1

Case Study-based Design Methodology

1.1. Methodology for designing a project product

"Methodology" should be taken to mean the preparation of an exhaustive file of the steps that must be followed at a research center. That file will contain the data defining the product, right down to the expression defining the need for it.

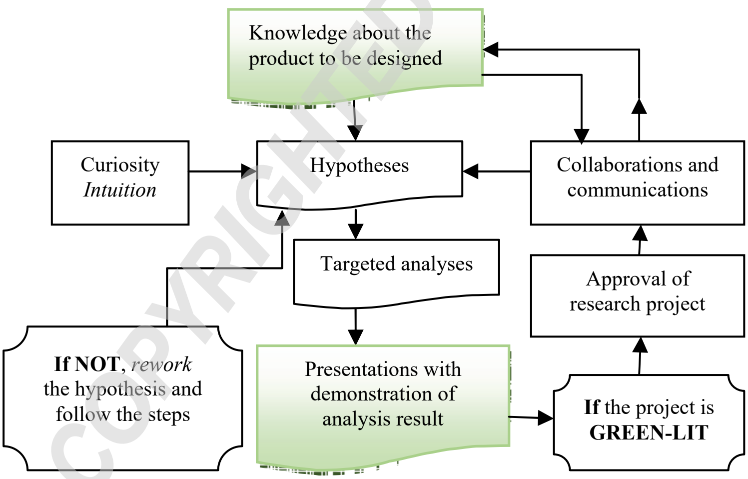

Figure 1.1. *Scientific approach to design*

The scientific approach is named as such because of the dissatisfactions pertaining to fields not explored by the core sciences. If the subject is unique or original, in collaboration between multiple disciplines, new hypotheses may be formulated and patented. Thus, the state of the art will be enriched.

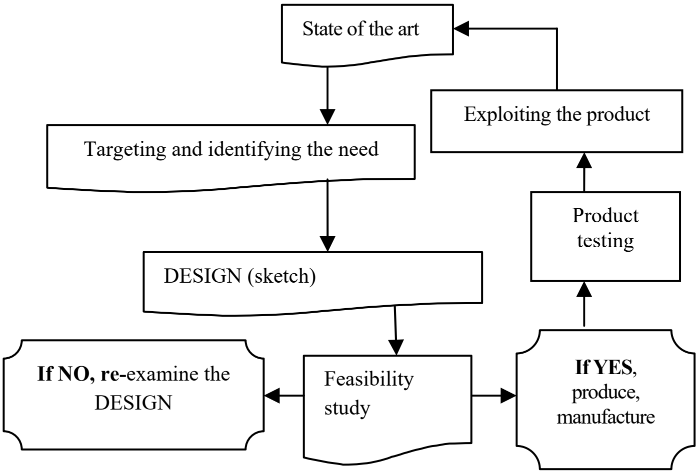

Figure 1.2. *Process of a design project*

Given the multi-disciplinarity (fields of mechanics, pneumatics, hydraulics, electronics, etc.) of subjects which encapsulate design and vast domains of application (the manufacturing industry, agriculture, civil and/or military construction, biomechanics, automotive engineering, aeronautics, etc.) in this book, we present examples found in systems in mechanical and civil engineering. The mathematical foundations are common to the two domains, but the behavior of the materials and structures sometimes differ.

We can already see that design is hugely complex. A designer must have good knowledge of numerous branches of science and technology, in addition to a keen sense of the dual organization of good intuition. The project approach is less stressful because the client will have clearly expressed their requirements at the outset. Solutions will be put forward with the aim of satisfying the requirements, in connection with the technical and economic feasibility. Once the designer has accepted the project to conduct manufacturing studies, tests will be carried out. If the result is a conclusive approval, then the product will be made and potentially released to the public.

1.2. Main players involved in the design process

Design projects are studied in a research hub (RH). Thus, the RH is an entity which is often complex, the size of which is subject to variation from one company to another. The teams employed at RHs are multi-disciplinary, complementary and diverse. The tasks are often trivial and overseen by: the study *engineer*; the study *designer* and the *projector*.

The research engineer is the head of the research project, but delegates some of the work to the projector. In addition to the calculations for which s/he is responsible for (graphic design, core sciences and applied sciences), the research engineer acts as an interface between the administrative and financial management teams.

The study designer, despite what the title suggests, actually deals with more than just designs. His/her role is to finalize the defining designs and drawings in the preliminary stage of the project.

The projector, as the etymology indicates, assists the research engineer in projecting technical tasks, including the defining design drawings. Depending on the structural organization of each company, the projector may sometimes deal with clients, with suppliers and with all the company's separate departments. In addition to the tasks of computer-aided design (CAD), the projector is indispensable in a research center, because the research engineer trusts projector and relies upon him/her for all the work needing to be done.

Specific publications on company structure offer fuller definitions of these hierarchical roles. This book, for its part, is intended to be an instructional design-support tool: sketches, calculations, tests, measurements and checks.

The design workspace evolves around the projector. The below diagram illustrates what we mean by this:

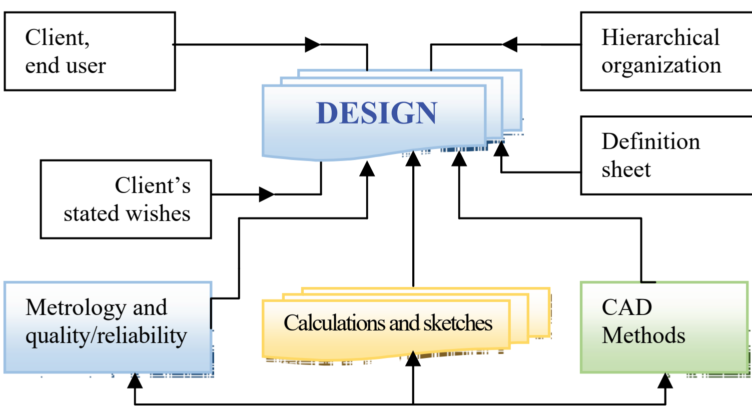

Figure 1.3. *Diagram illustrating the work environment*

The projector is in charge of the needs analysis, the feasibility study for the requirement and the execution of the preliminary ("pre-project") stage. It is worth bearing in mind that there are multiple possible combinations to create a product. The organigrams offered here are simply a few illustrative examples. The staff at the research hub, drawing upon their relevant experiences, would choose possibilities which fit in with their own working methods.

1.3. Conceptualization and creativity

At the initial stage of the design, it is wise to begin with proposals of ideas to help bring the product to life. The team then take an initial overall view of the adopted solutions to lay the foundations for the task of design.

Criteria behind principles of construction		
Human factors	Production	Reliability
Calibration function	Standards	Maintenance
Settings	Materials	Maintainability
Connections	Recycling	Environment
Setups	Components	Handling
Safety/security	…	Applied quality control
Accessibility	etc.…	Applied metrology

Table 1.1. *Main construction criteria in design*

1.4. Functional analysis in design: the FAST method

The method known as FAST – Function Analysis System Technique – is a workflow organization method which offers a logical and explicative diagram illustrating the operational and technical functions.

– *Why* does the function need to be performed?

– *How* does the function need to be performed?

– *When* does the function need to be performed?

It is an interrogative method, the answers to which will guide a designer in their choices and methods. Function Analysis System Technique, known by its acronym FAST, is used in functional analysis either to describe (descriptive FAST) or to create (creative FAST). FAST is said to be descriptive if the design solution already exists. This method is used, for example, to carry out a critical study of how a product's technical and/or economic functions are served. The process is as follows:

Prepare for the analysis → Gather and collate the technical functions → Sort the technical functions → Construct a FAST diagram (How? and/or When?) → Write up the technological adopted solution.

Creative FAST is used as follows: Prepare for the analysis → Search for and collect ideas (brainstorming, or "Kaizen") → Order the ideas → Construct a FAST diagram (How? and/or When?) → Write up the technological adopted solution.

Simplified example of a FAST approach in manufacture by machining

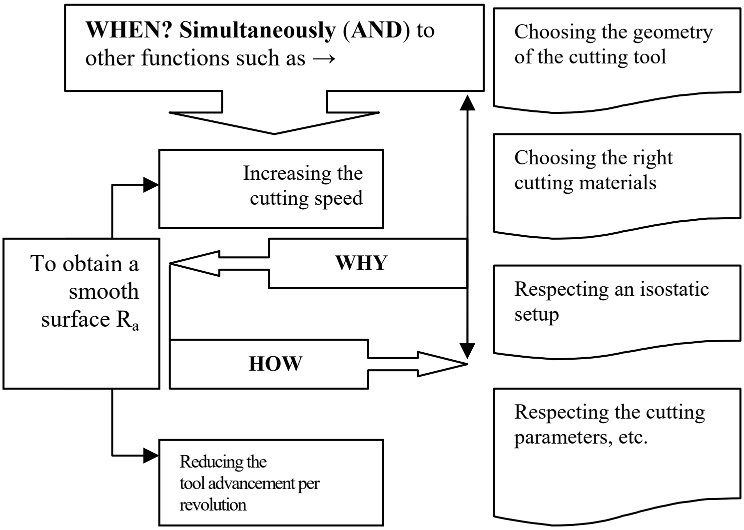

Figure 1.4. *FAST in machining manufacture*

1.4.1. *Decision-support tools in design*

Although decision-support tools can be very helpful if used properly, it is advisable not to blindly accept the accuracy of the proposed solutions. These tools are used at the end of the creative sessions that are an integral part of the preliminary design phase of a project. The purpose of using them is to stabilize the choice of solutions – in other words, to check the validity of the decision and to create a commentated decision dashboard.

Validity of the decision: The questionnaire is designed to extract the true requirements of the product. It then becomes a question of explaining the advantages and disadvantages weighing toward the maintaining of the solution.

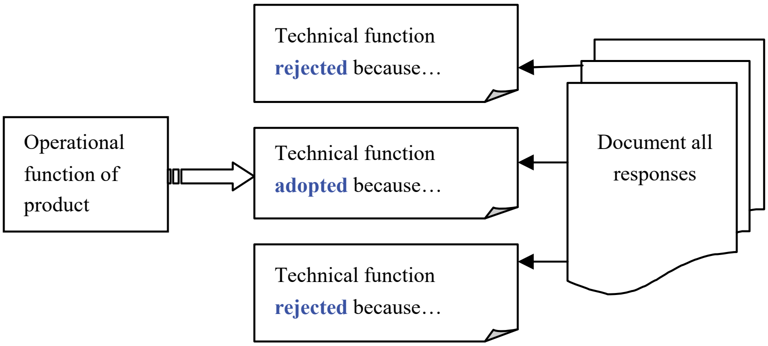

Figure 1.5. *Decision-support system (expert system)*

For example: why use one material instead of another? Why choose that environment? etc. The assessment criteria justify and support the characterization of the product's operational function. Of course, it is crucial to also take account of criteria such as cost, maintenance and even esthetic appearance, etc.

A so-called Bayes table (named after the Scottish statistician Thomas Bayes, 1702-1761), is a multi-criterion table used to formalize a decision. To draw up a Bayes table, we insert the factors contained in relation [1.1], below, in accordance with the following seven steps:

1) Define the objective of the decision to be made

2) Collate the proposed solutions (Sol_1; Sol_2; … Sol_j)

3) Collate the criteria ($Criterion_1$; $Criterion_2$; … $Criterion_j$), assigning each a score between 1 and 3, depending on the case study

4) Weight the criteria (κ_i) with weight scores ranging from 1 to 5

5) Find the value structure for each criterion

6) Carry out an overall evaluation (calculate the total sum)

7) Analyze the results to produce the best solution(s) as a function of the highest weighted score.

Decision dashboard relating to three solutions

$$Score_{Solj} = \sum_{i=1}^{n} N_i \times \kappa_i \quad where \left\{ \begin{array}{l} \kappa_i \textit{ is a weighting coefficient } (1 \le \kappa_i \le 5) \\ Score_{Solj} \textit{ is the score for solution } sol_j \\ N_i \textit{ is the criterion score } (1 \le N_i \le 3) \\ i \textit{ is the criterion number } (1 \le j \le n) \end{array} \right\} \quad [1.1]$$

Criteria collected	κ_i coef. Pond.	Solution 1		Solution 2		Solution 3	
		Score	Total	Score	Total	Score	Total
Criterion 1	5	3	5×3=15	1	5×1=5	3	5×3=15
Criterion 2	3	2	3×2=6	2	3×2=6	2	3×2=6
Criterion 3	4	1	4×1=4	2	4×2=8	2	4×2=8
Criterion 4	2	1	2×1=2	2	2×2=4	2	4×2=4
Criterion 5	3	1	3×1=3	1	3×1=3	2	3×2=6
Weighted total			Σ=30		Σ=26		**Σ=39**
Minimum score			**1**		**1**		**2**
Conclusion: **Solution 3** is the most advantageous. Hence, it will be given priority.							

Table 1.2. *Example of a decision dashboard*

1.5. Functional specifications (FS)

Before conducting any kind of design study, it is essential to know precisely what the client is looking for. In some cases, the client's expression of their needs may be unclear, lacking detail and sometimes even incomplete. Working closely alongside the client, it is crucial to clearly define the product that is to be designed.

Many methodological tools are put forward in the existing body of literature [FRE 85]; such as the interaction diagram or the APTE method (*Application aux Techniques d'Entreprise* – Application to Business Techniques – taking its name from its parent company, APTE), to cite only those examples. The client may not always be a designer. They will express a requirement, in their own words, which the designer will then have to implement. In order to do so, the designer begins by defining the operational functions of the product being designed.

As the FS cover the entire life cycle of a product, they must satisfy a number of requirements, at the following distinct stages: *design, manufacture, distribution, use, maintenance and end of life – i.e. disposal, recycling or, sometimes, value creation (upcycling)*. Thus, the definition of a product is a true reflection of the set of constraints relating to the environment.

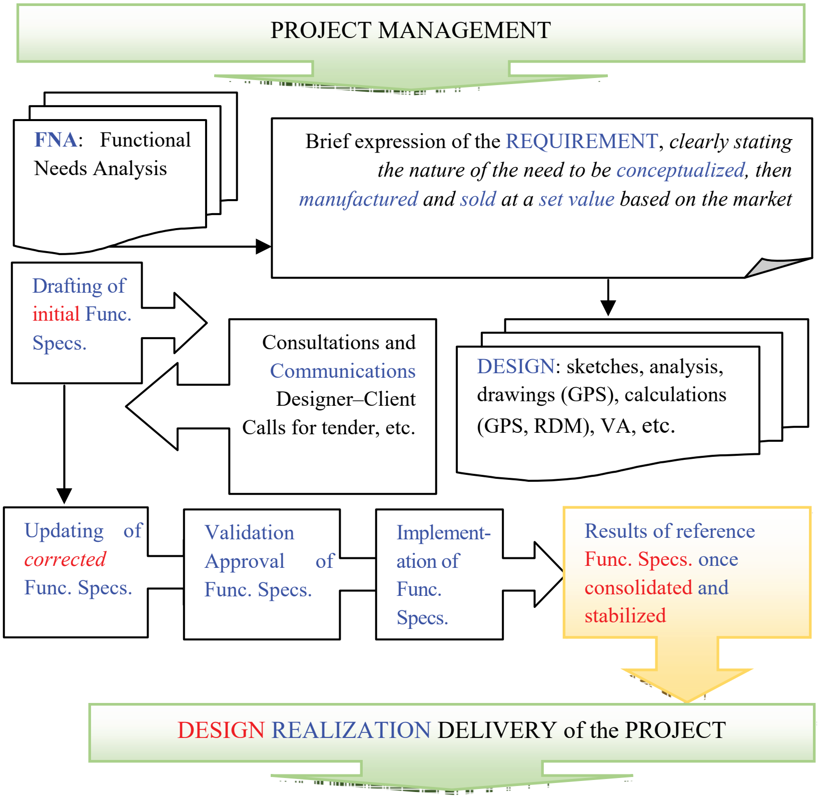

Figure 1.6. *General structure of functional specifications (Func. Specs). GPS: Geometric Product Specification. VA: Value Analysis. For a color version of this figure, see www.iste.co.uk/grous/design.zip*

1.5.1. *Operational functions, using the APTE method or octopus diagram*

The operational functions describe the client's requirement which the designer must serve. To do so, the designer can use a variety of workflow organization methods. For example, s/he might use an octopus diagram in the case, primarily, of designing mechanical systems. An example is given below.

– FP_1: This is the principal function of the product (e.g. a bicycle). It enables the cyclist to move over the ground (link between two media);

– FC_1: Constraint function: withstand disturbances on the cyclable track (road) and be easy to pedal;

– FC_2: Respect the environment;

– FC_3: Look attractive (esthetic value);

– FC_4: Resist external attacking forces (rain, snow, salt, etc.);

– FC_5: Be lightweight, safe and reliable;

– FC_6: Respect the standards and other codes in force;

– FC_7: Be comfortable.

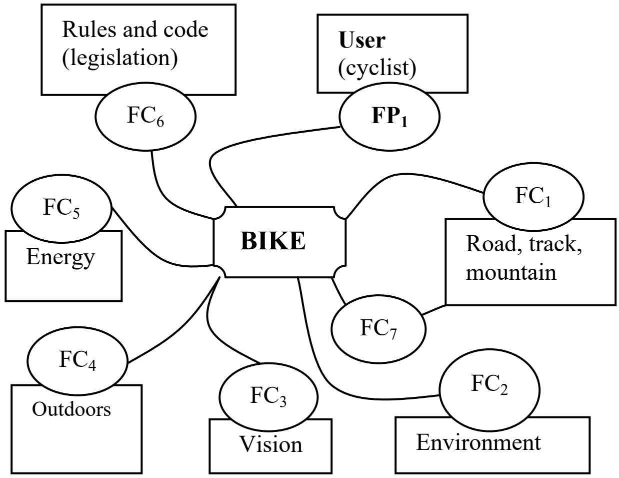

Figure 1.7. *Octopus diagram or APTE principle for a bicycle*

The steps to be taken are generally logical, including:

1) *States*: The states are operational, under construction and undergoing maintenance;

2) *Environment*: Above all, it is important to think about the surroundings of the product we are designing, such as: the physical elements, the user(s), the environment, reliability/safety, energy, etc.

3) *Principal functions*: Hitherto, it has not been customary to insist on the language to be used in technical documents. This, in the author's view, is a mistake, because the language and the expressions must be absolutely free of any ambiguity. A set of functional specifications is a contract between the designer and the client, where sentences need to be structured in such a way as to clearly show the elements of logic: subject, verb and object.

1.5.2. *Linguistic (or syntactical) writing of the functional specifications*

– the label "*subject*" obviously applies to the system to which the design pertains. It needs to be concise, clear and unambiguous;

– the action *verb* (indicative and transitive) must be in the present indicative tense. It is important to avoid verbs which render the statement of the function vague or evasive;

– the direct object *complement* (direct, indirect, circumstantial) applies directly to the user. An indirect object complement is a little different.

With the above completed, the FS can be drafted. The designer adds further information about the characteristics of each function, along with its title. If using an octopus diagram, the number of generated principal functions needs to be taken into account by the designer. The client is free to interject on matters such as F_{NN} (non-negotiable function), F_N (negotiable function) or even F_{FN} (fairly negotiable function).

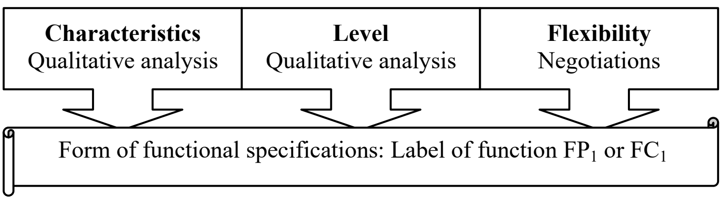

Figure 1.8. *Form of FS*

The designer presents the client with the FS, where all the functions are clearly defined by their characteristics. The levels will be annotated by the client depending on the operational needs for the product. The FS must be signed by both parties in order to formalize the contract. The time allowed for the FS is limited to around half a day's work, and the document is distributed in electronic format. The drawing up of FS constitutes a hugely important step. The design then becomes a matter for specialists. We then seek solutions from a range of specialists with a view of validating the pre-project, using the FMECA design tool.

1.6. Failure Mode Effects and Criticality Analysis

FMECA – Failure Mode Effects and Criticality Analysis – examines all the different types of failure which impact the system's ability to operate. This method, developed by the US Army, has the reference *MIL-P-1629* (1949). It is a reliability method whereby failures are ranked on the basis of their impact on equipment (reliability) and on personnel (safety). For that reason, FMECA is employed widely in aerospace engineering. By the 1970s, the automotive industry (including companies such as Toyota, Nissan, Ford, BMW, Volvo and Peugeot) was using FMECA widely. We can distinguish between different types of FMECA, depending on the domain:

– *product* FMECA can be used from the design of the product to ensure it fulfills the functions for which it was designed;

– *process* FMECA pertains to the realization phase, to verify the impact of the manufacturing processes on the product's conformity;

– *procedural* or *machine* FMECA relates to the equipment used in the manufacture;

– *design* FMECA relates to the design of the product, with the aim being to anticipate potential design failures at the pre-project stage.

We focus here on design FMECA, including the system (the derailleur in a bicycle gear system) and the formation of a research group composed of the maintenance manager, three maintenance agents and two technicians.

i) *failure analysis*: the detailed study of the work orders issued in the wake of the breakdown revealed two modes of failure with their associated effects and causes (see table below);

ii) *criticality calculation*: with the values adopted for F, D and G, it is possible to calculate the criticality attached to each failure of the winder of a hoist;

iii) *actions undertaken*: the highest criticality value, 12, is associated with the wear and tear on the components of the winder. The service decides on preventative action by changing the components of the winder every year.

Ranking of potential failures	
F for FREQUENCY	
1	Max. failure per year (low)
2-3	Max. failure per trimester (average)
4-5	Frequent failures each week
8	Very frequent failures
10	Failure all the time
D for NON-DETECTION	
1	Verification by an operator (naked eye)
2-3	Easy detection by simple examination
4-5	Easy detection by detailed examination
10	Undetectable to the naked eye

G for GRAVITY or UNAVAILABILITY	
1	No stoppage
2-3	No stoppage but sometimes annoyance
4-5	Stoppage > 1 day or nonstandard
8	Dangerous
10	Fatal

Definition of the terms used in Product FMECA (Bicycle)							
System, element or subset	FAILURES			CRITICALITY			
	Modes	**Effects**	**Causes**	**F**	**D**	**G**	$C = F \times D \times G$
Gear change of the hoist	*No gear change*	Winder non compliant	Failure of gear changer	1	2	2	**4**
Idem	Idem	Idem	Defective mechanism	1	2	2	**4**
Idem	Poor function of the winder	Idem	Worn parts of the winder	2	3	2	**12**

ACTIONS UNDERTAKEN	EVOLUTION			
	F	**D**	**G**	$C = F \times D \times G$
Changing of the **winder** every year	1	3	2	**6**
The **Risk Priority Number** is written: $C = N \times R \times P = F \times D \times G$				

Table 1.3. *FMECA for the example of a hoist*

– the criticality represents a mathematical product which evaluates the occurrence and severity, giving us the product: $C = Q \times S$.

The *checks* in design and manufacturing processes constitute mechanisms which prevent the causes at the root of failures. As in design, the clients are separate from the functional specifications. It is manufacturing processes which are affected by possible failures of the product.

– to evaluate the probability found by the check, we use the failure cause tool Statistical Process Control (SPC) [GRO 13];

– when a mechanism, a component or even the whole system ceases to function, *failure* occurs. It is possible that the system may not shut down completely. The performances lack – hence the word “failure”.

There are particular ways where failure manifests itself when a system deviates from the specifications. Depending on the kind of failure (abnormal strain, wedging, corrosion, buckling, surpassing of the dimensional tolerance values imposed, etc.), we note a specific *mode* of *failure*.

– the *causes of failure* (upstream) relate to the design and/or manufacture. They can be classified using the 5 M's method [GRO 13] (Machine, Method, Material, Man power/Mind power and Measurement/Medium);

– the *effects of failure* (downstream) are the symptoms of alteration of the components. The so-called risk priority number ($RPN = S \times O \times D$) expresses the severity (gravity) of the occurrence of detection. The RPN is used for high-quality products.

Advantages of FMECA	**Drawbacks to FMECA**
Managing the risks by means of preventative actions	Requires profound knowledge inherent to the question at hand, from design to delivery of the product. This requires a *pluridisciplinary* team. Thus, FMECA is a "cumbersome" method

1.7. PERT method

Program Evaluation and Review Technique (PERT – 1958) was initially introduced in order to study the manufacture programs by ordering numerous tasks, in the form of a grid. In view of their dependencies and chronology, these tasks lead to the obtaining of a finished product. This method is limited, as it contains neither the concepts of duration nor the date. PERT is constructed around the following elements:

a) listing the main operations in the project, placing emphasis on the temporary durations between them;

b) constructing a coherent, succinct graph;

c) quantifying the "at the earliest" and the "at the latest" dates, based on the steps inherent to each operation;

d) targeting the critical operational pathway, in connection with the above.

If necessary, it is possible to construct a Gantt chart. In order to gain a fuller understanding of the logic of PERT, let us look at a simple illustrative example.

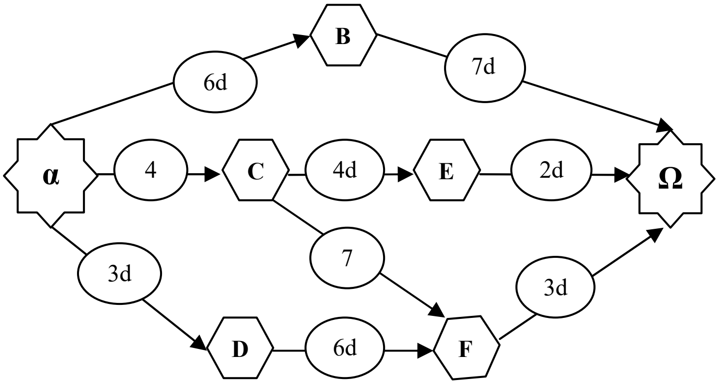

Figure 1.9. *PERT graph for the example (d = days)*

1.7.1. *Logic of construction of the graph per level of operations*

Level I: (α represents the starting point in constructing the network. As we have no previous history to go on, the level I tasks – i.e. C and D – are barred to define level II. Understandably, we first need to finish those steps before we can move onto step F.

Level II: Tasks B, E and F are at level II. Thus, we have to complete them before we are able to begin the final step (**Ω**). **Ω** represents the completion of the construction of the grid, which corresponds to the last day.

i) we must create a fictitious task to model the condition of anteriority C and E, which pre-date task B. The order of the tasks proceeds from left to right;

ii) "level" should be taken to mean the positions of each vertex illustrating the start of the relative tasks – i.e. $\tau_{prob\mathbf{1}}$, $\tau_{prob\mathbf{2}}$, etc. … τ_{probi}.

– the numbering proceeds from left to right (from → to …) – see Figure 1.9;

– the "*at the earliest*" tasks are performed *from left to right* by adding together the durations of each tasks. The highest value is considered to be at the intersections;

– the "*at the latest*" tasks are performed *from right to left* by successively subtracting the durations of the tasks, beginning with the final task (**Ω**). The lowest value is considered to be at the intersections.

iii) we read the *critical pathway* {**α** → C → F → **Ω**}, going *via* those tasks which correspond to the *earliest* realization date, which corresponds to the *latest* realization date.

– τ_{prob} indicates the probable duration of the task;

– τ_{pt} indicates the *earliest possible* date corresponding to the end of a task;

– τ_{ptd} indicates the *latest possible* date corresponding to the end of a task. Note that if ever that duration were to surpass the value indicated by τ_{td}, the project would suffer a serious delay. In that case, the subsequent steps would be automatically shifted.

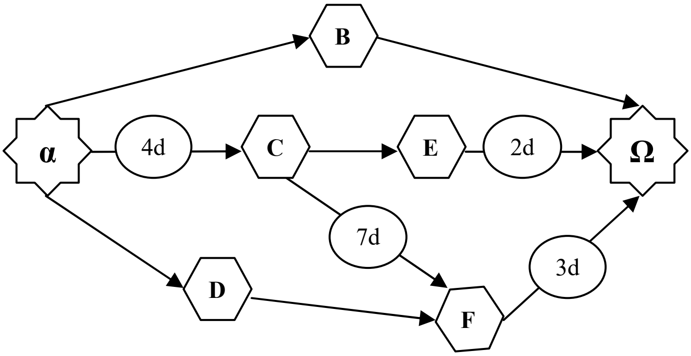

Figure 1.10. *Identification of the critical pathway {α → C → F→ Ω}*

– **Ψ** represents the margin in days thus calculated. $\Psi = \tau_t - \tau_{pt}$ is a tolerance value (in terms of a delay) to represent any possible delay in carrying out a task. For $\Psi = \tau_t - \tau_{pt} = 0$, there is no delay tolerated in the project.

Tasks	Previous tasks	Probable duration τ_{prob} (days)	Earliest possible date τ_{pt} (days)	Latest possible date τ_{td} (days)	Ψ, margin *in days*
Listed at will	Stress history	Durations (days) established	Durations (days) calculated	Durations (days) calculated	Duration $\Psi = \tau_t - \tau_{pt}$
A	-				
B	← A	6 days	6 days	7 days	1 days
C	← A	4 days	4 days	4 days	**0**
D	← A	3 days	3 days	3+2 = 5 days	2 days
E	← C	4 days	4 + 4 = 8 days	7+3+2 = 12 days	4 days
F	← D, C	6 days or 7 days	7 + 4 = 11 days	7+4 = 11 days	**0**
G	← B, E, F	7 days or 2 days or 3 days	7 + 4 + 3 = 14 days	7 + 4 + 3 = 14 days	**0**

Table 1.4. *PERT table explaining the reasoning with an example*

1.7.2. *Statistical approach to the PERT diagram using the Gamma distribution*

There is a statistical approach to representing durations. The chronological order proves to be identical to that which was presented above. To gain an idea of the possible delay tolerance range, we determine an (optimistic) minimum value τ_{-min-a} and a (pessimistic) maximum value τ_{-max-b}. Thus, the most probable duration $\tau_{-prob.}$ indicates the hope of achieving the total duration of the realization. We use τ_{-exp} to denote each expected task, with a statistical variance estimator (σ^2) whose statistical relations are as follows. S is a form factor.

$$\begin{cases} \Psi_{\text{margin}} = \tau_{td} - \tau_{pt};\ \tau_{td} = \sum_{\tau=1}^{k} \tau_{prob}\ ; \tau_{\exp} = \left(\tau_{\min\text{-}a} - 4\tau_{prob} - \tau_{\max\text{-}b}\right) \Big/ 6 \\ \sigma^2 = \left(\tau_{\max\text{-}b} - \tau_{\min\text{-}a}\right)^2 \Big/ 6;\ U = \left(P_S - \tau_{\max\text{-}b}\right) \Big/ \sqrt{\sum \sigma^2}\ ; 0 < P_s < 1 \end{cases} \quad [1.2]$$

The graphical (statistical) imbrication of PERT is presented as follows:

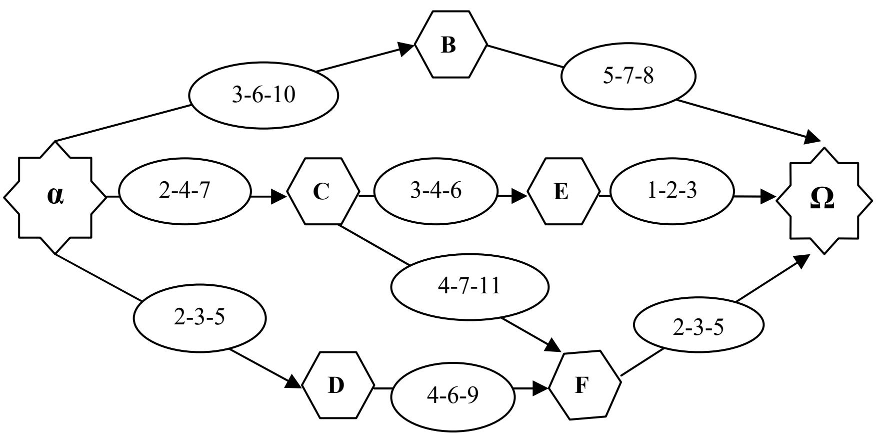

Figure 1.11. *PERT graph, for example, based on statistical durations*

Statistical application to the Gamma distribution for λ = 0.5 (form factor); κ = 5 (form factor) and τ = 0.5, 0.1, … 20 gives us:

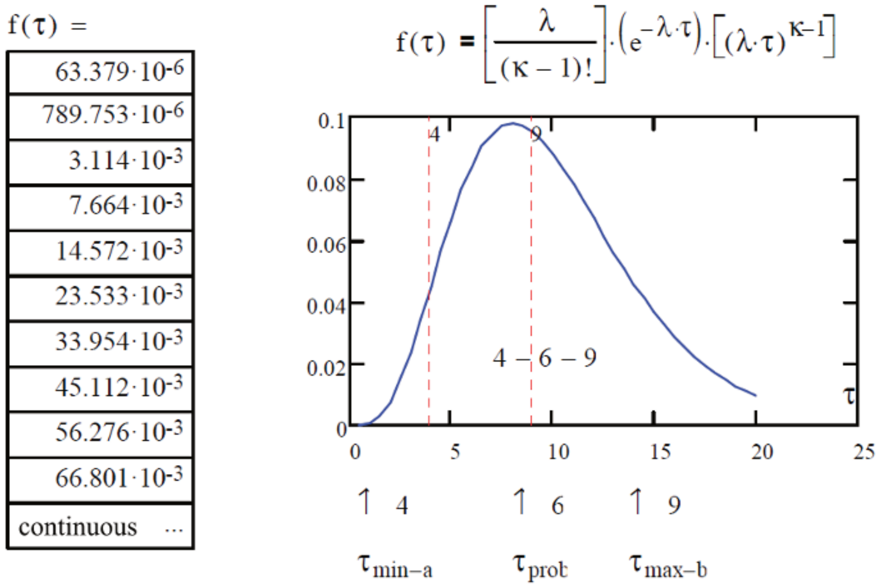

Figure 1.12. *Typical distribution based on the Erlang distribution (Gamma distribution). For a color version of this figure, see www.iste.co.uk/grous/design.zip*

1.8. The Gantt method (Henry Gantt's graph, devised 1910)

This method shows the duration of a task, a manufacturing cycle, an intervention or even expresses the workload of an operator (industrialist). This graph forms the link between the predicted time for a task and the time that is actually spent on it. The purpose is to improve workshop organization. The planning of tasks and activities is followed by deadlines, supported by resources. The Gantt chart helps:

– *adapt* to the set of activities;

– *structure* and *reference* the order in which tasks are to be carried out;

– *facilitate* comprehension – which can sometimes be complex – by simple visual representation;

– *improve* the organization of the workflow by offering an overall view of the structure of the project;

– *plan* the whole duration of the project;

– *dynamize* work by automating the calculations of the dates and durations for the tasks.

A great many project scheduling tools offer models. These software packages propose an approach that is more or less similar to that outlined below:

Step 1: Establish a list of the tasks whose subactivities will be attached, in a clear hierarchical ranking. Any omission or oversight will have repercussions for the state of advancement of the project.

Step 2: Assign the resources and manage the workload. The resources include load-management elements such as production units guided by a simogram.

Step 3: Plan the field of action where the tasks follow the time spread, beginning at the start dates. It is at this stage that the activities can be visually represented on the diagram.

Step 4: At this level, we create the connections between the tasks (arrows between the boxes). It is this connecting function which represents the program's real strong point.

Step 5: We insert the milestones (marking both upstream and downstream in the process). A milestone corresponds to a given step (e.g. the signing of the contract, or the publication of a project handbook). This is a crucially important period in the project. Here, the project gains visibility. Unlike the others, this section has no pre-determined duration.

Note that a task cannot begin if a previous one has not yet finished. Similarly, no other task *can commence* if a previous one *has not yet begun*. Also remember that a task may have several previous tasks (see Figure 1.8). In these scenarios, it is imperative that all tasks be completed, so that the subsequent ones can then begin.

It may also be that a task has several subsequent tasks attached to it. In that case, the end of the task conditions the start of the other, subsequent tasks.

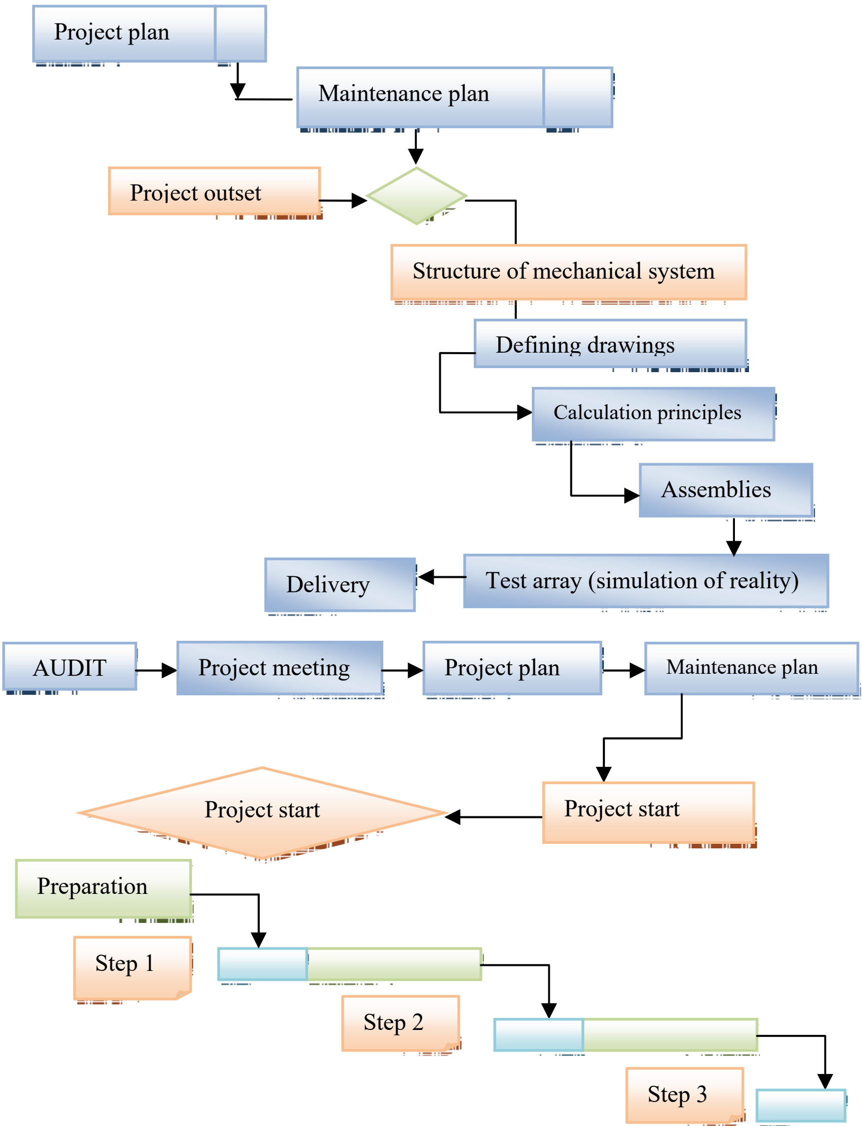

Figure 1.13. *Gantt chart for the example. For a color version of this figure, see www.iste.co.uk/grous/design.zip*

Once the chart has been drawn up, it needs to be followed closely in order to ensure good management of the project, over time. The critical pathway (see Figure 1.10: Identification of the critical pathway $\{\boldsymbol{\alpha} \rightarrow \mathbf{C} \rightarrow \mathbf{F} \rightarrow \boldsymbol{\Omega}\}$) serves to give us a concrete visualization of the succession of tasks, giving an indication of the overall length of the project. Any delay has an impact on the final date of the project.

By clearly visualizing the state of advancement of the tasks, the Gantt chart enables us to assign an appropriate state of advancement to each of the tasks.

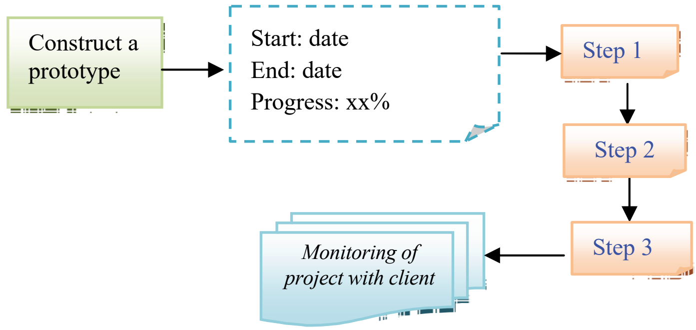

Figure 1.14. *Gantt chart for the example. For a color version of this figure, see www.iste.co.uk/grous/design.zip*

Of course, it is possible to modify the Gantt diagram by planning ahead: it is a dynamic, alterable tool. If, for example, we were to change the duration of a task, the diagram would recalculate the whole duration of the project. That adaptability is useful, and takes account of the interdependence of the created functions. An Excel spreadsheet is perfectly sufficient to create a professional Gantt chart (activity, duration, milestones, resources, etc.).

In the literature specializing in workflow organization, there are numerous interesting and beneficial methods to help save time and better organize the work both at the design stage and at the manufacturing stage. In this book, we shall limit ourselves to the main methods.

1.9. Principal functions of a product

A well-designed product is intended to satisfy the needs expressed by the client. There are numerous methods for analyzing design and manufacture which can be used alongside the FS. These methods are often used at the early stages of a project. The aim is to analyze the optimal path to follow in order to bring a project to fruition, and thus create a competitive finished product that conforms, as closely as possible, to the characteristics included in the FS. In order to do this, it is helpful to clearly define the functions of a product.

A) *Function of a product*: By "function of a product", we mean the action that the product performs in order to achieve its purpose. The verb expressed is in the gerund form. For example: Opening the patient's mouth (separating their jaws) using the mechanism (see case study in Chapter 11) enables the dental hygienist to easily examine their teeth. A product (mechanism) usually serves a range of functions. With this in mind, it is helpful to clearly classify or rank all the functions in the FS and value analysis (VA).

B) *Function of a service*: This function pertains to the use we make of a product. For example, the mechanism in case study 1 serves for (laboratory) demonstrations of the jaws (dental hygiene). It is important not to confuse *service function* and *usage function*. The usage function essentially pertains to the utilitarian aspect of the product. In case study 1, the usage function might not be justified, as the hygienist might be content to use the conventional way of manually separating a patient's jaws. The usage of the designed product is there to make the user's task easy, thus proving the usefulness of the product. There is also what is known as the *esteem function*, which, for its part, is a service function inherent to esthetic beauty and style.

C) *Principal functions (of constraints)*: To begin with, the principal function is the actual reason for creating the product. *Additional functions* could, as and when needed, be added to the principal function – e.g. using a pneumatic actuator rather than a mechanical one. Thus, the idea of a constraint comes into play at the level of mechanical strength, weight, pressure, etc. The *technical functions* are related to the design and manufacture of the product. Here, the client is not directly involved.

The criteria used to assess the aforementioned functions enable us to measure or evaluate the way in which the product's functions are fulfilled. These criteria define the acceptability limits, such as tolerance intervals (see Chapter 3 on GPS), thus proving flexibility, and determine whether a project is approved or rejected on the basis of its metrological quality. For example, choosing H7/h6 quality of assembly instead of H7/p6 could influence a product's flexibility, and thus earn it a less favorable assessment.

1.10. Functional analysis in mechanical design

In mechanical design, the main objective of conducting functional analysis is to: *collect, characterize, rank* and finally *value* all the functions (in the FS) of a product:

– to "collect" means to determine and identify the main functions of the product;

– to “characterize” them is to list the assessment criteria and the flexibility of the functions;

– “ranking” the functions means evaluating the order of importance of the functions considered and adopted;

– To “value” a function is to assign a weighting value to its importance in the project.

i) *External functional needs analysis*: the client (the user) obviously expresses a requirement for a product for which they already have an idea of the function. Thus, the client is best placed to flesh out the details of the product, in the form of service functions and even constraints. The client defines the role of the product. The idea resembles a sort of “black box”;

ii) *Internal functional needs analysis*: the client will have already expressed their requirements by an external functional needs analysis. The internal counterpart is a technical analysis which expresses the functional part. It contributes to the formalism of the architecture (a sketch which becomes a drawing defining the product), which expresses the technical functions of the components in the system. It is at this level that the designer contributes his/her opinion of the product.

1.10.1. *Product cost in mechanical design*

Cost is a factor which heavily influences the quality of a product being designed and manufactured. The cost of the product reflects the expenses incurred during the design, manufacture and commercialization routes. In design, that cost is closely related to the amount of time invested in studies (analyses, drawings, calculations, simulations, etc.).

1.10.2. *Creation- and monitoring sheets in mechanical design*

These “sheets” are important, because they contain all the relevant information.

PRE-PROJECT PROPOSAL DOSSIER	
Dossier manager: …………….	Project manager: …………………..
Date dossier **created**: dd/mm/yy	Dossier last **updated**: dd/mm/yy
Documents by dossier #	References by dossier #
Classification of solutions by dossier	XXX –YY AG 01
Pre-project # 1	XXX –YY AG 02
Pre-project # 2	XXX –YY AG 03
Pre-project # J	XXX –YY AG 0J
Specific notes:	

In that "dossier", the aim is to gather together all the salient ideas from the pre-project stage to constitute an initial classification document.

Solution classification dossier – Calculation principles	
Dossier manager: ………………	Project manager: ………………
Reasons: RDM-TMM	Calculations of moments: e.g. pivot shafts
Date dossier **created**: dd/mm/yy	Dossier last **updated**: dd/mm/yy
Dossier Pb # 00 CALCULS 00	Dossier Solution # 00
Dossier Pb # 00 CALCULS 00	Dossier Solution # 00
Dossier Pb # 00 CALCULS 00	Dossier Solution # 00
Solution criteria:	
Metrology/Quality/	
GPS-Tolerance	
Assembly	
Other	
	Criterion used
Explanatory notes:	

The aim of classifying the ideas, by problem, topic or discipline, is to more clearly classify the interests at play in order to assign them to each specialized department.

DOSSIER OF PRE-PROJECT # 1	
Dossier manager	Project manager
Date dossier **created**: dd/mm/yy	Dossier last **updated**: dd/mm/yy
Setting out the problem at hand and the associated calculation principles	
Explanatory drawing with tolerance values, dimensional and geometric constraints	
Drawbacks to the solution	Advantages and relevance of the solution
10-point criteria	Norms and standards
Accuracy-Metrology-Quality control	
Assembly-disassembly	
Materials, characterization	
Points of ease (use, storage, etc.)	
Other	
Specific notes:	

DOSSIER OF PRE-PROJECT # 2	
Dossier manager	Project manager
Date dossier **created**: dd/mm/yy	Dossier last **updated**: dd/mm/yy
Setting out the problem at hand and the associated calculation principles	
Explanatory drawing with tolerance values, dimensional and geometric constraints	
Drawbacks to the solution	Advantages and relevance of the solution
10-point criteria (for example)	Norms and standards
Accuracy-Metrology	
Assembly-disassembly	
Materials	
Points of ease (use, storage, etc.)	
Other	
Specific notes:	

It is wise to ensure that the pre-project is very clearly documented.

DOSSIER OF PRE-PROJECT # 3	
Dossier manager	Project manager
Date dossier **created**: dd/mm/yy	Dossier last **updated**: dd/mm/yy
Setting out the problem at hand and the associated calculation principles	
Explanatory drawing with tolerance values, dimensional and geometric constraints	
Drawbacks to the solution	Advantages and relevance of the solution
10-point criteria (for example)	Norms and standards
Accuracy-Metrology	
Assembly-disassembly	
Materials	
Points of ease (use, storage, etc.)	
Other	
Specific notes:	

This is a logical progression from the above.

Preliminary dossier defining the pre-project	
	| Dossier CODE |
Dossier manager	Project manager
Date dossier **created**: dd/mm/yy	Dossier last **updated**: dd/mm/yy
Exhaustive list of duly indexed documents	
Documents by classification	References
Brief description of the pre-project	Dossier # ……….
Drawings (2D and 3D) of the pre-project	Dossier # ……….
Sketches of the adopted pre-project	References # …….
Design FMECA	Dossier # ……….
Operating instructions (**if** assembly)	Dossier # ……….
Safety scores	Dossier # ……….
Relevant scores (ranges)	Dossier # ……….
Other	
Specific notes:	
	| Dossier CODE |

From the preliminary dossier onwards, we begin to project the sketches and drawings for the adopted pre-project.

FINAL SELECTION OF THE ADOPTED PRE-PROJECT	
	| Dossier CODE |
Dossier manager: ………………	Project manager: …………………
Date dossier **created**: dd/mm/yy	Dossier last **updated**: dd/mm/yy
Clearly documented reasons and explanations	
Overall drawing with standard names of the components	
Other	
Specific notes:	

Once the final pre-project has been decided upon, it makes sense to present the defining drawings, the assembly and the manufacturing process. This part is duly documented, based on the norms and other design conventions.

FINAL DESIGN FMECA	
	| Dossier CODE |
Dossier manager: ………………	Project manager: …………………..
Date dossier **created**: dd/mm/yy	Dossier last **updated**: dd/mm/yy
Function 1: ………………………………………………………………………… Failure mode 1: ……………………………………………………………… Effect: …………………………………………………………………………… Causes: ………………………………………………………………………….. Function 2: ………………………………………………………………………… Failure mode 2: ……………………………………………………………… Effect: …………………………………………………………………………… Causes: ………………………………………………………………………….. Etc. …	
Note:	

The design FMECA must not contain significant uncertainties. We have restricted ourselves to the example of two functions. The designer may have more functions in mind than the project actually needs.

ASSEMBLY INSTRUCTIONS FOR THE ADOPTED PRE-PROJECT	
	| Dossier CODE |
Dossier manager: ………………	Project manager: …………………..
Date dossier **created**: dd/mm/yy	Dossier last **updated**: dd/mm/yy
Clearly documented reasons and explanations	
Detailed drawing Assembly drawing	
Other	
Specific notes:	

Justification of the preliminary design	
	| Dossier CODE |
Dossier manager: …………………..	Project manager: …………………..
Date dossier **created**: dd/mm/yy	Dossier last **updated**: dd/mm/yy
Clearly documented reasons and explanations	
Schedule (Gantt, PERT) Sizing (GPS) and precise calculations	
Other	
Specific notes:	

The Gantt schedule clearly sets out the documented reasons for the preliminary project.

Additional dossier(s), if needed	
	| Dossier CODE |
Dossier manager	Project manager
Date dossier **created**: dd/mm/yy	Dossier last **updated**: dd/mm/yy
Clearly documented reasons and explanations	

Table 1.5. *Design dossiers: all the tables are in order*

It can quite easily be observed that the role of design in mechanics is crucially important, on more than one level. Design is based on intuition, calculation and core and applied sciences. It dictates the approach to production in the life cycle of a product or mechanism.

The quick and accurate development of software tools suited for CAD has enabled designers not only to draw better, but also to directly simulate the products of their designs. This considerably reduces the amount of time spent on prototypes. Prototypes make a valuable contribution to actually validating the choices made initially at the design stage, and proving the accuracy of the simulation analyses and calculations. However, for financial reasons, companies with powerful tools at their disposal tend to forego costly prototypes, instead basing their decisions on robust simulations. Powerful simulators yield conclusive results in terms of accidents, failure thresholds, etc.

1.11. Scientific writing on a project

Writing an exhaustive design dossier involves pulling together all the documentation pertaining to the conceptual study. The product must clearly satisfy all the issues raised in the functional specifications. The current chapter is focuses on documentation techniques. It targets the salient points and organization of workflow. As is the case in metrology [GRO 11], *vocabulary* is important in applied mechanical design. Mechanical engineering techniques are not ones in which we would use all our knowledge of mechanics. It is a domain of knowledge of engineering techniques. The universal syllabus for engineer training includes a vast domain of sciences of engineering. Science of Engineering includes solid mechanics, materials, fluid mechanics and thermodynamics, but not necessarily production techniques (Manufacturing), as suggested by the titles of many courses. The author, in his classes in Mechanical Engineering Techniques, has noticed a serious shortfall in Engineering. Sometimes, sadly, people confuse *Machining* and *Mechanical Engineering*. In mechanical design, the projects must be the subject of succinct reports, free of linguistic errors and properly documented. This means presenting and following a product-development process whose objective is stated in the FS from the client. Roughly speaking, the pathway is as follows:

1) Idea for the design project;

2) Study for the design of the project – FS;

3) Preliminary design (systems/subsystems) – pre-project;

4) Detailed design in distinct segments (calculations and drawings);

5) Production of a plan for the manufacture of working prototypes;

6) Validation of the prototype and WRITE-UP (of a report);

7) Confirmed realization of the idea.

1.11.1. *Project process*

The objectives of a development process consist of:

– defining the process: WHO does WHAT, WHEN and HOW to achieve the objective;

– constructing models of one or more systems (sketches and calculations);

– clearly and methodically organizing the progression of the project;

– managing the life cycle of the project from start to finish;

– managing the risks and dangers of the design;

– repeatedly obtaining products of consistent quality.

The activities of development consist of:

– planning and carrying out a feasibility study;

– specifying the theoretical and material needs;

– analyzing (with sketches and drawings based on succinct calculations);

– designing/creating (GPS/ISO technical specification);

– implementing (exact coding if the design is complex);

– testing (components, systems and subsystems);

– integrating and testing (metrology, quality control, esthetics, etc.);

– writing up and delivering;

– maintaining and providing after-sales services.

1.11.2. *Development of the conceptual model*

The development of the conceptual model starts with an idea and looks at how to make it a reality.

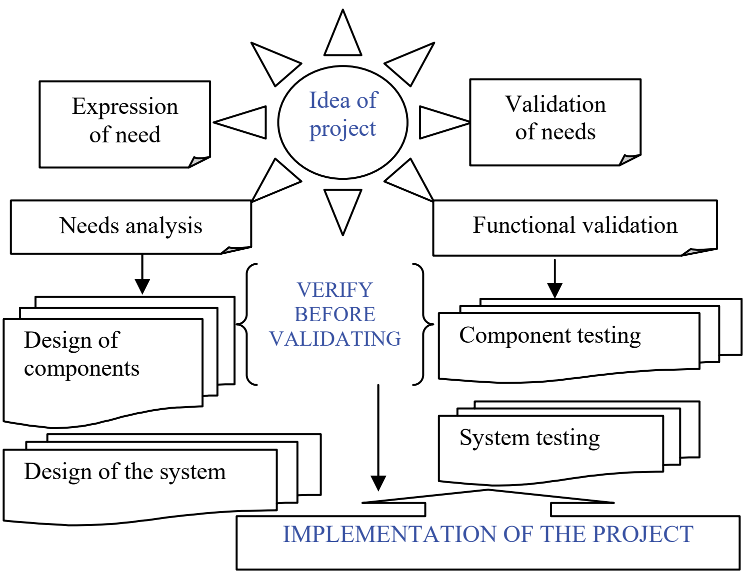

Figure 1.15. *Example of the conceptual model*

1.11.3. *Development (recap) on a spiral model*

There are various ways to present the development of an idea and its path through mechanical design; below is a spiral-type diagram of it.

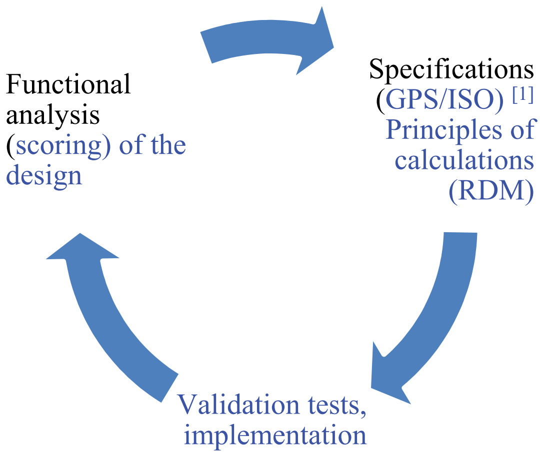

Figure 1.16. *Example of the spiral design model*

1.12. Esthetics of materials in mechanical design

In all future chapters of this book, we shall not touch on the esthetic aspect, focusing instead on the materials. Nevertheless, esthetics plays a not-insignificant role in design products. A well-designed mechanism, machine or even a simple component is functional, because it delivers on its function. If we want to give it a *handsome* and *pleasant finish*, we need to conform to the "*fashion*" in visually pleasing, *attractive* things.

In this book, the materials will be chosen on the basis of rigorous calculations. *Designers* are ordinarily fond of the esthetical dimension. They appeal to fashion sense, where advertising has a definite role to play. It is not true that a mechanical designer does not pay attention to the finish, to the touch and the equilibrium of the products s/he designs. The topics stemming from surface topography (rugosity) and surface treatment hold a twofold interest. Rugosity, for example, is an extremely important requirement in tribology, machining and dimensional metrology [GRO 11]. Surface treatments which are required for protection also produce attractive colors (galvanization, anodizing).

Designers are well-versed in the arts and industry. There is no question, here, of fashioning a meaningless, unsafe or frustrating product. Instead, there is a certain degree of advantage if the product is *pleasing*. An *accomplished* design involves an inventive approach, because it serves a particular need, and the materials used are undeniably a part of that accomplishment.

… MATERIALS AND TEXTURE

In mechanical design (manufacture, assembly and processes), there is an intellectual insouciance in the belief that materials are simply chosen, and that, automatically, their characteristics will conform to the requirements of the design. New materials are *tested*, and often offer more advantageous possibilities (in terms of weight, strength, etc.). Aviation and sports bicycles are enlightening examples of this. From a simple table fork or plastic comb to gargantuan airplanes, it is wise to remain *curious* and *open* to the use of new products.

… AND WHAT OF ENVIRONMENT IN DESIGN?

It is easy to think that the environment and manufacturing techniques can adjust well to time requirements. Many societies are making progress in various technologies and are able to take account of environmental conditions well. There is no incompatibility as long as we remain aware of and receptive to the advantages of methods which take account of the environmental parameter. Certainly, “wild” developments cost us dearly, resulting in natural disasters, health crises and even leading to exodes… All materials contain energy. That energy can be extracted in a variety of ways, and we can even recover emissions and waste to turn them into continuing energy as well. We simply need to remain humble, attentive and imaginative. This is what certain people refer to as eco-energy [GOE 95]. Thus, biodegradability (or its opposite, toxicity) necessitates a certain degree of isolation during the recycling process.

What can a designer do? Alone, not a great deal, other than ponder, research more fully and, above all, listen more closely in order to *attempt to convince others* with powers of persuasion!

1.13. Conclusion

It seems an inalienable necessity that the design process is, first and foremost, iterative: *from concept to concretization, and to the details*. The design is what links parts to the shape, texture, etc. – in a word, the attraction for the *consumer*.

The design steps [FRE 85] take place in accordance with a fundamental principle of operation. The functional decomposition presents the system and subproducts depending on the organization of the workflow [GRO 13], which is the subject of this chapter.

Concretization involves the dimensioning (geometry, stresses and environment) of the components. With the help of optimization techniques, we seek to maximize performances to finally put numbers to the ultimate design. It is at this point that the functional specifications (FS) are said to be concretized.