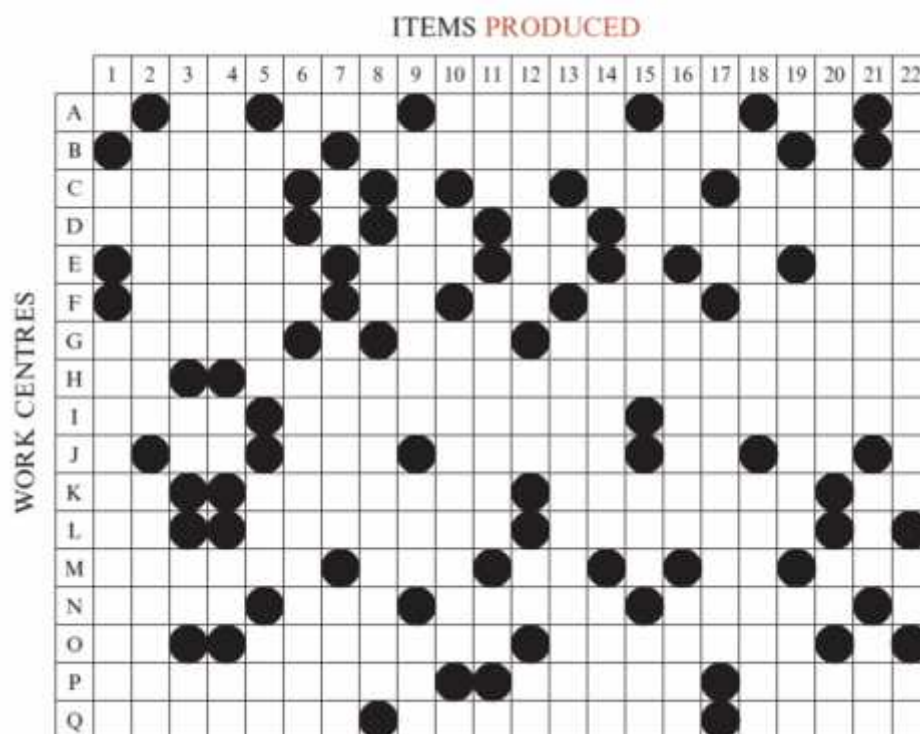
Fig. IV.17 Vertical modularisation



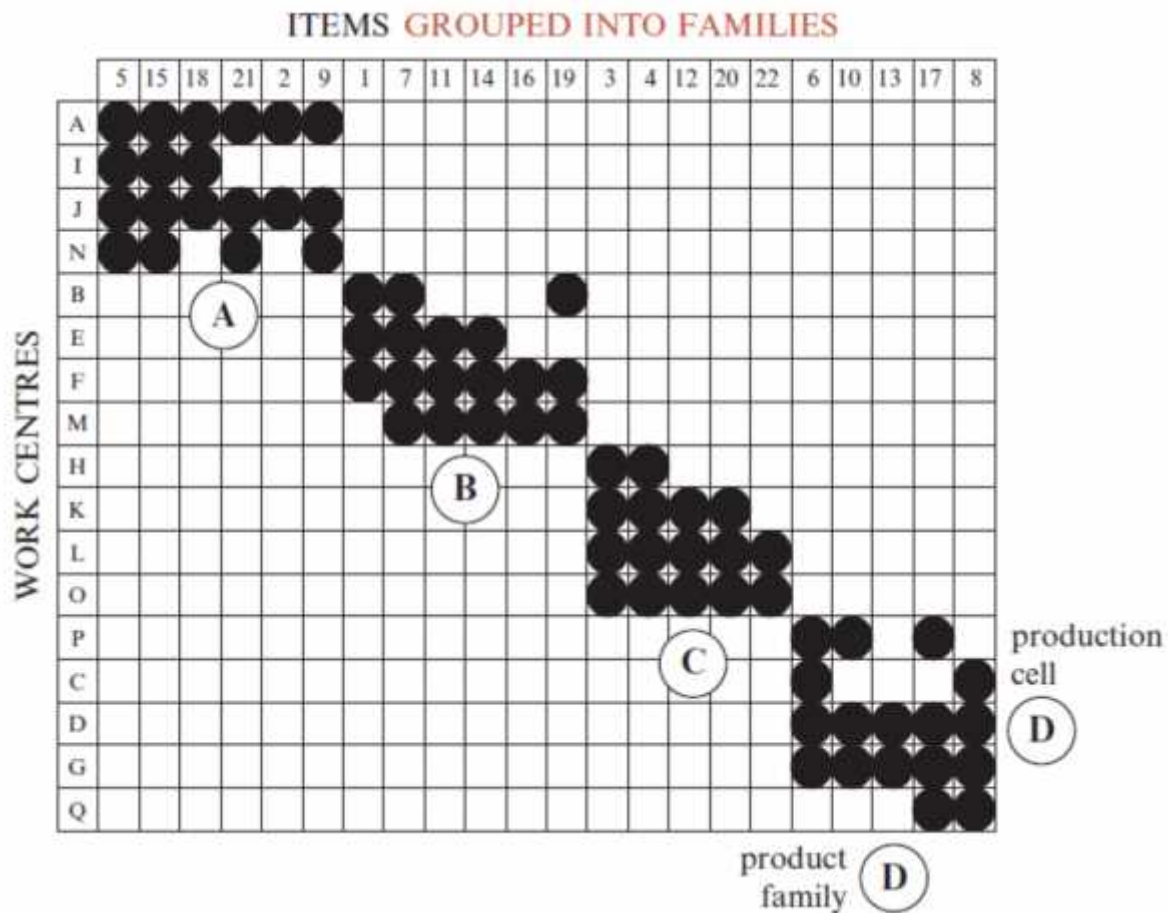
**Fig. IV.18** Horizontal modularisation

From a production viewpoint, the concept of modularisation has given rise to a specific process technology known as Group Technology, which, as the name suggests, groups the machinery into production cells according to the families of products that are manufactured and which features groups of similar parts (Figs. IV.19 and IV.20).

Finally, certain authors combine the management of carry-over, the principles of VRP and modularisation practices into one technique, for instance, calls it Edited Design or Henshu Sekkei and underlines the importance of distinguishing between fixed and variable parts, the latter ones playing a key role in satisfying market demands.



**Fig. IV.19** Creation of families of products and production cells through the Group Technology (A)



**Fig. IV.20** Creation of families of products and production cells through the Group Technology (B)

## IV.10 Simultaneous Engineering

Simultaneous (or Concurrent) Engineering uses a systematic approach for the simultaneous and integrated design of products and processes, including production and support. Ideally, it should take the place of the traditional, time-consuming pathway of serialised, repetitive adjustments, which determine a net separation between client and designer, as well as between designer and technician or the persons in charge of maintenance and technical assistance.

In other words, the duration of a project can be shortened, not only by thanks to the reduction of each activity, but also by joining the efforts and contributions of the protagonists of each stage. In a more stringent sense, Concurrent/Simultaneous Engineering (C/SE) aims at parallelising the activities, so as to reduce the overall duration of a project.

Some authors distinguish between Concurrent Engineering (joint, parallel interventions so as to shorten times by having overlapping stages of development) and Simultaneous Engineering (intended as contemporaneous design of various products a family using a multi-project management approach).

In practice, C/SE aims at integrating and overlapping the activities by increasing the exchange of information, producing interim reports and passing relevant data to the following activity in advance, before the previous one is over thanks to intensive team working and transversal meetings.

The principle behind C/SE is that a given activity must not necessarily start when the previous one is over, but there can be a certain degree of overlapping, which would promote a bilateral exchange

of information and help revise/adapt both activities, so as to reduce not only design times but also problems that could occur in the following stages.

Practice has shown however that C/SE may have certain drawbacks, due to an excessive amount of parallel modules and a more complex management and technical integration.

Rapid Prototyping (RP) makes it possible to pass directly from 3D CAD drawings to prototypes made either of special resins or the actual materials used for the end product. The prototype is constructed by means of stereolithography (which hardens a photopolymer – thanks to the selective action of a laser beam) or laser synthetisation (in this case, the models are obtained by the thermo-fusion of powders).

Not only can these procedures be used to create the prototypes of parts and products, but also to test production equipment such as tools and moulds (Rapid Tooling). The Research Centre in Fiat – CRF – has defined a process to build moulds for the pre-series, consisting of four elements: (1) a hull derived from the CAD model, made by electro-deposition or metal spray, which is used to create the shape, (2) its lining with carbides, ensuring resistance to wear, (3) its resin support, ensuring mechanical resistance, (4) a metal sheet container, which connects the mould to the press.

It is also possible to carry out Virtual Prototyping (VP), which helps study the functionality of a product or its manufacturing process without actually creating any physical artefact. Virtual technology, originally applied for space exploration and defence, then expanded to the field of entertainment and has now become popular in the industrial sector too. The computer recognises the virtual product and the context where it is used; the model defined by the CAD is transferred into a virtual world so as to visualise/animate it and simulate functionality tests. There are three main systems currently used, listed according to their complexity and costs:

(1) the CAD viewer, where the engineer is not immersed in the virtual world but simply observes it through special glasses and can use virtual dummies to test the ergonomics of a product, (2) third-party systems, where the engineer is shot, and the images are reproduced by the computer and then immersed into the virtual world, so that the engineer can interact with the product, (3) immersion systems, where (thanks to special devices such as gloves, helmets, etc.) the engineer is de facto in a virtual world.

## **IV.11 Reverse Engineering**

Techniques of Reverse (or Feedback) Engineering – RE – include Design of Experiments (DOE), Rapid Prototyping (RP) and Failure Mode and Effect Analysis (FMEA). These tools help assess and approve the choices already during the stages of design/engineering, hence before the product is actually made, so that it is unnecessary to use the manufacturing plants and start production.

Design of Experiments (DOE) helps identify the physical and operational parameters that have the greatest influence on the features or performances of the product: in this way, the engineers know what tests and trials to carry out when designing and optimising the product. It is also known as design-build test cycle, to underline that the definition of the tests and trials is an integrating part of the product's design. Experiments are carried out to define models linking the physical/operational parameters of the product to the results, in order to assess their impact as their values change. During this stage, also the trials and experimental designs are defined. From a practical viewpoint, it is necessary to follow the steps listed here:

- Define the feature/performance to achieve or improve, identifying its target value

- Define the physical parameters and the conditions under which it is tested and used
- Choose the experimentation levels for each parameter (number of levels and values)
- Choose the experimental design/procedure
- Interpret the results of experiments
- Repeat the experiments
- Identify the best parameters/solutions

Early Problem Detector Prototyping (EPDP) exploits prototypes to identify the problems and defects of a given design as soon as possible. The prototypes may be similar to the end product or only perform some functions, each of which must be tested separately.

Prototyping, when not rapid/virtual, requires pilot runs and can be carried out while the previous product is being manufactured, to then gradually extend to the other stages of production (step-by-step prototyping).

It is important to detect problems as soon as possible, because the cost of change increases exponentially as product development advances; for this reason, it is advisable to prepare a wide range of solutions during the first stages of design, which should be then screened, to narrow down the options. This procedure is like a funnel, and the wider it is at the top and the sooner it becomes narrow, the less it will cost to revise the project.

A dilemma thus arises: whether to make a decision that will have a fundamental impact on the performances of the product/plant at an early stage, relying on uncertain and incomplete data, or postpone the choice, awaiting more detailed information and clearer opportunities.

FMEA, also known as Failure Mode Effect and Criticality Analysis (FMECA), is a technique used to assess the reliability of a product. It was first defined by the US Army to determine equipment failures and their consequences on the system (military procedure MIL-P-1629 dated 11 September 1949). FMEA, comprising both a product FMEA and a process FMEA, became the standard method (and procedure) applied in the field of Advanced Product Quality Planning (APQP), in compliance with TS16949 norms.

The importance of reliability as an intrinsic performance of the product (together with its features and functionality) requires great care during the stages of design, where possible causes of product failure must be identified, studied and eliminated. FMEA considers the possible types of failure (of the whole product, and due to faults arising from wear, incorrect handling, etc.), their effects and causes, verifying whether they can be ascribed to the materials used or the manufacturing processes.

Both product and process FMEA follow the procedure described in Fig. IV.21. The starting point is the identification of the functions, i.e. the intended scope of the product or the process, which must be analysed; the following step consists in the identification of failure modes and their effects, their severity being ranked on a scale from 1 to 10 (the latter value being the most severe, i.e. that in which the life of the person – either the user or the process operator – may suddenly be in jeopardy).

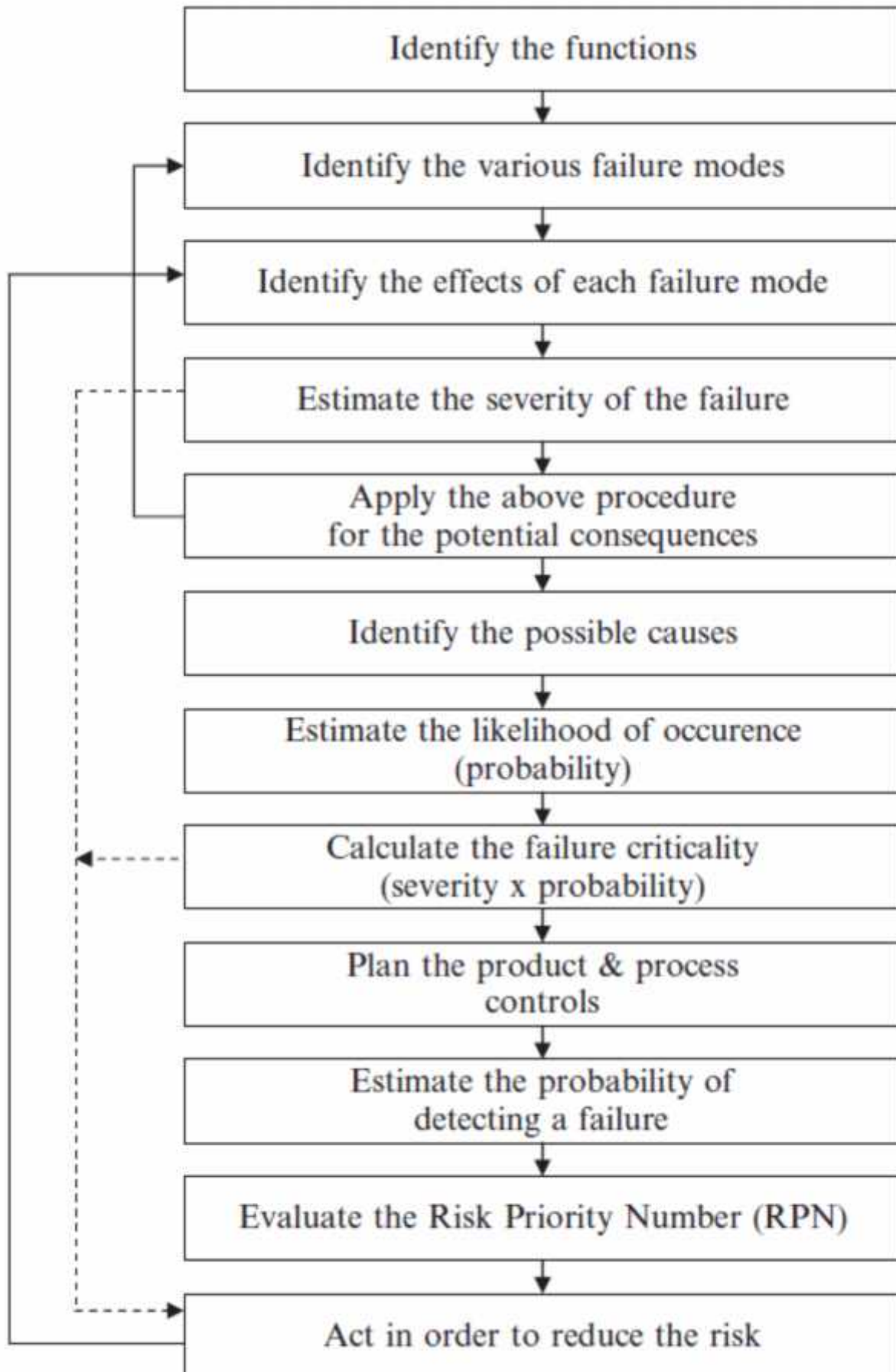
After identifying possible causes of failure and analysing their potential consequences, it is necessary to calculate the likelihood of failure occurrence, once again on a scale from 1 to 10 (1 being a fault occurring with a probability lower than 1/1,500,000 and 10 with a probability greater than 1/2).

When its criticality, namely the severity of failure multiplied by the likelihood of its occurrence, has been determined, it is time to define the tests to be carried out both on the product and on the process. There are three types of test: (1) type 1, to avoid the occurrence of a failure cause or mode, thus reducing the likelihood of failures, (2) type 2, to discover the cause of failure and define corrective actions, (3) type 3, to reveal failure modes before the product reaches the customer.

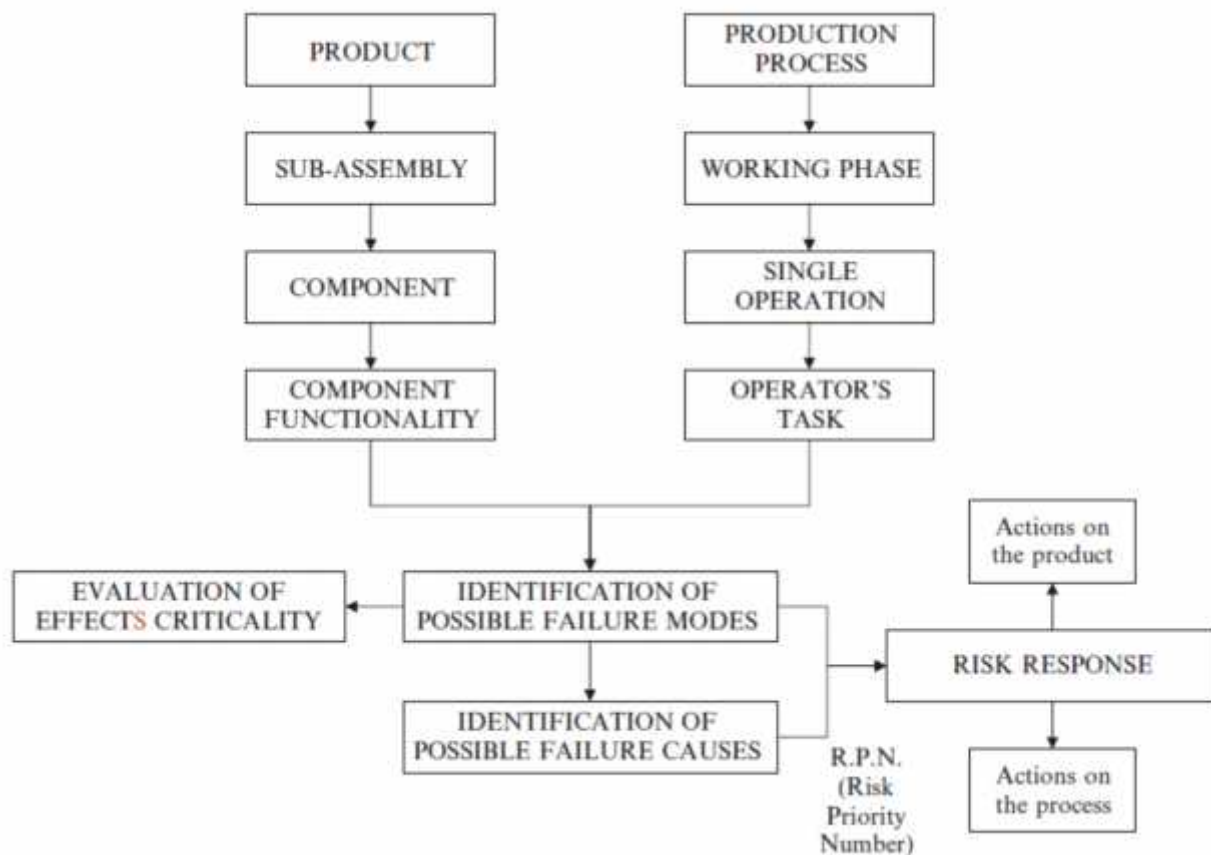
It is then necessary to estimate the probability of detecting a fault; the values, in this case, range from 1 (the test will nearly certainly reveal the potential cause of the failure or the consequent failure mode) to 10 (the test will probably fail to reveal the potential cause of failure and the consequent failure mode, or the test is not carried out).

The last step is to calculate the so-called Risk Priority Number (RPN), which is equal to the severity of failure multiplied by the probability of occurrence and the probability of interception, namely the possibility of identifying the cause of failure. RPN values range from 1 to 1,000: statistical data show that the average value is around 160, whereas only 6% of all indexes are higher than 500 (median: 105). FMEA should be performed both on the product and on the manufacturing process, as shown in Fig. IV.22.

FMEA can also be applied in the field of services; in this case, the RPN is calculated by multiplying the likelihood of a disservice by the criticality of its effects and the ability to detect it.



**Fig. IV.21** The Failure Mode and Effect Analysis (FMEA) methodology



**Fig. IV.22** Logical flow for FMEA

## IV.12 Risk Process

The risk and the possibility of suffering damage arising from circumstances that are more or less foreseeable.

The profit and loss account is one of the fundamental elements that determine the result of the job order; this means that the PM needs to know the details to calculate it and, during the job order process, must be able to foresee any corrective actions that may be needed to stay within the budget or improve the result itself. This is not really management of the profit and loss account but of the activities and phases that determine its result.

Consequently, the PM must be aware of the economic impact on the product line, caused by correct management of the job order; therefore, meetings are held periodically to define the general progress of the product line and the various business units to be able to set priorities and take general action. It is important to provide some definitions to help us understand the contents of analysis.

The presence of an economic job order element, considered as a cost, is determined in the JET tool, which contains all the analytical data to correctly monitor the progress of the job order. Splitting the contractual scope of supply into several components in order for production to determine the operating flows, identifies each item and its internal cost, which is the target cost of the project.

The offer review already takes into account the contractual critical points and therefore the first phase is considered to be complete, which is the phase that analyses the risks that could impact on

the commercial and technical part. This is not a detailed analysis but is based on first-phase experience and analysis of the technical features of the supply and is done by the people who participated in the REO.

Today, risk assessment needs to be more specific, structured and professional.

The human factor is very important and since a person in the company is aware of the risks, his/her attitude may influence the accuracy of risk perception as well as how he/she responds. An attempt must be made to create a homogeneous approach to risk management adapting it to the company's organisation based on relationships of trust where communication and decision-making are open and truthful since the answers to the risks are their own, showing how the organisation creates a balance between assuming and pre-venting the risk. The organisation must therefore be actively present for the entire stage of the project.

The risk process is a flow of activities that go from management planning and, through identification, quantitative and qualitative analysis, determine response planning by means of checking and monitoring.

Useful in analysis is a risk breakdown structure (RSB) of a project and its components such as organisational and technical aspects, external factors and finally Project Management.

We feel that financial risks are clearly highlighted and analysed by the financial department, which consequently dictates the guidelines for optimum management based on cash flow forecasts. The analysis of these risks can therefore be included in the general risk package of the job order that the PM will create or request.

For the technical part, the risks reach high levels of specificity because they generally concern equipment or plant performance, and therefore must be studied by the process experts and engineering firms possessing the specific know-how required to quantify and highlight them. These risks can have an economic impact on the job order's budget, and therefore the PM includes them in the contractual analysis.

Technical risks can be numerous. The most obvious is when, for example, the acceptance of certain contractual conditions is not standard but practically a target, which, although it has never been pursued in the past, we are certain we can reach. This is particularly applicable to machines with new engineering where technical design analysis combines theory and practical experience, producing a result that fulfils the customer's requirements.

Technical risk analysis is inevitable, clearly, for prototypes or improvements, which are necessary to the customer and which may occur. The making of tailor-made plants can increase the risk factor because they incorporate components that have not been fully proven.

The risks described earlier are to be considered internal risks and as such controllable by the PM. External factors are an important variable because they cover a wide range used by various company departments that have to deal with risks; these are non-controllable risks because they are affected by external factors such as politics and the market economy.

As for Project Management, we have to consider that the PM acts as coordinator and link within the company, carrying out functions such as estimates, planning and control. Therefore, we have to target risk verification and analysis more systematically due to the various problems that arise in the management of complex projects in difficult contexts and then analyse the various possible management methods that could be implemented depending on whether it is an LSTK (lump sum turnkey) contract or an EPC Contract.

Today, for example, the market also provides the possibility of analysing the production of large projects of customers, with longstanding industrial tradition in various countries of the world and where various contractual forms are used. This condition requires and necessarily involves excellent Project Management and risk management capabilities. Developing the capacity for analysis first of all within the company then allows you to be a contributor to the positive result of the Customer's investment.

When we start with analysis, we have to set a clear goal that is visible to every-one during the execution and production of the project. Our goal is to classify the types of risks that can arise during the execution of a project in order to systematically analyse risks and consolidate the feedback of past projects in an organised manner.

The field in which the Company operates can definitely propose different routes and specific analyses depending on the sector. In any case, if we begin with what typically constitutes a contract, we can try to first of all determine the possible risk areas to see if they need to be considered and classified immediately to be used in future valuations.

Let us take as an example the standard areas: Execution Risk, Project Environmental Risk, Technological Risks, Performance Risks, Personnel and Plant Integrity Risk, Time schedule Risks, Financial Risks, Economical risks.

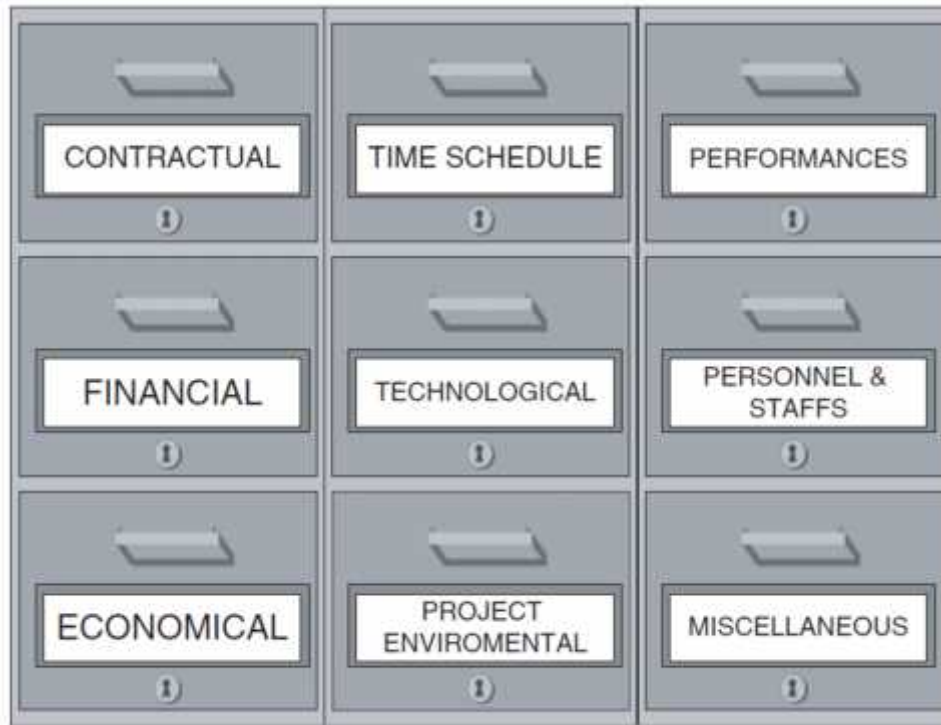
Putting all the possible risk areas on the table does not necessarily mean that each one of them has to be weighted in the analysis and thus have a specific valuation. A lot depends on how we decide to consider the contract and its possible impact on the company's profit and loss account. An analysis must definitely be done for projects that the company considers large and important for its products and image. Therefore, the areas we are going to examine in the risk analysis need to be shared/combined. In the chest of drawers as per Fig. IV.23, each drawer contains the elements required for our analysis.

Once we have determined and identified the risk sources, we will do another more thorough analysis based on significant risk sources whose occurrence is highly probable, that do not produce secondary/side effects, that have precise reference data, that have other contrasts and facilities, which all together have to constitute a sensibility analysis (Fig. IV.24). Considering the type of company activity, we will create two main risk classes and groups, i.e. repetitive and non-repetitive.

The former can be identified during the offer phase and in the initial project phases and can be run by establishing repetitive strategies according to the type of risk.

Non-repetitive risks are clearly more difficult to identify and manage since they can occur in each executive phase of the project and the signs indicating their presence are often weak. In this case, it is the people involved in the project, who, with their management experience, can ensure early identification and effective management.

It is therefore up to Project Management to assume the main responsibilities for the management of these risks. It is therefore important to be a Project Manager who is more and more sensitive and able to properly identify and manage project risks, as well as applying effective control methods with the participation of company structures in those project events that require solving of risks.



**Fig. IV.23** The *risks* chest of drawers

### **IV.13 Risk Evaluation**

To analyse risk management, we have to necessarily monitor project risks through actions that are important in the first phase of the analysis and then in all the other project phases, identifying possible upsetting events, analysing the extent of their consequences, evaluate and apply the most suitable procedures. This is all done for the purpose of minimising the results arising from negative events and maximising the results arising from positive events.

After having established a technical risk monitoring process we can use a flow chart to guide us in the various initial planning stages, where, as already mentioned, we will have to identify and describe possible risk events, assess and determine the importance and extent of possible risk events, plan and define actions and prepare a risk plan.

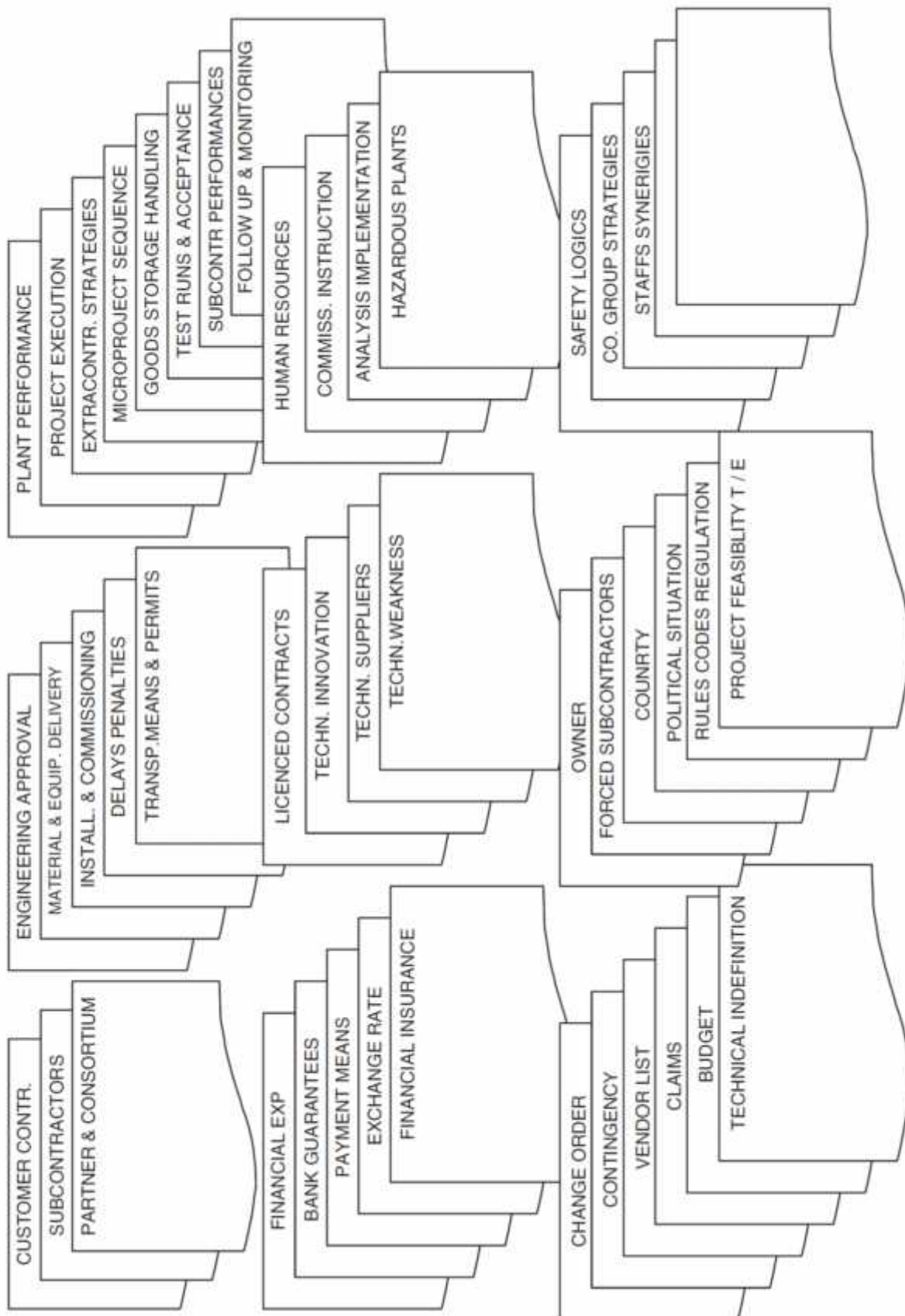


Fig IV.24 Risk detail folders

During work progress, we will have to set up actions and update the risk plan. The risk assessment stage aims to calculate the extent of possible consequences and will therefore have two parts: quality-based to classify the significance of the risk and quantity-based to determine the extent of the risk itself.

The goal is to create a risk exposure matrix through actions focusing on so-called key risks, so that the matrix is able to support the definition of more effective intervention strategies, and to define the classification criteria of the significance of risk-related consequences.

The following Table IV.2 gives a base representation of how we could summarise and group the possible risk items. This will all be entered in a matrix, which will have the characteristics shown in Table IV.3.

| Conditions to define impact scale on principal target of project (negative impact) |                               |                               |                                                |                                  |                               |
|------------------------------------------------------------------------------------|-------------------------------|-------------------------------|------------------------------------------------|----------------------------------|-------------------------------|
| Project target                                                                     | Very low                      | Low                           | Medium                                         | High                             | Very high                     |
| Financial cash flow                                                                | Financed                      | LC (letter of credit)         | Mix LC/TT (letter of credit, telegr. transfer) | PN (promissory notes)            | TT (Telegr. transfer cash)    |
| Costs                                                                              | Not significant cost increase | Cost increase CI < 10%        | Cost increase 10 < CI < 15                     | Cost increase 15 < CI < 30       | Cost increase CI > 30%        |
| Time                                                                               | Not significant cost increase | Time increase TI < 5%         | Time increase 5 < TI < 10                      | Time increase 10 < TI < 15       | Time increase TI > 15%        |
| Innovation technology                                                              | Typical product               | Common ready                  | Common tailor-made                             | Research department. New project | Unknown technology to acquire |
| Quality                                                                            | DWS 100%                      | DWS 50%<br>DFE 25%<br>DME 25% | DWS 20%<br>DFE 20%<br>DME 20%<br>EXT 40%       | EXT 80%                          | Unknown Supplier<br>EXT > 80% |

**Table IV.2** Risk definition

| Matrix of probability and impact |       |    |    |    |    |             |    |    |    |     |
|----------------------------------|-------|----|----|----|----|-------------|----|----|----|-----|
| Probability                      | Risks |    |    |    |    | Opportunity |    |    |    |     |
| 90                               | 5     | 10 | 20 | 40 | 80 | 80          | 40 | 20 | 10 | 5   |
| 70                               | 4     | 8  | 16 | 32 | 64 | 64          | 32 | 16 | 8  | 4   |
| 50                               | 3     | 6  | 12 | 24 | 48 | 48          | 24 | 12 | 6  | 3   |
| 30                               | 2     | 4  | 8  | 16 | 32 | 32          | 16 | 8  | 4  | 2   |
| 10                               | 1     | 1  | 2  | 4  | 8  | 8           | 4  | 3  | 1  | 1   |
|                                  | 0.5   | 10 | 20 | 40 | 80 | 80          | 40 | 20 | 10 | 0.5 |

Impact (ratio scale) on a goal (i.e. cost, time, quality)

**Table IV.3** Matrix of probability

The area shaded in dark grey represents the highest risk, and that in light grey with the low numbers represents the lowest risk. We can therefore assign a numerical value to each goal.

Numerical scale representation can be done in a linear fashion such as 1, 3, 5, 7, 9, or a non-linear fashion such as 0.5, 1, 2, 4, 8. By means of a non-linear scale, we aim to avoid high-impact risks to try and take advantage of opportunities with high impact even with low probability of occurrence. The more complex use of non-linear scales requires more detailed knowledge of the meaning of each numerical value and the reciprocal relations (Table IV.4). In the same way, we can linearise the values of the elements to be analysed in the project and, while maintaining the critical perspective of the table, we can have a graphical representation such as the one in the figure where the major critical points are shown, which need to be migrated to more manageable areas.

The quality check is shown on a matrix-based graph represented in Fig. IV.25

In making decisions, various solutions are applied, such as the decisional criterion of probability, which associates to each system status the corresponding probability of occurrence.

We will then have to introduce an executive procedure to assist us in making decisions through a diagram that defines a decision tree showing circumstances, decisions, events, probabilities, terminal nodes – all connected to definable routes. In creating a structured risk analysis we will try to provide the company with simulation techniques to properly quantify the risks with a risk assessment tied to a time variable and by checking the effects on the entire duration of the project (or intermediate phases) of alternative work cases applied to the project grid.

Therefore, in applying alternative hypotheses we could take various routes that hook up to the grid resolution in PERT if it was used for planning. We also have to prepare a questionnaire (for each type of project) containing the main risk sources, components of each source, the variables that characterise each component and the dimensioning metric of each variable. We could, for example, consider the total risk assessment of a project, consisting in the supply of a finishing line for a bar rolling mill supplied by one of the companies of the group (Table IV.5). This is also applicable to all the other components in order to obtain the project risk RADAR program configuration as the sample in Fig. IV.26.

| Conditions to define impact scale on principal target of project (negative impact) |                     |                     |                     |                     |                     |
|------------------------------------------------------------------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|                                                                                    | Project 1<br>Target | Project 2<br>Target | Project 3<br>Target | Project 4<br>Target | Project 5<br>Target |
| Financial                                                                          | 4                   | 32                  | 20                  | 10                  | 24                  |
| Costs                                                                              | 12                  | 4                   | 64                  | 16                  | 48                  |
| Time                                                                               | 40                  | 12                  | 16                  | 16                  | 24                  |
| IT                                                                                 | 2                   | 8                   | 16                  | 4                   | 6                   |
| Quality                                                                            | 2                   | 2                   | 2                   | 8                   | 16                  |
| Total mark                                                                         | 60                  | 58                  | 118                 | 52                  | 128                 |

**Table IV.4** Risk impact scale condition

|             | % BAC   |
|-------------|---------|
| WORST       | > 40    |
| CRITICAL    | 20 - 40 |
| HEAVY       | 10 - 20 |
| SECONDARY   | 5 - 10  |
| NEGLILGIBLE | < 5     |

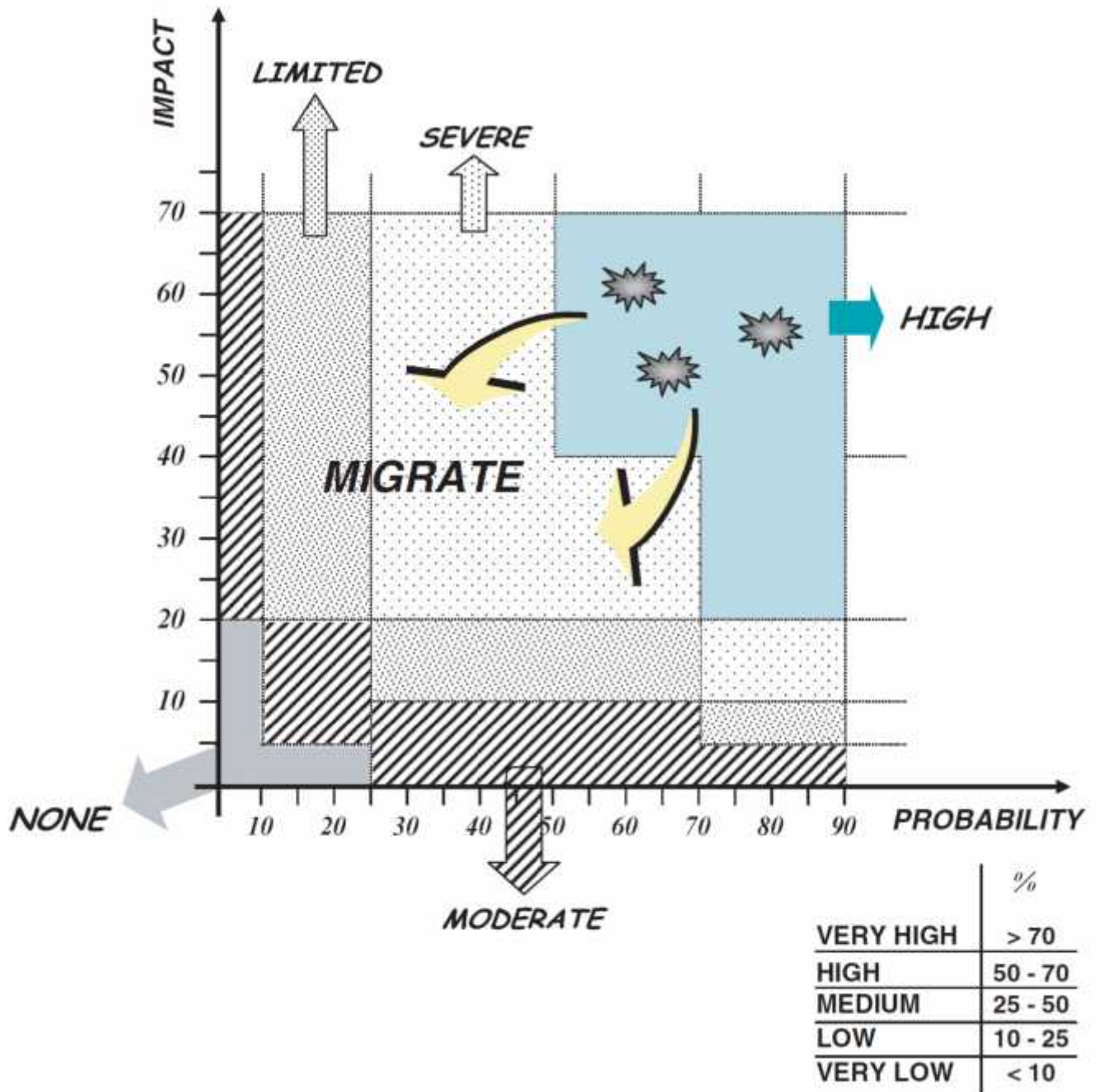


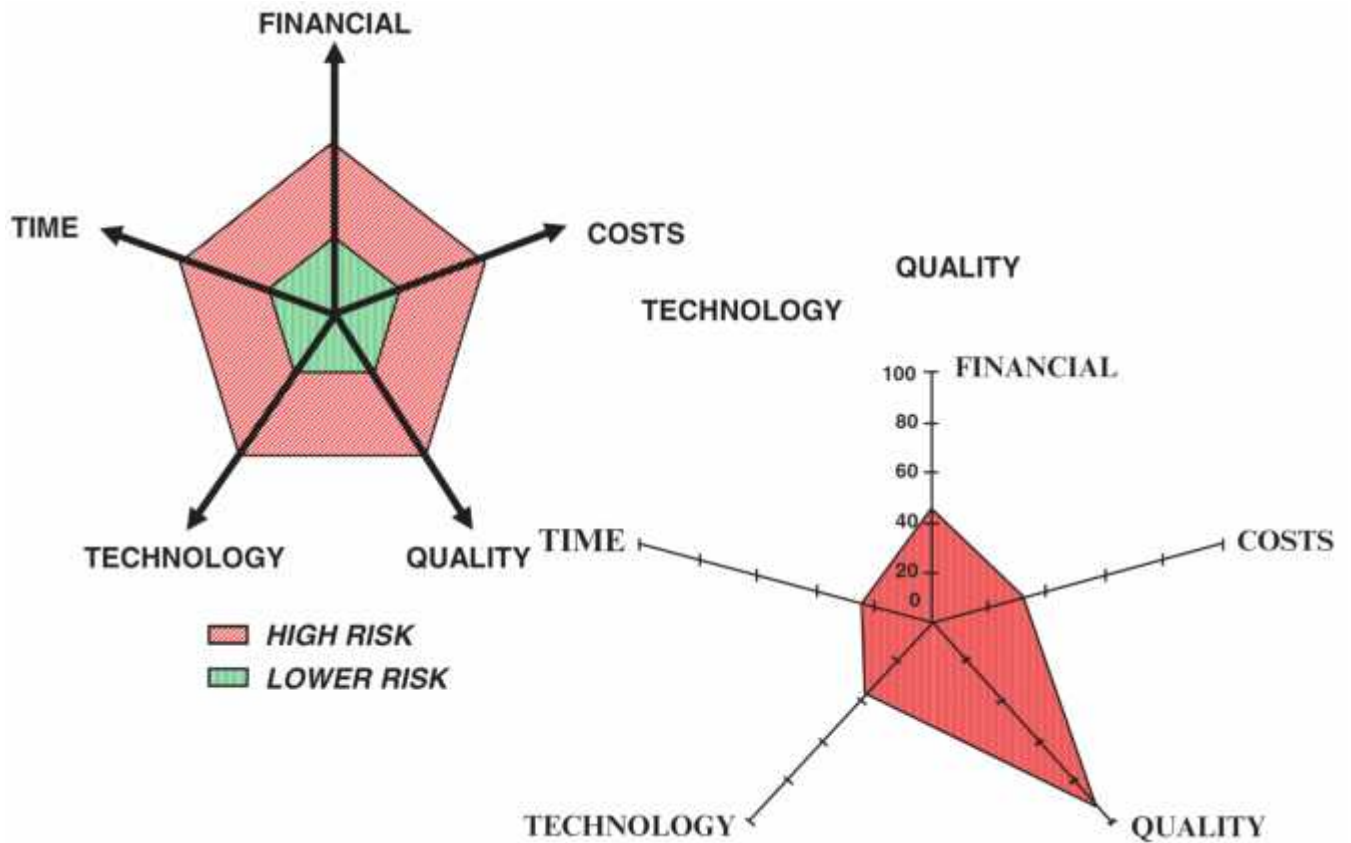
Fig.IV.25 Matrix of risks

## IV.14 Risk Monitoring

The specific analysis of technical risks must refer to the supply; project data must be checked, such as output, types of steels, types of finished products, standards and non-standard supplies to identify details, vendor list, the features of the foundations and buildings, type of installation, supervision and startup.

| Definition of components and variables |                                                                                                                                                                                                                                                                                                                                                                                                |
|----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Components                             | Variables                                                                                                                                                                                                                                                                                                                                                                                      |
| Financial                              | <ul style="list-style-type: none"> <li>• Down payment</li> <li>• Progress payments by event</li> <li>• Payment at goods readiness</li> <li>• Payment at delivery DDP</li> <li>• Payment at hot startup</li> <li>• Payment at FAC</li> <li>• Exchange rate</li> <li>• Payment and performance bond</li> <li>• Penalty for late delivery DDP</li> <li>• Penalties for performances</li> </ul>    |
| Time                                   | <ul style="list-style-type: none"> <li>• Delivery engineering</li> <li>• Receiving rough material first lot</li> <li>• Preliminary foundation engineering</li> <li>• Final foundation engineering</li> <li>• Receiving main rough material second lot</li> <li>• Equipment ready for shipment</li> <li>• Delivery equipment DDP</li> <li>• Hot Startup</li> <li>• Finale Acceptance</li> </ul> |
| IT                                     | <ul style="list-style-type: none"> <li>• Production round, angle, channel</li> <li>• Performance on angle, channel, flat, round, rebar</li> <li>• Productivity CLS of stacker</li> <li>• Cut shear tolerance</li> <li>• Straight tolerance</li> <li>• Bundles head alignment</li> </ul>                                                                                                        |

**Table IV.5** Risks: definition of variables



**Fig IV.26** Radar risk configuration

Risk or project analysis is continuously evolving and requires continuous improvement in project risk management. So to keep the process and the analysis structure active, one strategy is to hold regular project review sessions on the analysis and management of project risks. The lessons learned aim to improve the company production cycles and project management methods and cross-referencing of management experiences for the project.

Typical project review sessions are as follows: Project staff meetings are held regularly every 1 or 2 months during the life of the project; it is attended by General Management (DG), the project manager (PM) with some people of the project group (GdP) and the managers of all company structures. In this session, the PM explains the executive status of the project and the risks, and requests any exceptional interventions.

This is the moment of truth avoiding among the liars around the table, where any unclear situations (lies) emerge, on the status of the production cycles and management strategies in order to define realignment actions.

The information exchanged and the decisions made are recorded in minutes of meeting, which are distributed to all the concerned sectors and which will eventually make up the daily project log, which can be consulted at the end for a final review.

Project risk checkpoints are specific project review sessions requested by the project manager when he/she feels that the status of the project requires a cold eye analysis by a group of experts outside the Project Group made up of other PMs and company managers.

The post-project review meeting is held at the end of the project where the PM reassumes the risk areas found during project development, expresses his/her opinion on the final results and uses them as lessons learned, in terms of both positive examples to be copied and negative examples to be avoided. The post-project review is organised according to an agenda that allows you to feed a company database with the risks managed during projects.

In this database we also have to consider the levels at which these subjects have been handled, with high and medium risks generally discussed in detail, while for the minor risks, a periodically updated watch list would be sufficient.

Often, in the execution of particularly complex projects, there are risks triggered by production processes that are no longer suitable and by improper management of customer relations. When these issues become generalised or occur repeatedly, a specific session is held before the project is completed. Only management times are analysed in these sessions for the purpose of identifying general solutions that could entail modifications to the production processes and company organisations.

The decisions that are made become operative for all new projects.

These extraordinary meetings identify general solutions for risks that tend to become repetitive, improve company processes through lessons learned and support the exchange of experience among GdPs.

The database referred to in the analysis becomes a register of the risks that arise during identification, which are mainly as follows:

- Identified risks, description of risks, concerned project areas, relative causes and influence on project goals
- Risk holders and assignment of responsibilities
- Output from quantitative and qualitative analyses with priorities and probabilities of occurrence
- Agreed response strategies
- Specific actions to develop the selected response strategy
- Establishing symptoms and warning signals for possible risk occurrence
- Budget and planned activities required to fulfil action strategies
- Contingency reservations in terms of time and costs with corresponding plans
- Reserve plans to be used as risk reaction for unsuitable response
- Residual risks together with those accepted together
- Collateral risks occurring after the application of a solution
- Contingency reservations calculated in terms of project quality

In conclusion, the goal of the described process is to feed a virtuous corporate circle that can be summarised as follows. Improve the company's ability to identify and manage project risk and increase confidence in pursuing new opportunities. This virtuous circle is simplified in Fig. IV.27 in which, starting any point of the circle, we can transfer each other's experience, having a continuous improvement in the risk evaluation and minimising as much as possible the impacts.

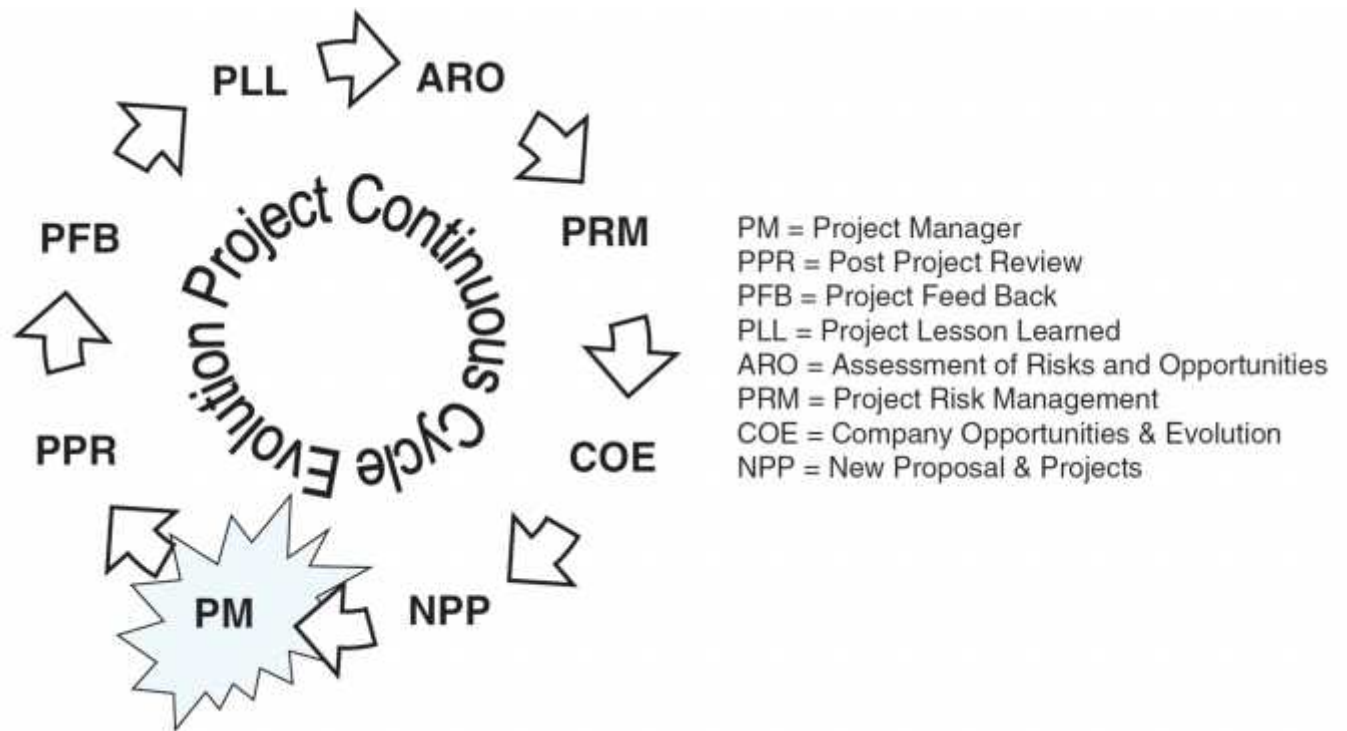
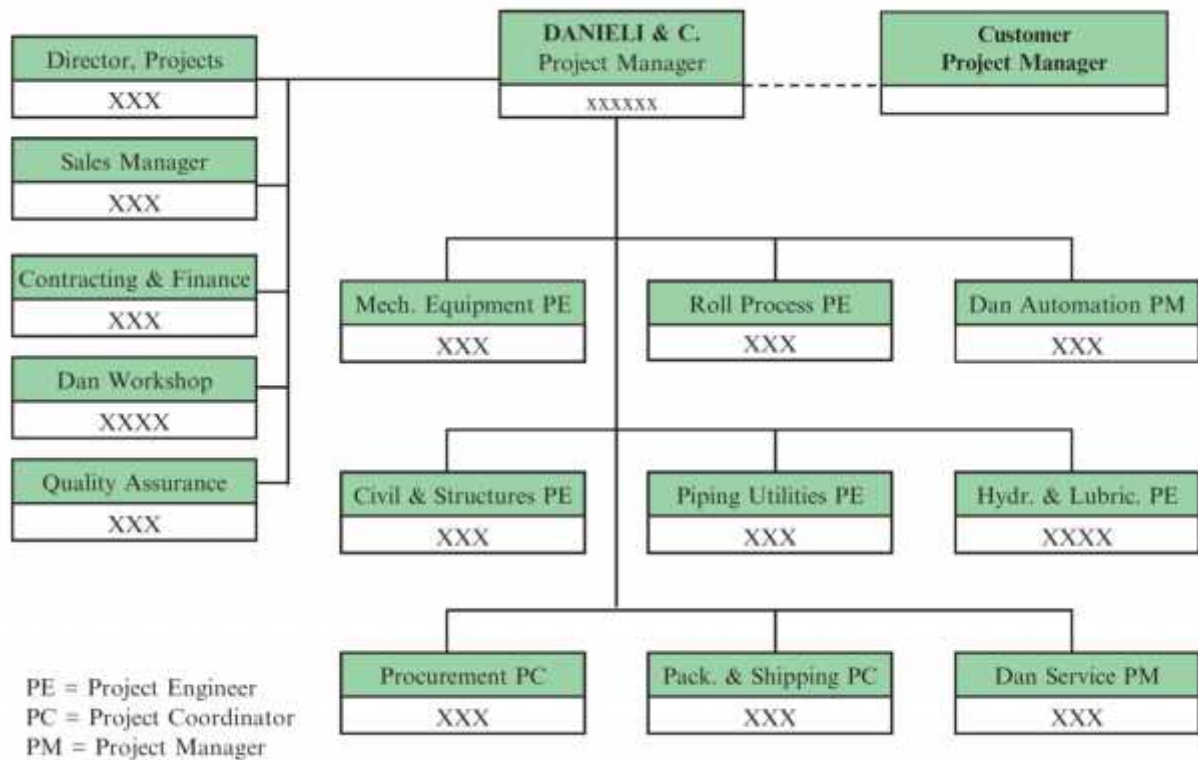


Fig. IV.27 The virtuous circle

## Conclusion

- Project management stands at the intersection of strategy, organization, and innovation. It equips future engineers and managers with the ability to transform ideas into structured and achievable objectives. Throughout this course, students acquire not only the theoretical foundations of project management but also practical competencies that are essential in professional environments, such as planning, resource allocation, risk mitigation, communication, and leadership.
- Moreover, the course emphasizes adaptability in a world where projects are increasingly complex, multidisciplinary, and technology-driven. By integrating modern approaches and international standards like PMI and PRINCE2, students learn to manage uncertainty, foster teamwork, and ensure continuous improvement.
- Ultimately, this course aims to prepare students to become proactive and responsible project leaders, capable of driving innovation while ensuring efficiency, quality, and sustainability across all phases of a project's lifecycle.

Some issues relevant to the management can be represented by pictures that are commonly used as samples. Here are some spot images (Figs. A.1–A.11, Tables A.1–A.4).



**Fig. A.1** Project organization chart – a common chart that gives the typical tree organisation of team key personnel for a TK project

[illegible]

**Fig. A.2** Open package inspection – discovering the missing pieces and looking for the right label

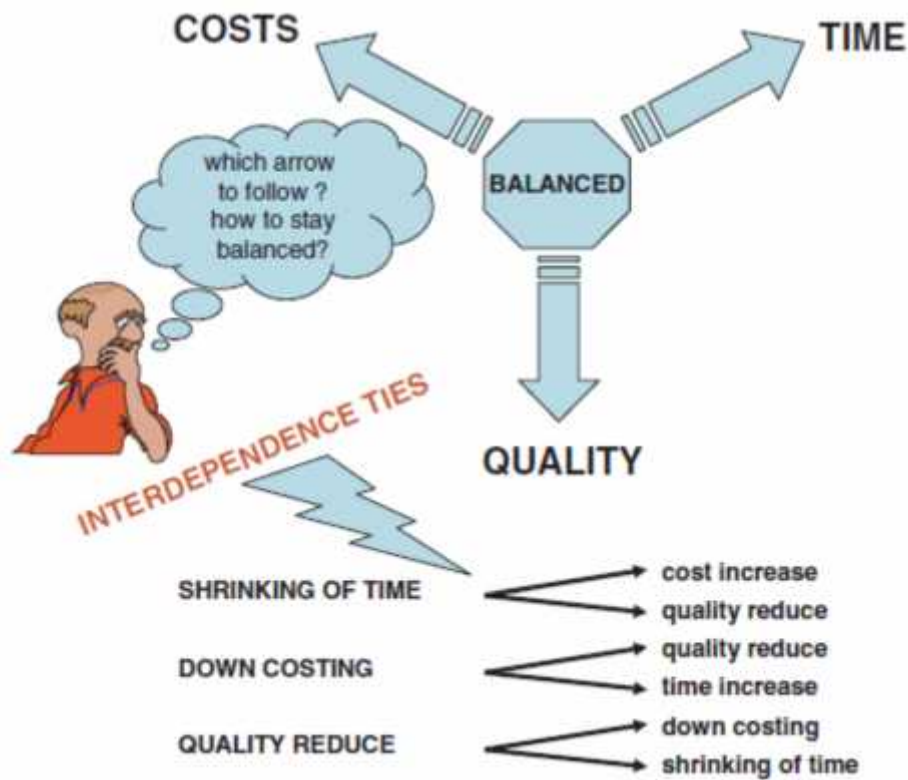


Fig. A.3 The tensor of ties – which arrow to follow? how to stay balanced?



Fig. A.4 The player scheme – looking around the project

[illegible]

**Fig. A.5** Risk plan – summary table to report how we are going

## The “top-ten” of Project Management

- ↓ To agree the targets (time, costs and quality)
- ↓ To delagate the responsibility
- ↓ To fix key meetings
- ↓ To spread the information regularly with lucidity
- ↓ To record the progress without derogation
- ↓ Constant verification of budget
- ↓ To contest the modifications (without be inflexible)
- ↓ Do not hide the problems, tackle it today...
- ↓ ...tomorrow will be greater, because:



**if something can go wrong, it will !!!**

Fig. A.6 Top ten – keep it in mind

an overall job report to have an overview of the ongoing projects

Time Now

| JOB CODE | TIME              | COSTS |  |  |  |             | INCOMING |       |               |                         |                     |        |       |                              |
|----------|-------------------|-------|--|--|--|-------------|----------|-------|---------------|-------------------------|---------------------|--------|-------|------------------------------|
| XXXXXX   | CONTRACTUAL       | D.P.  |  |  |  | TOT. BUDGET | USED     | TO GO | UP COMPLETION | DELTA %                 | FORECAST UP TO DATE | CASHED | DELTA | FORECAST DATE FOR RECOVERING |
|          | REAL / EXTIMATION |       |  |  |  | a           | b        | c     | (b + c)       | $\frac{(b + c) - a}{a}$ | a                   | b      | a - b | (if DELTA < 0)               |
| WWWWWW   | REAL / EXTIMATION | D.P.  |  |  |  | TOT. BUDGET | USED     | TO GO | UP COMPLETION | DELTA %                 | FORECAST UP TO DATE | CASHED | DELTA | FORECAST DATE FOR RECOVERING |
|          |                   |       |  |  |  | a           | b        | c     | (b + c)       | $\frac{(b + c) - a}{a}$ | a                   | b      | a - b | (if DELTA < 0)               |
| ZZZZZ    | REAL / EXTIMATION | D.P.  |  |  |  | TOT. BUDGET | USED     | TO GO | UP COMPLETION | DELTA %                 | FORECAST UP TO DATE | CASHED | DELTA | FORECAST DATE FOR RECOVERING |
|          |                   |       |  |  |  | a           | b        | c     | (b + c)       | $\frac{(b + c) - a}{a}$ | a                   | b      | a - b | (if DELTA < 0)               |

Fig. A.7 Summary report – to have an overview of the ongoing projects

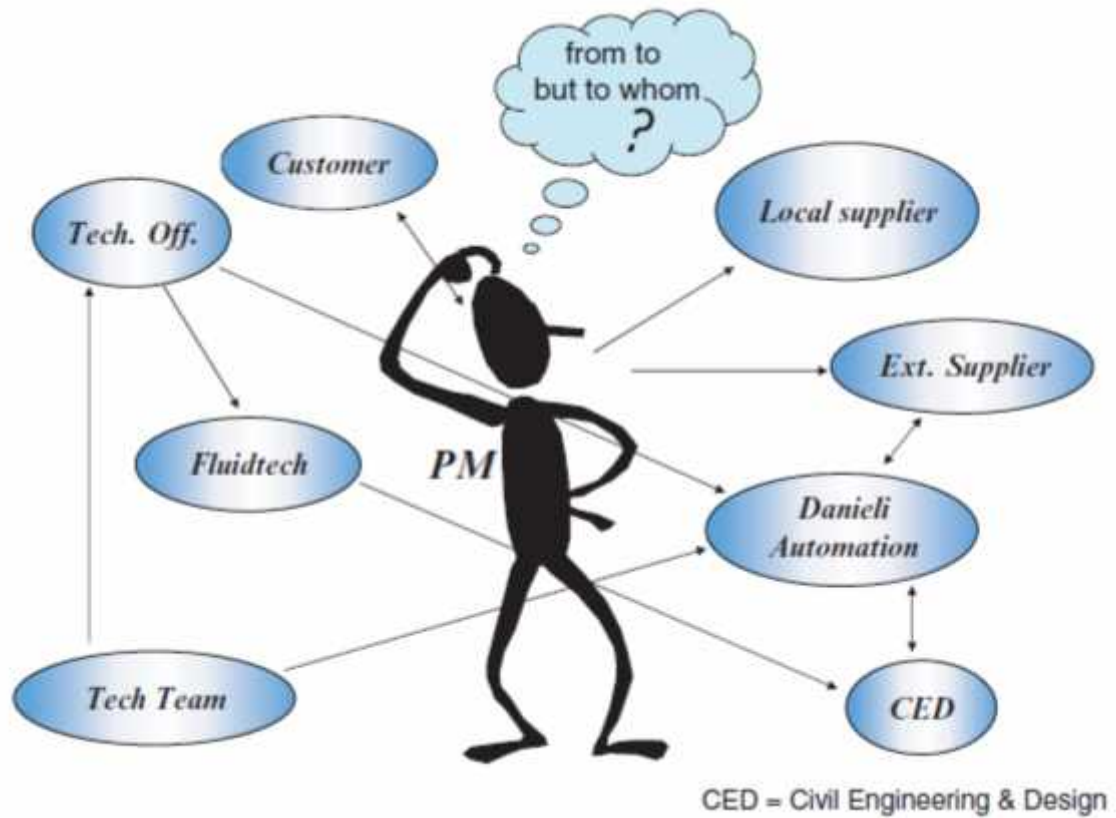


Fig. A.8 Engineering document – from to but to whom

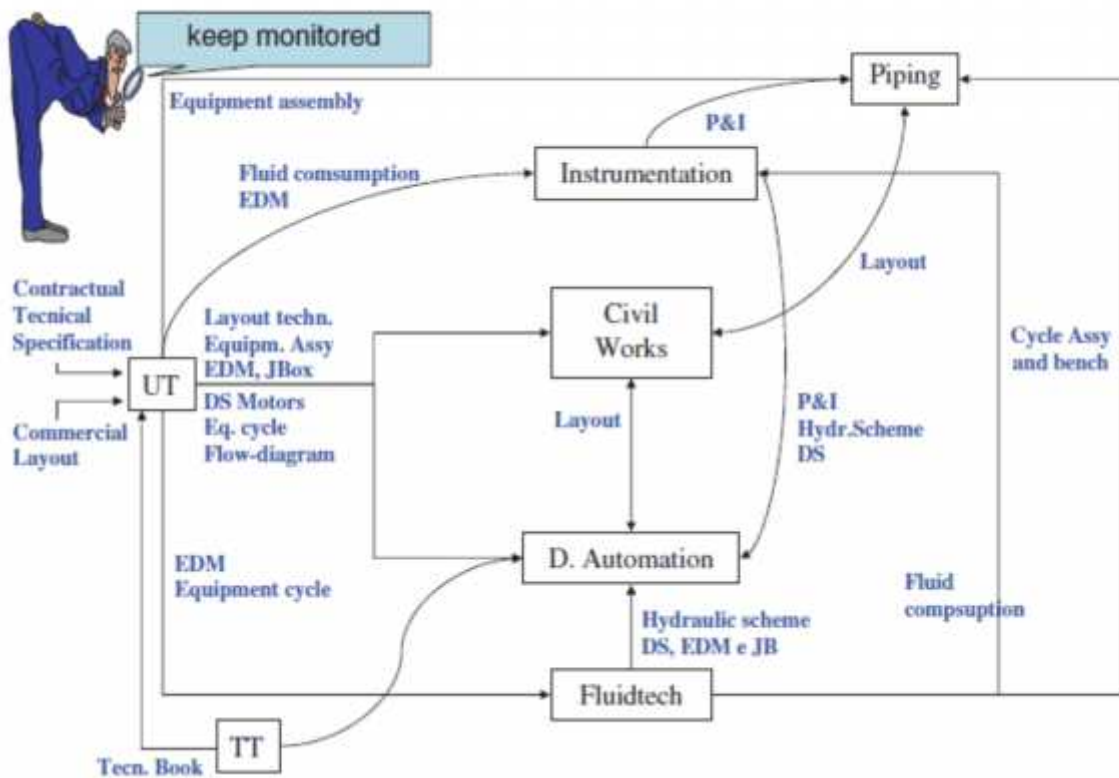


Fig. A.9 Between technical offices – keep monitored

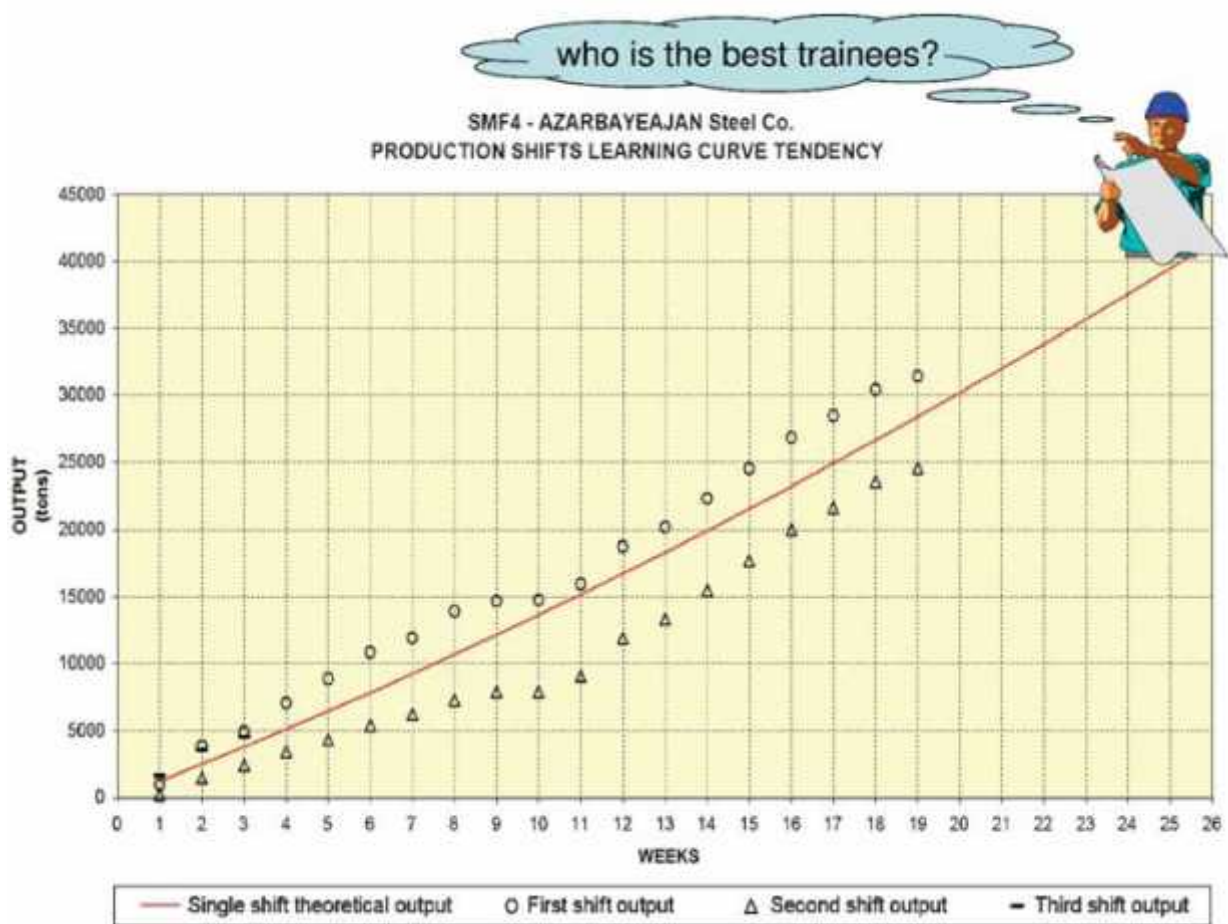


Fig.A.10 Learning curve diagram – who is the best trainee?

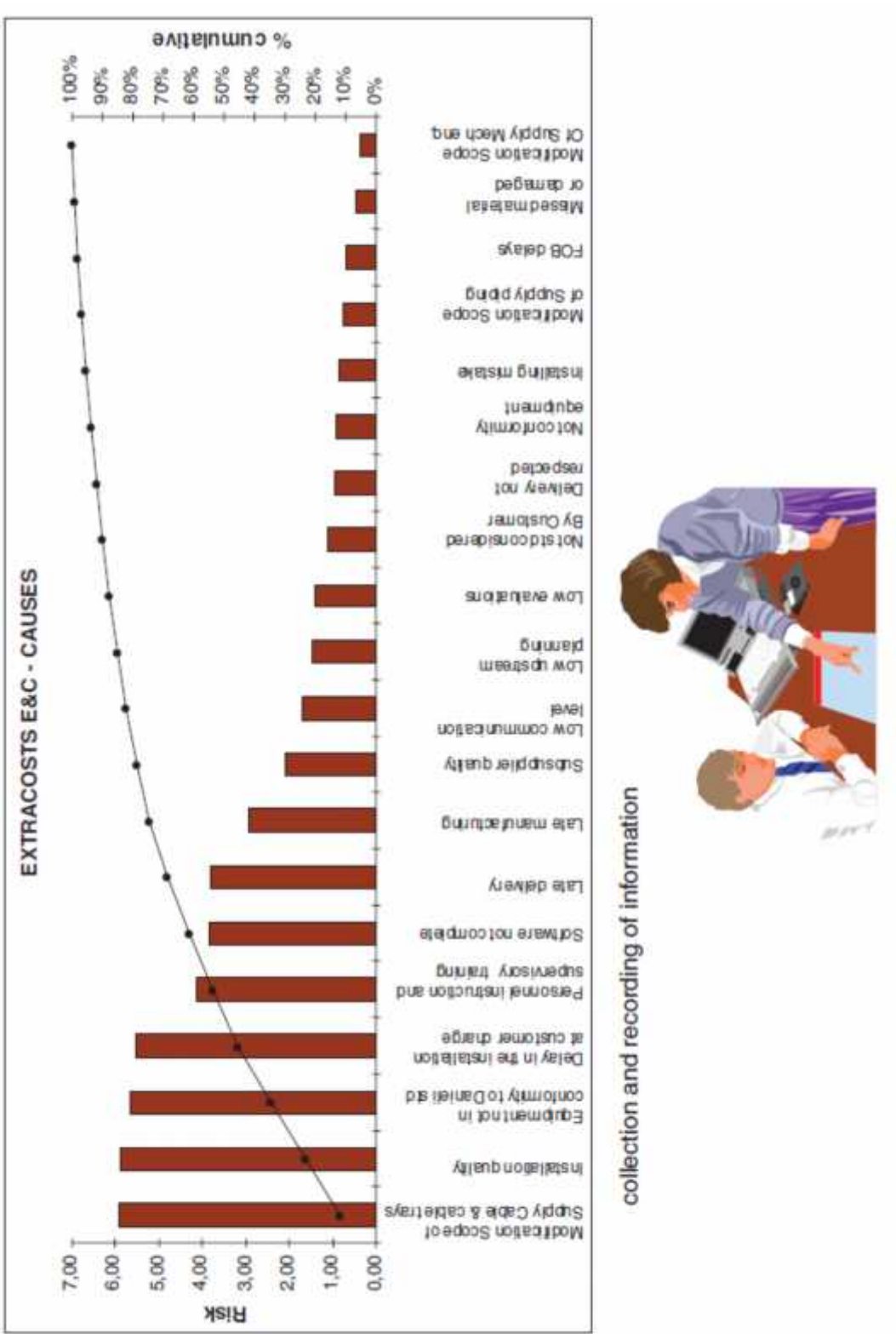


Fig. A.11 Risks in the erection & commissioning – collection and recording of information

|     | LOADING ON TRUCK | EXPORT CUSTOMS FORMALITIES | CARRIAGE TO PORT OF DEPARTURE | UNLOADING FROM TRUCK AT PORT OF DEPARTURE | LOADING CHARGES AT PORT OF DEPARTURE | CARRIAGE TO PORT OF DESTINATION | UNLOADING CHARGES AT PORT OF DESTINATION | LOADING ON TRUCK AT PORT OF DESTINATION | CARRIAGE TO FINAL DESTINATION | INSURANCE | IMPORT CUSTOMS FORMALITIES | IMPORT TAXES AND DUTIES |
|-----|------------------|----------------------------|-------------------------------|-------------------------------------------|--------------------------------------|---------------------------------|------------------------------------------|-----------------------------------------|-------------------------------|-----------|----------------------------|-------------------------|
| EXW | NO               | NO                         | NO                            | NO                                        | NO                                   | NO                              | NO                                       | NO                                      | NO                            | NO        | NO                         | NO                      |
| FCA | YES              | YES                        | YES                           | NO                                        | NO                                   | NO                              | NO                                       | NO                                      | NO                            | NO        | NO                         | NO                      |
| FAS | YES              | YES                        | YES                           | YES                                       | NO                                   | NO                              | NO                                       | NO                                      | NO                            | NO        | NO                         | NO                      |
| FOB | YES              | YES                        | YES                           | YES                                       | YES                                  | NO                              | NO                                       | NO                                      | NO                            | NO        | NO                         | NO                      |
| CFR | YES              | YES                        | YES                           | YES                                       | YES                                  | YES                             | NO                                       | NO                                      | NO                            | NO        | NO                         | NO                      |
| CIF | YES              | YES                        | YES                           | YES                                       | YES                                  | YES                             | NO                                       | NO                                      | NO                            | YES       | NO                         | NO                      |
| CPT | YES              | YES                        | YES                           | YES                                       | YES                                  | YES                             | NO                                       | NO                                      | NO                            | NO        | NO                         | NO                      |
| CIP | YES              | YES                        | YES                           | YES                                       | YES                                  | YES                             | NO                                       | NO                                      | NO                            | YES       | NO                         | NO                      |
| DAF | YES              | YES                        | YES                           | YES                                       | YES                                  | YES                             | NO                                       | NO                                      | NO                            | NO        | NO                         | NO                      |
| DES | YES              | YES                        | YES                           | YES                                       | YES                                  | YES                             | NO                                       | NO                                      | NO                            | NO        | NO                         | NO                      |
| DEQ | YES              | YES                        | YES                           | YES                                       | YES                                  | YES                             | YES                                      | NO                                      | NO                            | NO        | NO                         | NO                      |
| DDU | YES              | YES                        | YES                           | YES                                       | YES                                  | YES                             | YES                                      | YES                                     | YES                           | YES       | NO                         | NO                      |
| DDP | YES              | YES                        | YES                           | YES                                       | YES                                  | YES                             | YES                                      | YES                                     | YES                           | YES       | YES                        | YES                     |

|     |     |     |      |     |
|-----|-----|-----|------|-----|
| EXW | FCA | FAS | FOB  | CFR |
| CIF | CPT | CIP | DAF  | DES |
| DEQ | DDU | DDP | HOME |     |

EXW ex-works, FOB free on board FCA free carrier, FAS free alongside ship, CFR cost and freight, CIF cost, insurance and freight, CPT carriage paid to, DAF delivered at frontier, DES delivered ex ship, DEQ delivered ex quay, DDP delivered duty paid, DDU delivered duty unpaid

Table A.1 INCOTERMS 2000 – what does it mean?

|                |                                         |  |                      |  |
|----------------|-----------------------------------------|--|----------------------|--|
| <b>DANIELI</b> | <b>CHANGE / DEROGATION REQUEST FORM</b> |  |                      |  |
|                | <b>Project name :</b>                   |  | <b>Project ref :</b> |  |
|                | <b>Date of opening :</b>                |  | <b>Sheet # :</b>     |  |

|                                 |                                              |                                                |                                                   |
|---------------------------------|----------------------------------------------|------------------------------------------------|---------------------------------------------------|
| <b>Modification demanded by</b> | <input checked="" type="checkbox"/> Customer | <input type="checkbox"/> Sub-contractor: ..... | <input type="checkbox"/> Danieli internal : ..... |
|                                 | <input type="checkbox"/> Customer's engineer | <input type="checkbox"/> Co-contractor : ..... | <input type="checkbox"/> Other: .....             |

**MODIFICATION REQUEST SOURCE** with references of the documents : mail, meeting minutes...

**REMINDER OF SERVICES PROVIDED FOR IN CONTRACT** with references of contractual documents :

**DESCRIPTION OF THE REQUESTED MODIFICATION:**

**TECHNICAL/COST CONSEQUENCES** (list each time the references of affected documents and, for installation, the concerned zone)

| Studies | Supplies / Spare parts | Installation | Tests / Performances | Delay |
|---------|------------------------|--------------|----------------------|-------|
|         |                        |              |                      |       |

| WRITER of the sheet |             | PROJECT MANAGER SIGNATURE |             |
|---------------------|-------------|---------------------------|-------------|
| Name :              | Entity :    | Name :                    | Entity :    |
| Function :          | Signature : | Function :                | Signature : |

|                                   |                                           |                                             |                                            |                                           |                           |
|-----------------------------------|-------------------------------------------|---------------------------------------------|--------------------------------------------|-------------------------------------------|---------------------------|
| <b>Project manager's decision</b> | External circulation to :<br>Date : ..... | For observation<br><input type="checkbox"/> | For acceptance<br><input type="checkbox"/> | Internal circulation to :<br>Date : ..... | Actions to be conducted : |
|                                   |                                           | <input type="checkbox"/>                    | <input type="checkbox"/>                   |                                           |                           |
|                                   |                                           | <input type="checkbox"/>                    | <input type="checkbox"/>                   |                                           |                           |
|                                   |                                           | <input type="checkbox"/>                    | <input type="checkbox"/>                   |                                           |                           |

|                                                         |                                                            |
|---------------------------------------------------------|------------------------------------------------------------|
| Acceptance decision / External addressee's observations | Company :<br>Name :<br>Function :<br>Date :<br>Signature : |
|---------------------------------------------------------|------------------------------------------------------------|

Table A.2 Derogation form – check and authorize

[illegible]

**Table A.3** Macroplanning general table – looking for the future

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