ENGINEERING

(product development’s management)

Engineering - *introduction* - definitions

Engineering

The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions; all as respects an intended function, economics of operation and safety to life and property.

[Accreditation Board for Engineering and Technology]

Industrial Engineering

Industrial engineering is a branch of engineering concerned with the development, improvement, implementation and evaluation of integrated systems of people, money, knowledge, information, equipment, energy, material and process. It also deals with designing new prototypes to help save money and make the prototype better.

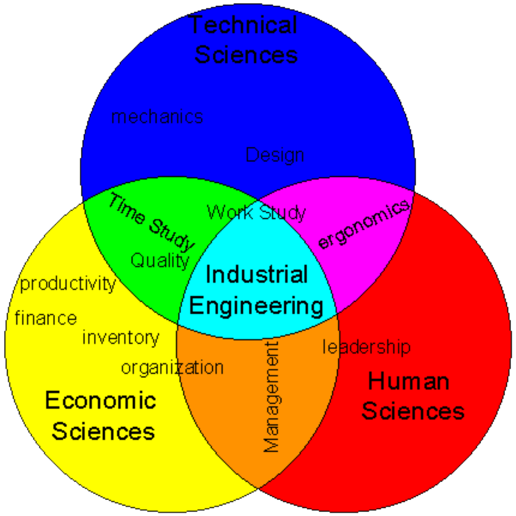
[www.wikipedia.it]

Concern with the optimization of resources (human, materials, facilities, and time) in operation of systems.

[Accreditation Board for Engineering and Technology]

beyond the similitarities of the two definitions one can reckon technical issues in the Engineering one, while the Industrial Engineering one subtends managerial topics.
Anyway **the management of a product's (or service's) development requires** (even if at different levels) **both competiences**.

Engineering - *introduction* – IPD and holistic view)



[www.ahmedfarukuslu.com]

Some managerial topics are suitably showed by the sketch, which spans the two concepts of

- **integrated product development (IPD)**: a management process that integrates all activities from product concept through production/field support. using a multifunctional team, to simultaneously optimize the product and its manufacturing and sustainment processes to meet cost and performance objectives.
  [Guide to integrated product and process development – U.S. Department of Defense]

- **holistic view**, that's a view which "deals with or treats the whole of something or someone and not just a part" management process that integrates all activities from product concept through production/field support. using a multifunctional team, to simultaneously optimize the product and its manufacturing and sustainment processes to meet cost and performance objectives.
  [https://dictionary.cambridge.org/dictionary]

see App. 1 for any body of knowledge definitions.

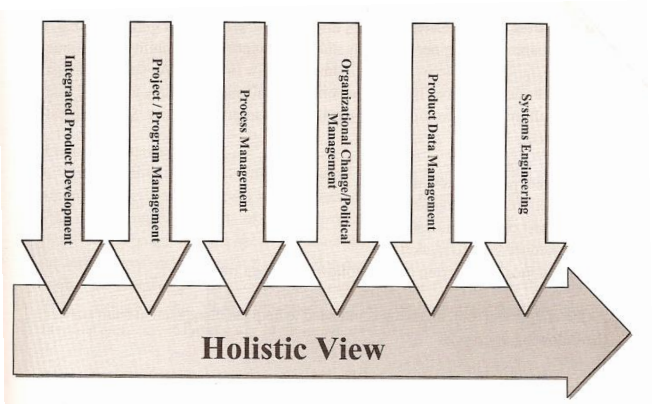


Figure 1-2: The holistic view of the bodies of knowledge

[S.C. Armstrong – Engineering and product development management]

Engineering - ***introduction*** – IPD and holistic view

Just as very preliminary, developing a product consistently with IPD and/or the holistic view requires to answer the following questions:

- «what» must be carried out?
- what progress control (deliverables) should one consider?
- what are the necessary knowledges and skills?
- how long will the development last and which its limitation?
- how much will the development cost and which its limitation?
- which will be the boundaries between the development phases?
- which verification steps should one take into account?
- what drawbacks could arise?
- how to involve company’s group?
- …

Engineering - *introduction* – course's definition of engineering

… so, taking into account the acceptation of engineering showed in the previous pages, one could say that

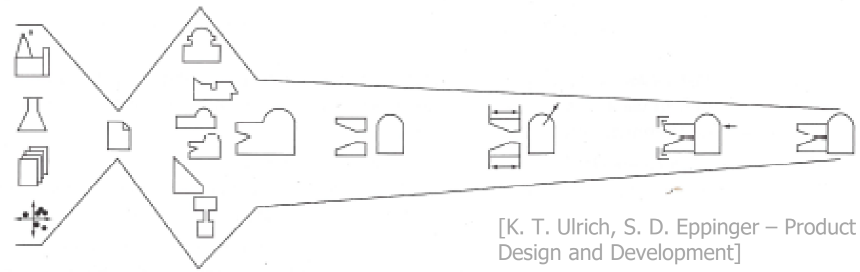
Engineering reminds an iterative process which is

- ✓ **triggered by some ideas (concepts) on a good (product or service) related to the fulfilment of some end users' requirements**
- ✓ **… and substantiated by studies and trials finalized:**
  - **to verify the consistency between the stake-holders expectations and**
    - **both the good's performances**
    - **… and the characteristics of the processes linked to the good's life cycle.**
  - **to check the technological and organizational feasability of the good about which the above trials are carried out,**
  - **to make all the arrangements necessary for the processes generally related to the logistics and manufacturing (at any rate taking into account the available technologies and the limit of the good's cost),**

and whose outputs work on the up-mentioned ideas in order to confirm the related good or to actionate suitable modifications.

Engineering

- *introduction* – engineering pattern



[K. T. Ulrich, S. D. Eppinger – Product Design and Development]

The drawing shows a generic engineering process.

Just two notes:

- looking at the content of LIUC Industrial Design course (ref. to Engineering module), engineering starts about from the concept development and ends at «testing and refinement».
- the showed process implies «concurrent engineering» logic, indeed all company's departments are involved in any phase.

Concurrent engineering will be mentioned in the continuation of these lecture's notes. Anyway, in a very rough way one can consider it as a way finalized to fit time-to-market expectation (and/or to manage complexity).

	Planning	Concept Development	System-Level Design	Detail Design	Testing and Refinement	Production Ramp-Up
Marketing	• Articulate market opportunity. • Define market segments.	• Collect customer needs. • Identify lead users. • Identify competitive products.	• Develop plan for product options and extended product family.	• Develop marketing plan.	• Develop promotion and launch materials. • Facilitate field testing.	• Place early production with key customers.
Design	• Consider product platform and architecture. • Assess new technologies.	• Investigate feasibility of product concepts. • Develop industrial design concepts. • Build and test experimental prototypes.	• Develop product architecture. • Define major sub-systems and interfaces. • Refine industrial design. • Preliminary component engineering.	• Define part geometry. • Choose materials. • Assign tolerances. • Complete industrial design control documentation.	• Test overall performance, reliability, and durability. • Obtain regulatory approvals. • Assess environmental impact. • Implement design changes.	• Evaluate early production output.
Manufacturing	• Identify production constraints. • Set supply chain strategy.	• Estimate manufacturing cost. • Assess production feasibility.	• Identify suppliers for key components. • Perform make-buy analysis. • Define final assembly scheme.	• Define piece-part production processes. • Design tooling. • Define quality assurance processes. • Begin procurement of long-lead tooling.	• Facilitate supplier ramp-up. • Refine fabrication and assembly processes. • Train workforce. • Refine quality assurance processes.	• Begin full operation of production system.
Other Functions	• Research: Demonstrate available technologies. • Finance: Provide planning goals. • General Management: Allocate project resources.	• Finance: Facilitate economic analysis. • Legal: Investigate patent issues.	• Finance: Facilitate make-buy analysis. • Service: Identify service issues.		• Sales: Develop sales plan.	• General Management: Conduct postproject review.

EXHIBIT 2-2 The generic product development process. Six phases are shown, including some of the typical tasks and responsibilities of the key business functions for each phase.

Engineering - MIL-STD-499B (i)

see App. 2 as well for on overview on other engineering standards.

App. 3 shows MIL STD 499.B index, a glance about is useful in order to properly understand the possible applications..

Now, same things subtended by previous page drawing are instituzionalized by several standards: **MIL STD 499B** (System Engineering) is one of the most well-known.

- **Primary Functions**: those essential tasks, actions, or activities that must be accomplished to ensure that the system will satisfy customer needs from a system life-cycle perspective. The eight primary system functions are development, manufacturing, verification, deployment, operations, support, training and disposal.
- **System**: an integrated composite of people, products and processes that provide a capability to satisfy a stated need or objective.

… so, topics **whose effective composition requires several attempts** as shown by next page drawing.

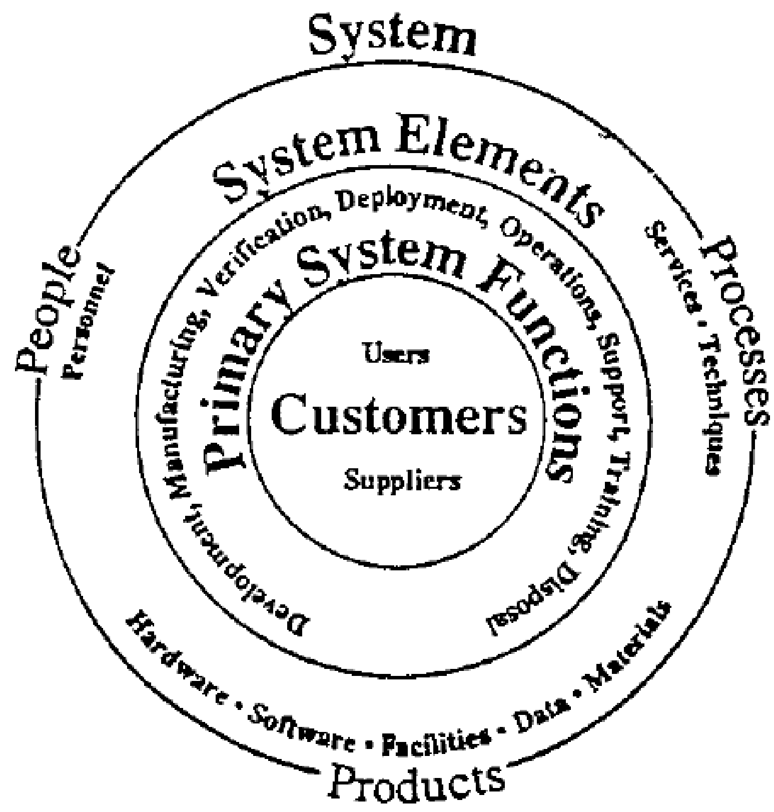


FIGURE 1. Key Terms

[System Engineering MIL STD 499B]

Engineering - MIL-STD-499B (ii)

the drawing well shows the iterative characteristic of any engineering work

The key point is the **repetition of verifications on the primary systems functions. Such repetition is leaded by the four shown macro-phases**, that's:

- requirements analysis,
- functional analysis/allocation
- synthesis
- systems analysis and control

Following pages show the definitions both of the above macro-phases and of the primary systems functions.

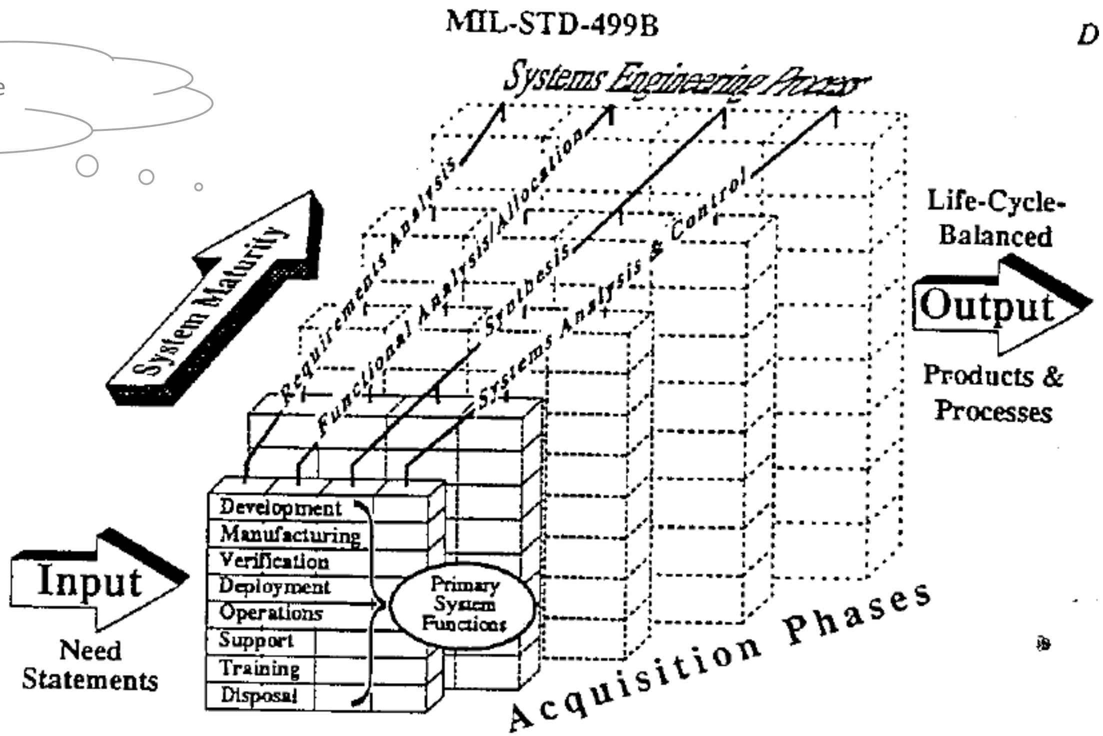


FIGURE 2. Systems Engineering Life-Cycle Application

[Systems Engineering MIL STD 499B]

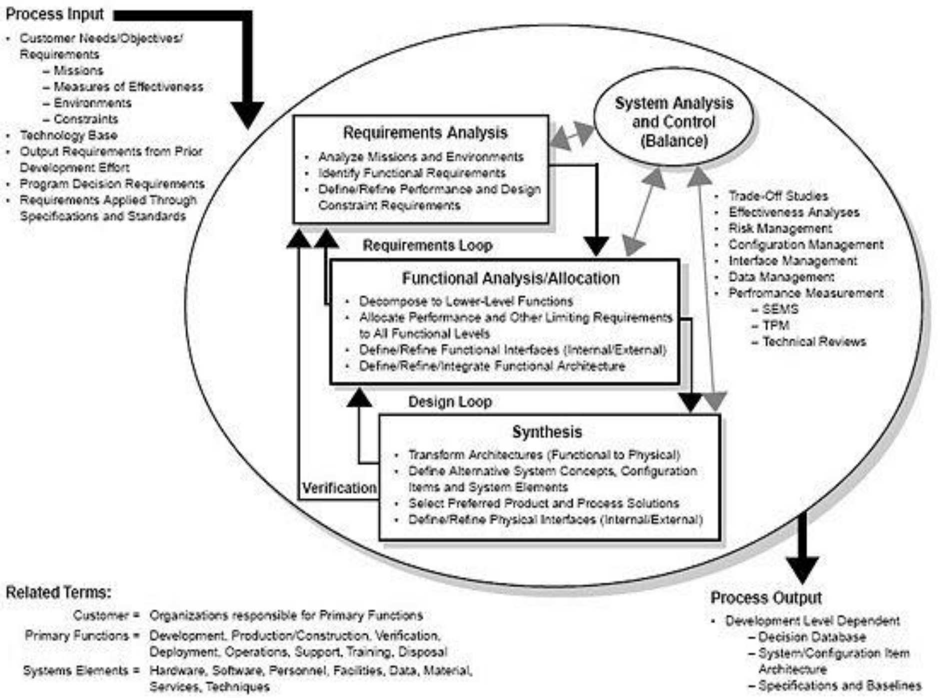
… for your work it's important you to adopt the showed definitions and **mostly to customize them to your work's context.**

In some of the definitions, words like «mission», «peacetime», «wartime», «demilitarization» etc. are used. You don't have to be astonished, indeed such defintion come from a military standard whose content is anyway very useful for any context.

Engineering - MIL-STD-499B (iii)

Legenda from MIL STD 499B:

- **Requirements analysis**: the determination of system specific performance and functional characteristics based on analyses of customer needs, requirements and objectives, missions, projected utilization environments for people, products and processes; constraints and measures of effectiveness. The bridge between customer requirements and system specific requirements from which solutions can be generated for the primary system functions.
- **Functional analysis and allocation**: examination of a detailed function to identify all the subfunctions necessary to accomplishment of that function; identification of functional relationships and interfaces (internal and external) and capturinig these in a functional architecture; and flow-down of upper-level performance requirements and assignment of these to lower-level subfunctions.
- **Synthesis**: the transation of input requirements (including performance, function and interface) into possible solutions (resources and techniques) satisfying those inputs. Defines a physical architecture of people, product, and process solutions for logical grouping of requirements (performance, function and interface) and then designs the solutions.
- **Systems Analysis and Control**: the imposition of structure and discipline into system evolution by: measuring progress based on demonstrated performance; identifying, developing and examining alternatives; making decisions based on schedule, performance, and risk to effect balanced results; documenting the evolution and rationale; and controlling resulting configurations.



[System Engineering MIL STD 499B]

Engineering - MIL-STD-499B (iv)

Legenda from MIL STD 499B:

- **Development**: tasks, actions and activities to be performed with required resources to evolve the system from customer needs to system product and process solutions. The function encompasses the planning and execution of the definition, design, design implementation, integration, analyses and control types of activities. Development applies to new developments, product improvements and modifications, as well as any assessment needed to determine a preferred course of action for material solutions to identified needs, deficiencies, or problem reports.
- **Manufacturing**: tasks, actions and activities to be performed with required resources to convert raw materials and components into a product. It provides for definition of manufacturing designs (including manufacturing layouts), methods, and processes; and fabbrication, assembly, and checkout of component elements (including equipment, tooling, and machinery).
- **Verification**: tasks, actions and activities to be performed with required resources to evaluate progress and effectiveness of evolving system products and processes and to measure compliance with requirements. Analysis (including simulation), demonstration, test and inspection are verification proof of concept. The function encompasses all Test and Evaluation including Development Test and Evaluation activities such as technology validation, manufacturing process proofing, quality assurance and acceptance, as well as Operational Test and Evaluation.
- **Deployment**: tasks, actions and activities to be performed with required resources to bring a system, or upgrades to the system into a state of full operational capability. The function encompasses transport, receive, process, assemble, install, test, checkout, operate and, as required, emplace, house, store, or filed typed of activities.
- **Operations**: tasks, actions and activities to be performed with required resources to accomplish defiined mission objectives and tasks in the peacetime and wartime environments planned for expected.
- **Support**: tasks, actions and activities to be performed with required resources to provide support for operations, maintenance, logistics, field performance information feedback, training, and material management. The function encompasses the defintion of tasks, equipment, skills, personnel, facilities, materials, publications, data, services, supplies, and procedures required to ensure the proper supply storage and maintenance of a system end item.
- **Training**: tasks, actions and activities to be performed with required resources to achieve and maintain the knowledge and skill levels necessary ti perform operations and support functions efficiently and effectively.
- **Disposal**: tasks, actions and activities to be performed with required resources to ensure that disposition of products and by-products that are no longer useful, or no longer fit for use, complies with applicable classified and environmental regulations and directives. The function encompasses the short and long term impact to the environment and health hazards to humans and animals as well as recycling, material recovery, salvage for reutilization, demilitarization and disposal of by-products across the life.cycle.

Engineering - **Deployment of engineering definition**

- contents

Now, let’s forget for a bit the engineering process and look for the tools, that’s the methodologies one should apply in order to carry on an whole project. In order to do that, let’s focus some words and sentences of the engineering proposed definition (ref. page 5) and link them to suitable tools.
Such words and sentences could be the following:

- ✓ **… some ideas (concept) on a good (product or service)** related to the fulfilment of some end users’ requirements
- ✓ … **studies and trials**
- ✓ … **consistency between the stake-holders and …**
- ✓ … **technological and organizational feasability**
- ✓ … **arrangements necessary for the processes generally related to the logistics and manufacturing … the available technologies and the limit of the good’s cost.**

Engineering - **Tools for engineering concepts producing** (i)

So, let's start from «ideas on a good (product or service)». **About this, it has to be clear that such ideas must be meant as the output of a process, whose input can only be the end users' requirement.**

Is it all? No, it isn't. Indeed how would you start working? Of course you'd work taking into account your own experiences and context, **so at least you must feel if the new product could be a (more or less) updating of existing ones or if you should provide a radically new one. In other words: an important topic is the choice between a modular or conventional design.**

Any other note? Yes, of course! Indeed you need to have some **suitable tools** (or to get learnt about).

inputs

… end users' requirements → … framework of the **good's functions** → … choice of the **design typology** → **… some ideas (concepts) on a good (product or service)**

outputs

tools

Mktg tools

Mktg tools aren't subject of this lecture's notes.

- Affinity diagram
- QFD (first matrix / Product Planning Matrix)
- …

- Technology strategy (modular or integral design)
  - modular design
  - integral design.
- DSM (Design Structure Matrix)
- Axiomatic Design
- Triz
- creatvity
- …

the three dots (…) means that , for a speific project, some other topics could be taken into account. In other words, the listed tools are not exhaustive.

an **important** point of emphasis must be given to the Technical Performance Measurement (TPM), that's the «… underlying basis for evaluating the performance of the architecture alternative [Eisner - Essentials of project and system engineering management] Indeed (assuming concepts and architectures as syonymous) one must choose among concepts.

Affinity diagram is just a way finalized to a suitable grouping of collected information.

For instance: the below example is related to fix some performance mesaures (may be preparatory for an improvement); the process starts from the collection of opinions and/or expectations (ref. fig. 1), which are then grouped just for their meaning affinity in four clusters: product quality, manufacturing costs, maintenance, safety and environmental.

Anyway, **it's important to keep in mind that the affinity diagram is the input to the first «QFD house».**

Possible Performance Measures	
% purity	# of OSHA recordables
% trace metals	# of customer returns
Maintenance costs	Customer complaints
# of emergency jobs	Overtime/total hours worked
lbs. produced	$/lb. produced
Environmental accidents	Raw material utilization
Material costs	Yield
Overtime costs	Utility cost
# of pump seal failures	ppm water
Viscosity	Color
Cp_k values	Service factor
Safety	Time between turnarounds
Days since last lost-time	Hours worked/employee
% rework or reject	lbs. waste
Hours downtime	Housekeeping score
% uptime	% capacity filled

Figure 1 Brainstorming for Affinity Diagram Example

[https://asq.org/quality-resources/affinity]

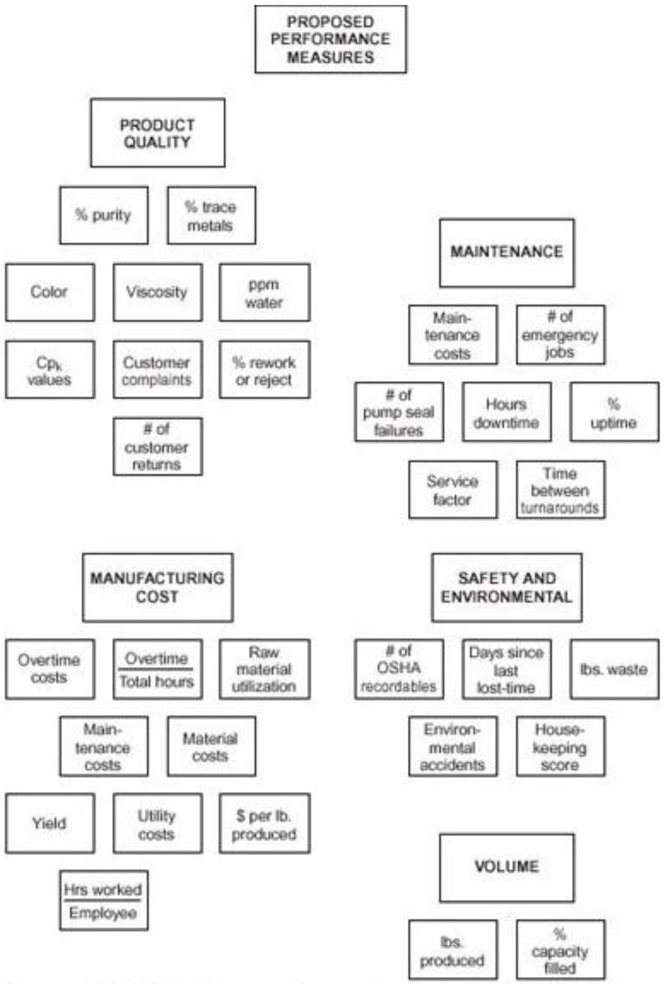


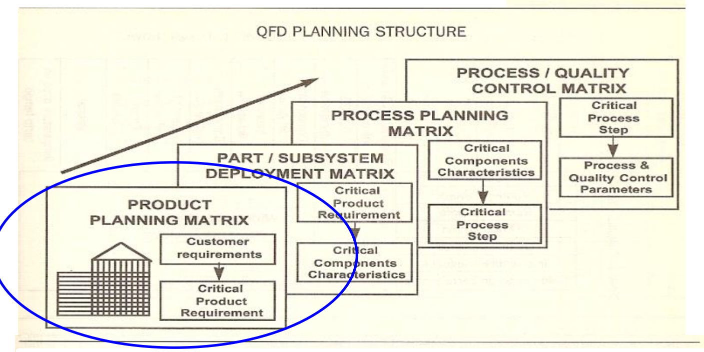
Figure 2 Affinity Diagram Example

Engineering - Tools for engineering concepts producing (iii) – QFD definitions od the good's functional requirements.

QFD is a well-known methodology for the whole product development (from market expectations till operations' processes).

Now, at this stage we're mostly interested **to focus the first QFD matrix**, whose output are the expected product's characteristics.

Conceptual scheme of the QFD development



[*abstract from* F. Franceschini – Quality Function Deployment]

In other words: first matrix gives the **translation of the customer requirements into functional** (and then technical) **requirements**.

That said: **the key point is just functional requirements which can be meant as base references in order to decide between modular on integral (conventional) design.**

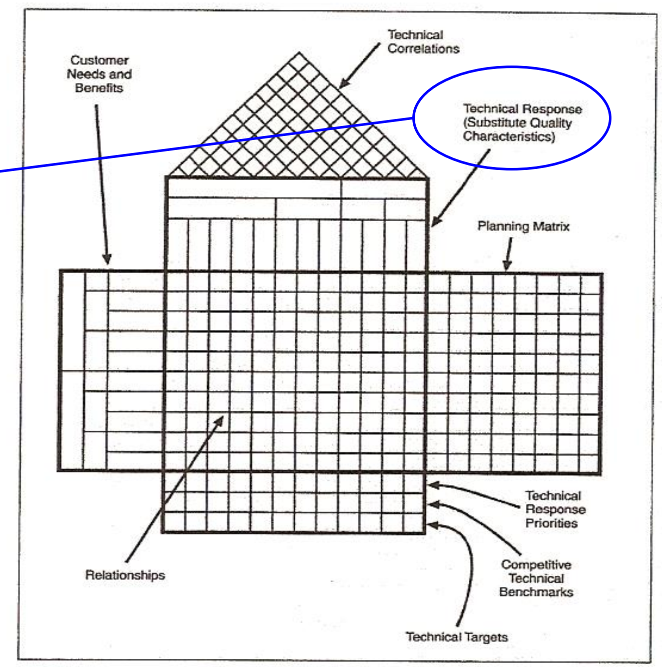


Diagram 4-1. The QFD House of Quality

[L. Cohen – Quality Function Deployment]

Engineering - **Tools for engineering concepts producing** (iv) – from technology strategy to product's typology definition.

The decision between modular or integral design is propedeutic to the **technology strategy** of the company, that's:

- taking strategy as «… strategy making is the process of matching an organization's *internal resources* with *environmental opportunities and risks* to *accomplish goal*»
- *…* one way to define technology strategy is by understanding the products and services a firm brings to market and the intersection of these outputs with their underlying technologies.

[J. Ettlie- Managing Technological Innovation]

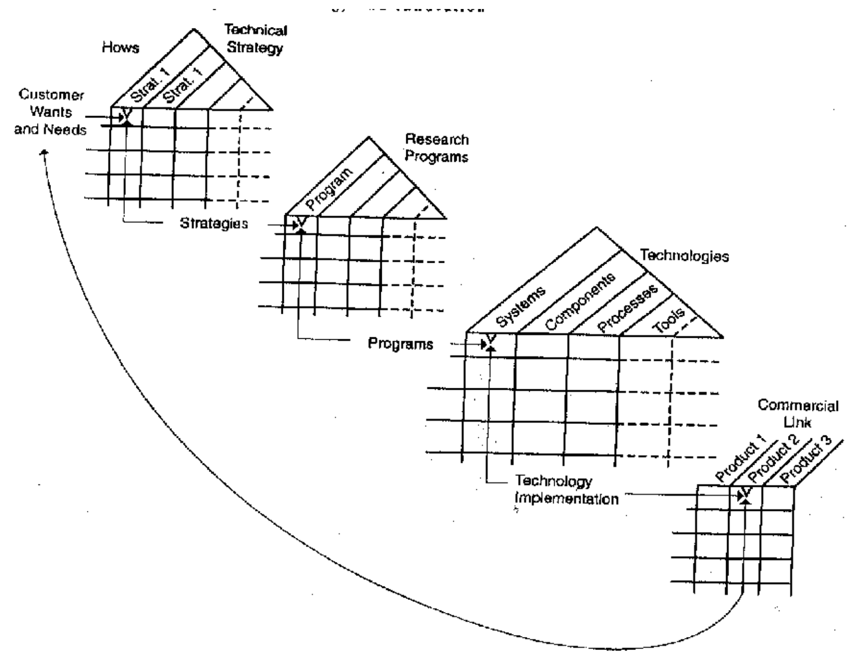


Figure 4-5 Managing Technology at Caterpillar

In other words: as (again) the QFD sketch shows, **the company must decide if to carry on a modular and integral product, that's to define its designing guide-line** (that's the references for products' development).

These subjects will be detailed on next slides, anwyay that means to carry on an organizational analysis. Anyway, technological variables is related to the key variables affecting the operations. Such variables and the individual variables (in rough words: the company skills) depict what a company is able to make.

… and here we have a preliminary **very important remark**, that's the question is «what one should take into account in order to define its designing guidelines?» The answer isn't complexed, but it's important to keep it in mind «of course its **context**, but first of all its **technological variables**».

Engineering - Tools for engineering concepts' producing (v) - modularity

Anyway, assuming technology strategy meaning just in its facet of choising between modular or conventional design, the below table shows the related difference.

Table 2 Differences in Product Definition, Design, and Development in Conventional Versus Modular Product Design

	Definition	*Design*	*Development*
Conventional Product Design	Attributes of 'optimal' product are determined by marketing research.	Product functionality is decomposed into components, but component interfaces are determined during component development processes.	Component designs and product architecture co-evolve in a reiterative process. Product architecture is defined in the final design for the product – i.e., as the output of the development process.
Modular Product Design	Product is conceived as a platform for leveraging product variations and improved models to serve a range of market preferences.	Modular product architecture fully specifies component interfaces at beginning of development and constrains component development.	Modular product architecture allows component development processes to be concurrent, autonomous, and distributed. Product architecture defined at outset does not change during development.

[R. Sanchez – Managing product creation, European Management Journal Vol. 14 1996]

That said, two concepts can clarify the meaning of modular design, that's **platform** and **architecture.**

Engineering - Tools for engineering concepts' producing (vi) – modularity

That said, two concepts can clarify the meaning of modular design, that's **platform** and **architecture.**

Platform is the set of assets shared across a set of products.

K. T. Ulrich, S. D. Eppinger – Product Design and Development]

… and such assets will be combined in order to achieve a suitable architecture whose definition can be

Architecture as "the scheme by which the functions of a product is allocated to physical component".

[Ulrich, K. (1995), "The Role Of Product Architecture In The Manufacturing Firm," *Research Policy* 24, Elsevier Science B.V.]

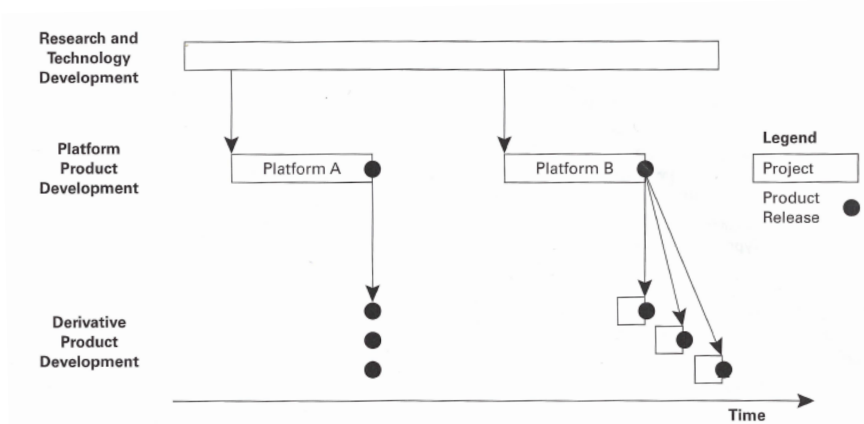
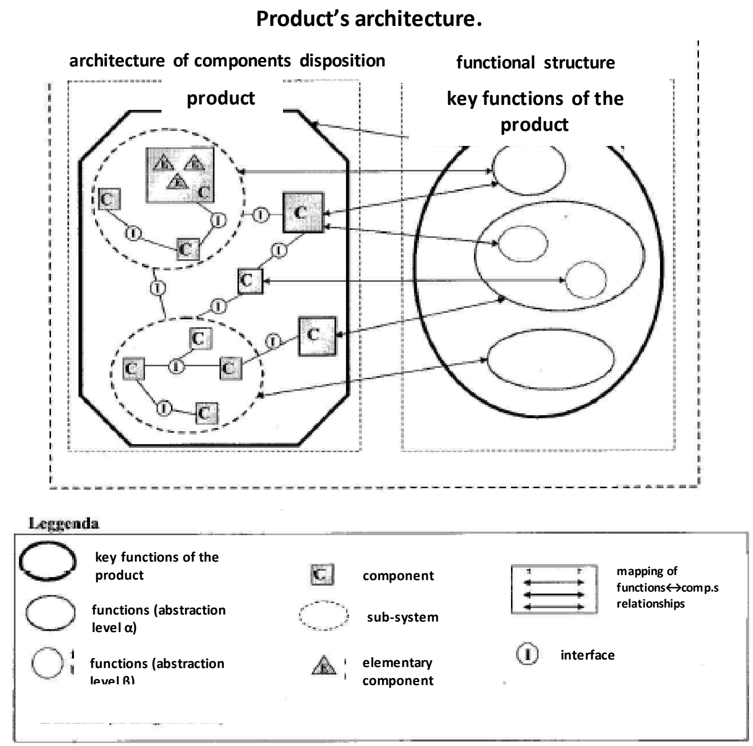


EXHIBIT 4-6 A platform development project creates the architecture of a family of products. Derivative products may be included in the initial platform development effort (Platform A) or derivative products may follow thereafter (Platform B).

K. T. Ulrich, S. D. Eppinger – Product Design and Development]

Graphic description of the concept of product's architecture.



[*abstract from* M. Bordignon – La modularità e il suo potenziale ruolo nelle imprese - Aracne, 2009]

The above drawing (and the App. 4 example as well) can help: starting from a definition of asset as component and/or subassembly, one can get different products by suitable combination of the available assets.

Engineering - Tools for engineering concepts' producing (vii) – modularity

For completion some other things on modularity. First the defintions of modularity and module

Modularity is a special form of design that intentionaly creates a high degree of independence or "loose coupling" between components design by standardizing component interface specifications.

[R. Sanchez, J.T. Mahoney – Modularity flexibility, and knowledge management in production and organization design]

A module is a unit whose elements are powerfully connected among themselves and relatively weakly connected to elements in other units. Clearly there are degrees of connection, thus there are gradations of modularity.

[C. Y. Baldwin, K. B. Clark – Design rules: the power of Modularity]

Such definitions let us introducing to other two things.

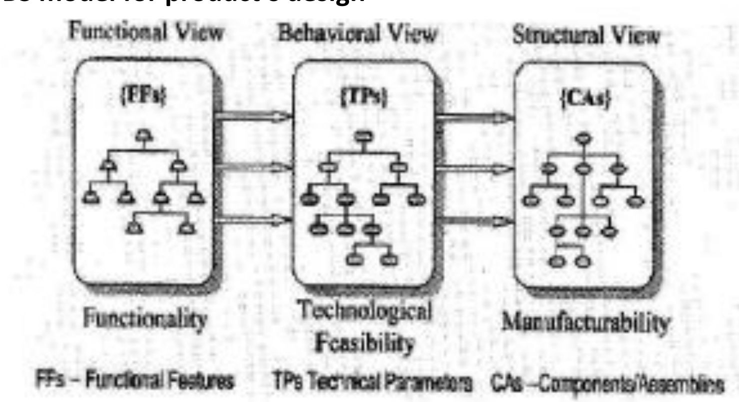
First one is related to the «component interface specifications» mentioned by modularity definition. It means that **a whole modularity design must provide:**

- ❖ **architecture**
- ❖ **interfaces**
- ❖ **standards**

Indeed modules (that's component and or sub-assemblies whose whole makes the asset) must fit, that's must suitably interfacing each other, so one has to provide convenient interfaces, and, looking at their working environment, must fit it, then comply with proper standards.

Second is about the application of modularity concept through the whole development, so there will be an architecture related to the expected functions of the product (FFs), followed by one on the technical choices (TPs) and by the last which will take in account manufacturing issues (CAs).

FBS model for product's design



[*abstract form* S. Gallinaro – LA modularità sviluppo dei prodotti e dei servizi, Imp Progetto n. 1 2009]

Engineering - Tools for engineering concepts' producing (viii) – Design Structure Matrix DSM (basic notes)

One of the design tools linked to modularity is **Design Structure Matrix (DSM).**

Now, DSM is built on some steps:

- Hierarchy of Design Parameters
- Design Structure Matrix
- Tasks Structure Matrix
- Integration and Testing Rules

		1	2	3	4	5	6	7	8	9	10
Material	1	•	x	x			x	x	x		x
Tolerance	2	x	•	x			x	x	x	x	x
Mfr. Process	3	x	x	•			x	x	x	x	x
Height	4			x	•	x			x		x
Vessel Diameter	5		x	x	x	•	x	x	x		
Width of Walls	6	x	x	x	x	x	•	x	x		
Type of Walls	7	x	x	x		x	x	•	x	x	
Weight	8	x		x	x	x	x	x	•	x	
Handle Material	9	x	x	x				x	x	•	x
Handle Shape	10	x	x	x	x					x	•

... hierarchical relationship and interdependencies among design parameters can be formally mapped using a tool called *Design Structure Matrix* (DSM).

➢ **Hierarchical Design Parameters** (HDP)

- it's about **existance of dependance conditions of some parameters by some others.**
- ... by setting a series of switches early on, designers can bound their immediate problems (the design at hand) to one that is manageable given their knowledge and resources. Modular designs are the result of a purposeful, consistent and rigorous application of this boundary.

Such interdependence concept is **important both on modularity theory and generally speaking for designing**: indeed at a certain design stage you must define something around which you'll develop your product.

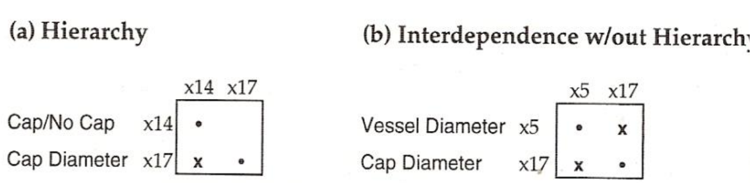


Figure 2.2 Design structure: hierarchical and interdependent design parameters.

[C. Y. Baldwin, K. B. Clark – Design rules: the power of Modularity]

Engineering - **Tools for engineering concepts' producing** (ix) – Axiomatic Design (basic notes)

Axiomatic Design is a system design methodology using matrix methods to systematically analyze the transformation of customer needs into functional requirements, design parameters and process variables. Specifically, a set of Functional Requirements (FRs) are realted to a set of Design Parameters (DPs) by a matrix.

$$\begin{bmatrix} FR_1 \\ FR_2 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \end{bmatrix}$$

[https://en.wikipedia.org]

- Axiomatic Design is based on four basic things:
  - **domains**,
  - **hierarchies**
  - ***zigzagging***
  - **design axioms**

- **Domains** concept is related the four steps fo the transformational process. The output of each domain is the input of the following, so one will have:
  - Cas (Customer Attributes)
  - FRs (Functional Requirements
  - DPs (Design Parameters)
  - PVs (Production Variables)

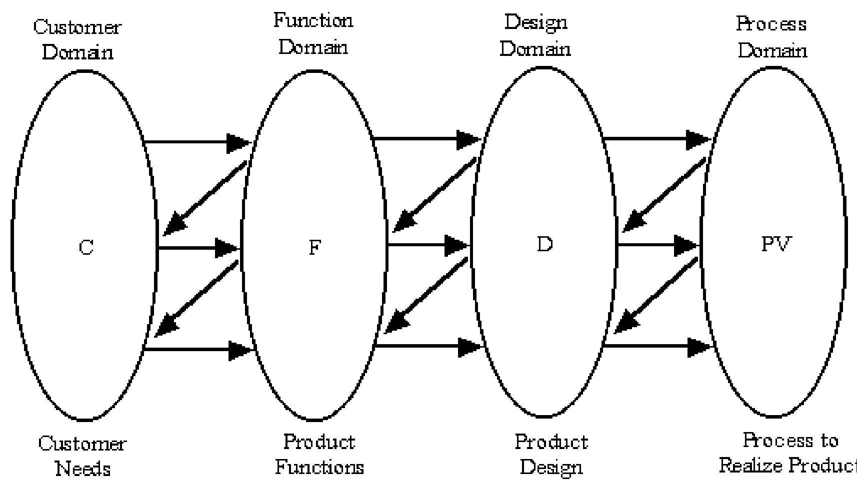
  Of course, there are some constraints related to the possibile solutions, which are represented by a suitable matrix.

- **Hierarchy**, which underlines the possible splitting of high level FRs into second level FRs, determines the product's architecture.

  For instance: the FR is «to fill a bottle», can be deployed in two lower levels Frs like «to avoid the liquid pouring» and «o to guarantee the expected liquid quantity», which could involve two DPs like «to have a funnel» and «to dispose a weighing machine».

- **Zigzagging** expresses the resolution of a design in hierarchies and, in order to find a solution of suitable balances of the variaibles, the alternating among the domains.

- Design **Axioms** are musts which include:
  - indipendence axiom: a specific DP must be linked a specific FR (withiut any link with the other FRs.
  - Information axiom: a good project must minimize the number of links among FRs and DPs.



Product Design (source: Nam P. Suh)

[www.ielm.ust.hk]

Goals = (Design Matrix) * Actions

$$\begin{bmatrix} FR_{11} \\ FR_{12} \\ FR_{21} \\ FR_{22} \\ FR_{23} \\ FR_{24} \end{bmatrix} = \begin{bmatrix} A_{1111} & 0 & A_{1121} & A_{1122} & 0 & 0 \\ A_{1211} & A_{1212} & 0 & 0 & 0 & A_{1224} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & A_{2222} & 0 & 0 \\ 0 & 0 & 0 & A_{2322} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & A_{2424} \end{bmatrix} \begin{bmatrix} DP_{11} \\ DP_{12} \\ DP_{21} \\ DP_{22} \\ DP_{23} \\ DP_{24} \end{bmatrix} \quad (8)$$

[http://www.google.com/patents/US8244503]

Engineering - Tools for engineering concepts' producing (xi) – TRIZ (basic notes)

TRIZ is the acronymous of a Russian noun (Teoriya Resheniya Izobretatelskikh Zadatch) which means «theory of inventing problem-solving»; it has been built by a G. Altshuller (an engineer involved in the Soviet Military Navy) during the sixties, by the analyzing of about 200.000 patents in order to find the related thought patterns.

In the end, Mr. Altshuller defined three basic things:

- **«contradictions»**: a contradiction is defined as a situation which emerges when two opposite demands have to be met in order to provide the results required.
- **«39 engineering parameters for expressing contradictions»**.
- **«40 inventing principles engineering parameters for expressing contradictions**

TRIZ introduces **three types of contradictions: a) Administrative, b) Technical, c) Physical.** TRIZ states that to obtain an inventive (breakthrough) solution, a contradiction has to be eliminated rather than optimized or compromised.

39 engineering parameters for expressing technical contradictions

1 *Weight of moving object*	20 *Energy spent by nonmoving object*
2 *Weight of nonmoving object*	21 *Power*
3 *Length of moving object*	22 *Waste of energy*
4 *Length of nonmoving object*	23 *Waste of substance*
5 *Area of moving object*	24 *Loss of information*
6 *Area of nonmoving object*	25 *Waste of time*
7 *Volume of moving object*	26 *Amount of substance*
8 *Volume of nonmoving object*	27 *Reliability*
9 *Speed*	28 *Accuracy of measurement*
10 *Force*	29 *Accuracy of manufacturing*
11 *Tension, pressure*	30 *Harmful factors acting on object*
12 *Shape*	31 *Harmful side effects*
13 *Stability of object*	32 *Manufacturability*
14 *Strength*	33 *Convenience of use*
15 *Durability of moving object*	34 *Repairability*
16 *Durability of nonmoving object*	35 *Adaptability*
17 *Temperature*	36 *Complexity of device*
18 *Brightness*	37 *Complexity of control*
19 *Energy spent by moving object*	38 *Level of automation*
	39 *Productivity*

[H. J. Harrington – Lean TRIZ]

40 inventive principles (1–20)

Principle 1	Segmentation
Principle 2	Taking out/extraction
Principle 3	Local quality
Principle 4	Asymmetry
Principle 5	Merging/consolidation
Principle 6	Universality
Principle 7	*Nested doll*
Principle 8	Antiweight
Principle 9	Preliminary antiaction
Principle 10	Preliminary action
Principle 11	Beforehand cushioning
Principle 12	Equipotentiality
Principle 13	Do it in reverse/*the other way around*
Principle 14	Spheroidality/curvature increase
Principle 15	Dynamics
Principle 16	Partial/excessive actions
Principle 17	Transition to another dimension
Principle 18	Mechanical vibration
Principle 19	Periodic action
Principle 20	Continuity of useful action

40 inventive principles (21–40)

Principle 21	Rushing through/skipping/hurrying
Principle 22	Converting harm into benefit
Principle 23	Feedback
Principle 24	Intermediary/mediator
Principle 25	Self-service
Principle 26	Coping
Principle 27	Cheap, short-living objects
Principle 28	Mechanical interaction substitution
Principle 29	Pneumatics/hydraulics
Principle 30	Flexible shells and thin films
Principle 31	Porous materials
Principle 32	Color changes
Principle 33	Homogeneity
Principle 34	Rejecting and regenerating parts/discarding and recovering
Principle 35	Parameter changes
Principle 36	Phase transition
Principle 37	Thermal expansion
Principle 38	Accelerated oxidation/strong oxidants
Principle 39	Inert atmosphere
Principle 40	Composite materials

[H. J. Harrington – Lean TRIZ]

Engineering - Tools for engineering concepts' producing (xii) – TRIZ (basic notes)

Here below the contradictions matrix, which, for any engineerin parameter, shows the related inventive principles.

The example shows first lines of the matrix. For instance: taking an «weight of a mobile object» as engineering parameters, contradictions arise with «lenght of a mobile object» and «area of a mobile object», whose possible inventive principles are:

- n. 15 – Dynamics, whose possible suggestions are:
  - to allow or design characteristics of an object, external environment, or process to chage to be optinal or to find an optial operating condition.
  - to divide an object into parts capable of movement relative to each other.
  - if an object (or process) is rigid or inflexible, make it movable or adaptive
- n. 8 – Anti-weight (Counterweight), about which the related proposals are:
  - to counter the weight of an object, merge it with other objects that provide lift.
  - to compensate for the weigth of an object, make it interact witht he environment (e.g. use aerodynamics, hydrodynamics, buoyancy, and other froces).
- ...

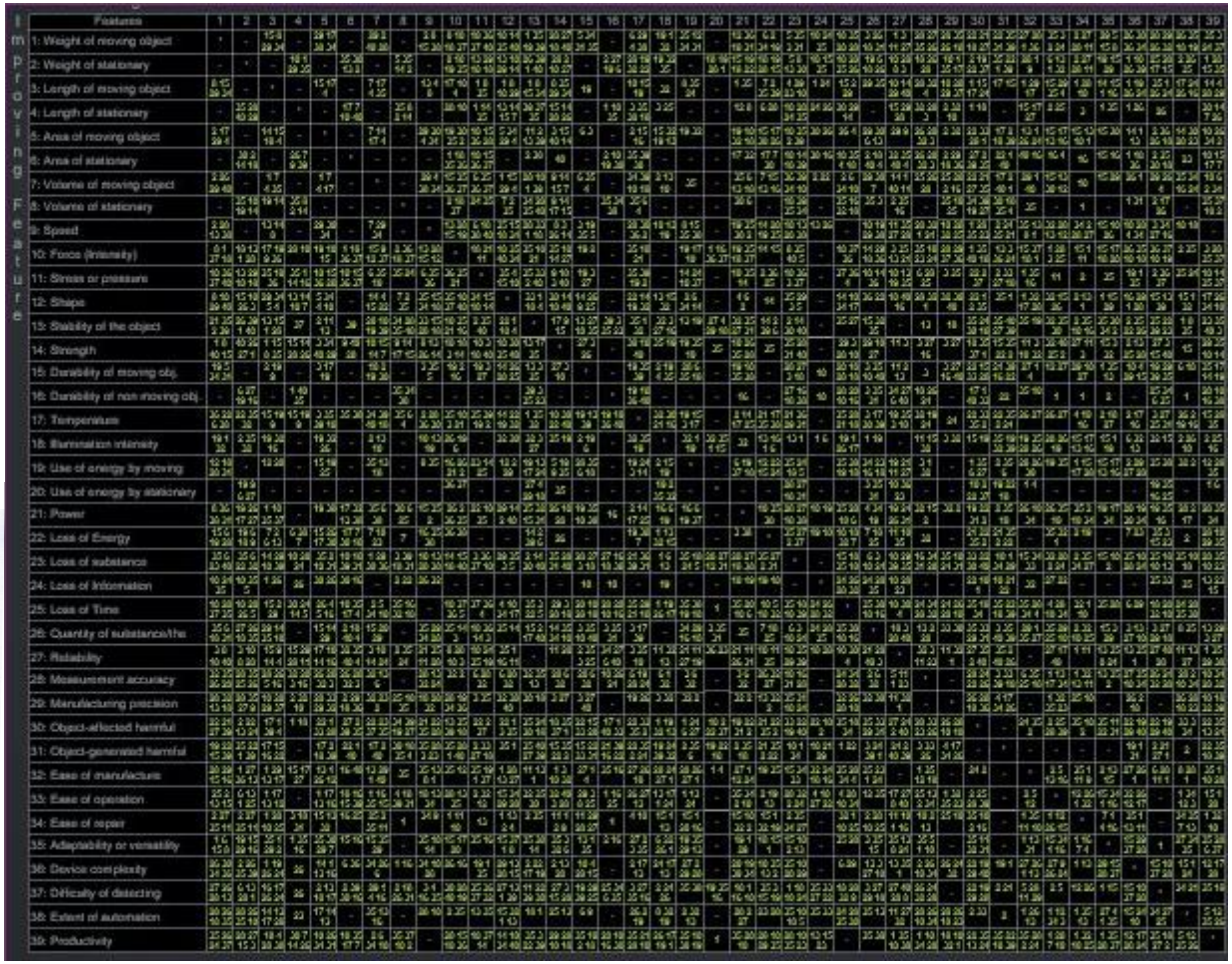
[*abstract from* S. D. Savransky\ - Engineering of creativity]

		Weight of a mobile object	Weight of a stationary object	Length of a mobile object	Length of a stationary object	Area of a mobile object
		1	2	3	4	5
Weight of a mobile object	1			15, 8, 29, 34		29, 17, 38, 34
Weight of a stationary object	2				10, 1, 29, 35	
Length of a mobile object	3	8, 15, 29, 34				15, 17, 4
Length of a stationary object	4		35, 28, 40, 29			
Area of a mobile object	5	2, 17, 29, 4		14, 15, 18, 4		

FIGURE 2.21
First five lines on the matrix of system constraints.

[*abstract* H. J. Harrington – Lean TRIZ]

[www.triz40.com]



Engineering - Tools for engineering concepts' producing (xiii) – TRIZ (basic notes)

That said, let's have a more complete definition of TRIZ.

TRIZ is a human oriented knowledge-based suystematic methodology of inventive problem solving

S. D. Savransky\ - Engineering of creativity]

Indeed:

- **Knowledge**
  - the knowledge about the genercio problem-solcing heuristics (i.e., rules for making steps during problem-solving) is extracted from a vast number of patents worldwide in different engineering fields. …
  - it uses knowledge of effects in the natural and engineering sciences. …
  - it uses knowledge about the domain where the problem occurs.
- **Human-oriented**
  - … the TRIZ practice is based on dividing a technique into subsystems, distinguishing the useful and harmful functions of a technique, and so on. Such operations are arbitrary because they depend on the problem itself and on socio-economics circumstances, so they cannot be performed by a computer. …
- **Systematic**
  - … generic and detailed models of artificial systems and processes are considered within the TRIZ frramework … and the systematic knowledge about these systems and processes is important. …
  - Procedures for problemsolving adn the heuristics are systematically structured …
- **Inventive problems and solving**
  - … TRIZ abstractions for inventive problem and solving include:
    - often the unknown step appears because of contrddictory requirements for the system,
    - often the unknown desirable situation can be replaced temporarily by an imaginary ideal situation,
    - usually the idel situation can be obtained due to resources from the environment or from inisde the technique,
    - Usually the ideal situation can be projected from known trends of echnique evolution.

[*abstract from* S. D. Savransky\ - Engineering of creativity]

Engineering - Tools for engineering concepts' producing (xiii) – TRIZ (basic notes)

Cretivity involves the use if skill and imagination to produce something new or a work of art

So, creativity needs to overcome inertia: the personal will of involvement in different fields is the tool

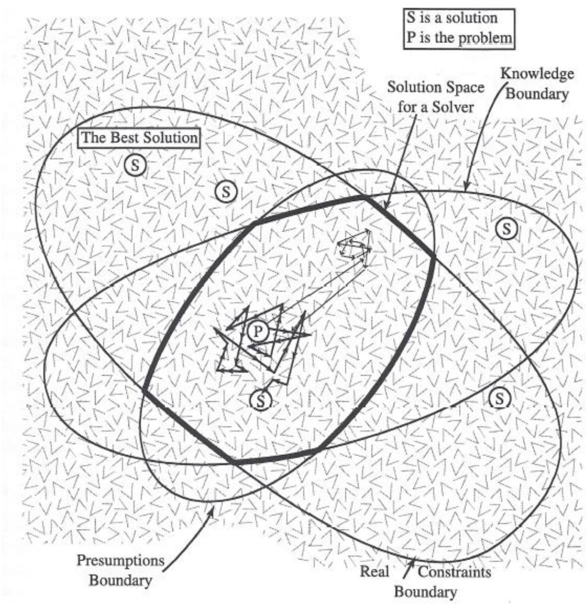


FIGURE 1.2 The trial-and-error method by a solver with high psychological inertia.

[S. D. Savransky\ - Engineering of creativity]

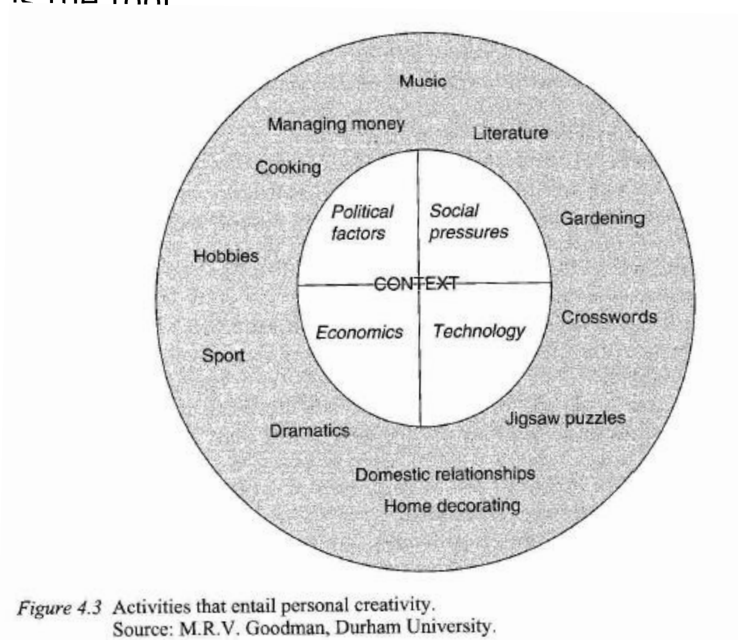


Figure 4.3 Activities that entail personal creativity.
Source: M.R.V. Goodman, Durham University.

[M. Goodman, S. Dingli – Creativity and strategic innovation management]

By the way, as showed in the prosecution of these lecture's notes, an organizational analysis is necessary in order to proper manage a project. One of the variables is related to individuals, so, in this case, to their creativity level as well.

Engineering - **studies and trials** - introduction - WBS

Let's come back to the engineering definition (ref. page 5): once one has defined its concepts, it has to pass to «study adn trials», about which first question is: studies and trials on what?

Indeed it's a sensible question, whose first logical answer is on the parts composing the concept, so first step is the cocept decomposition, that's to work accordingly to the application of **WBS** logic (**Work Breakdown Structure**).

- ✓ **triggered by some ideas (concepts) on a good (product or service) related to the fulfilment of some end users' requirements**

WBS ⇩

- ✓ **… and substantiated by studies and trials finalized:**

That said, there is another question: **which should be the decomposing level?** There isn't any definite answer, **one has to define it accordingly to its-own knowledge needs** (roughly speaking: you should further decompose accordingly to the increase og technical intricacy).

A good reference for WBS meaning and application is MIL-STD-881C (Work Breakdown Structures for Defence Materiel Items).

By the way, as underlined by the above standard, WBS provides a common thread for Project Mgmt as well, indeed, the engineering process decomposition is a proof about (it'll be better defined later taking on Engineering Process Framework).

1.5.3 Work Breakdown Structure (WBS). This term is defined as:

a. A product-oriented family tree composed of hardware, software, services, data, and facilities. The family tree results from systems engineering efforts during the acquisition of a defense materiel item.

b. A WBS displays and defines the product, or products, to be developed and/or produced. It relates the elements of work to be accomplished to each other and to the end product. In other words, the WBS is an organized method to breakdown a product into sub-products at lower levels of detail.

c. A WBS can be expressed to any level of detail. While the top three levels are the minimum required for reporting purposes on any program or contract, effective management of complex programs requires WBS definition at considerably lower levels. This is particularly true of items identified as high-cost, high-risk, or high technical interest. Under these circumstances, it is critical to define the product at a lower level of WBS detail. In this case, managers should distinguish between WBS definition and WBS reporting. The WBS should be defined at the level necessary to identify work progress and enable effective management, regardless of the WBS level reported to program oversight.

[*abstract from* MIL-STD-881C]

Engineering - **studies and trials** - introduction - WBS

The sketches show two WBS examples coming from MIL-STD-881C and related to the decomposition of:

- the an whole (acquisition) process,
- the a system (product)

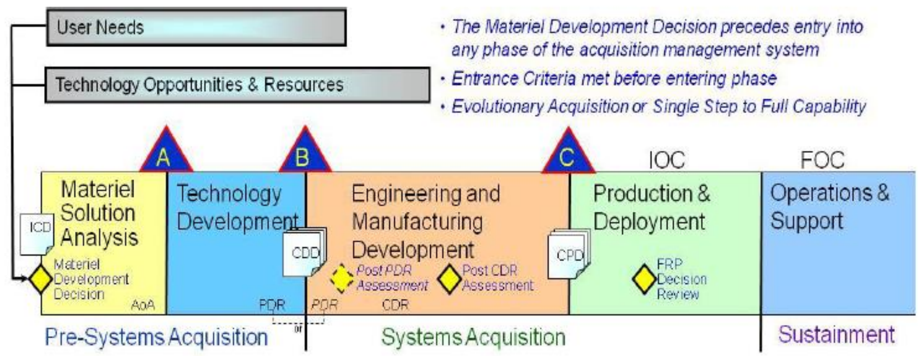
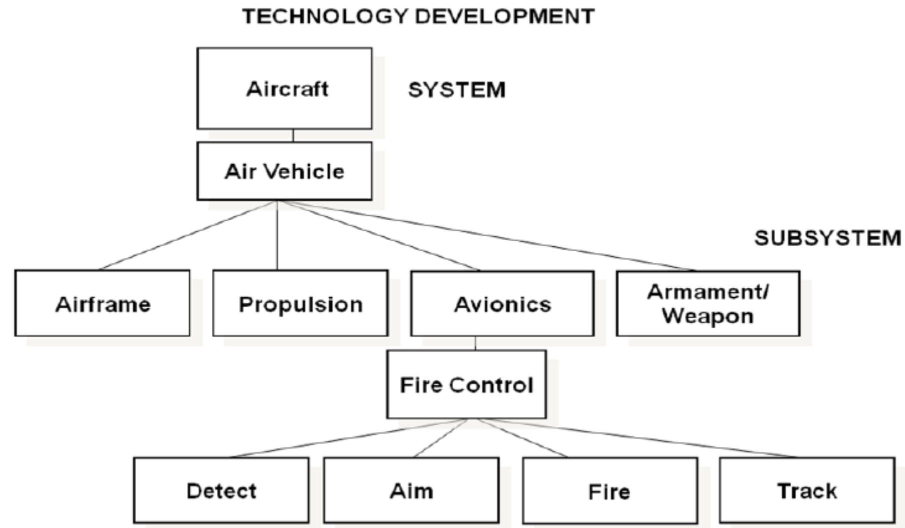


FIGURE 1. The Defense Acquisition Management Framework

[*abstract from* MIL-STD-881C]



[*abstract from* MIL-STD-881C]

FIG

Engineering - **studies and trials** - introduction - purpose

First: why should one carry on «studies and trials»? The answer could be obvious, anyway it's easy and comes just from the meaning of design. Indeed a design must contain novelties, so something whose characteristcs and/or outputs are uncertain; in the end **«studies and trials» are in order to reduce uncertainty and/or to prevent not functionality or dissatisfaction risks**.

That said: uncertainty, not functionality and dissatisfaction on what? Let's remind the definition of engineering showed at pag. 5.

✓ **… studies and trials finalized:**

- **to verify the consistency between the stake-holders expectations and**
  - **both the good's performances**
  - **… and the characteristics of the processes linked to the the good's life cycle.**
- **to check the technological and organizational feasability of the good about which the above tests are carried out,**
- **to make all the arrangements necessary for the processes generally related to the logistics and manufacturing (at any rate taking into account the available technologies and the limit of the good's cost),**

The above matters arise a lot of things. Nevertheless it couldn't be different taking into account that a project implies some new things, which one must know, that's one must experience and check.

> Defintion of project: "… an endeavour in which human, material and financial resources are organized in a novel way, to undertake a unique scope of work of given specification, within constraints of cost and time, so as to achieve unitary, beneficial change, through the delivery of quantified and quantitative objectives".
> [C. Chapman, S, Ward – Project risk management]

So, looking at what above, studies and trials must be done on a lot of things, indeed:

- one will have to analyze if the stake-holders expectations (see page27), which won't be only related to the good you're designing, that involves some **managerial analyses** (for instance a company could be stimulated to outsource or viceversa, to build a new location etc.).
- technological and organizational feasability means:
  - that you have to assess your concept, that's you must make it true. This mean to carry out technical studies and investigations, which could include suitable **calculations** (like, and of course if applicable on the specific project you're working out, structural calculations, eletrical parts' dimensioning, materials properties' investigations etc.) and **prooves**, and inferences on the prooves' level of confidence as well. Furthemore (anyway likely) may be that your product must comply some specific tests (for instance for safety, environment etc.) provided by international standards or by your client or by your company and business sector themselves.
  - about organizational the key topic is about your company, so does it have the right skills (generally speaking resources) in order to develop the project? Such matter implies a sort of **organizational analysis** just on organization's abilities (completeness).
- ref. to «logistics and manufacturing»: again a lot of issues to be checked, anyway two fundamental subjects:
  - suppliers must be involved during the project development (not after the project's completion). Indeed if one chooses a supplier for a new or updated component, it must be sure that such supplier is really able to supply the requested part before the production starting; besides it must be sure to supply at the expected quality level, cost and quantity. This will mean to carry out a **suppliers scouting** activity.
  - of course expectations on quality, cost, capacity (may be lead time as well) must be also considered on your manufacturing facilities (also in case of outsourcing), so it will imply an analysis on your **technological variables**.

Engineering - **studies and trials** - introduction – overview on contents

Summing up:

inputs

... concepts → ... «studies and trials» → ***outputs*** ... product and processes documentation prototyping → ... production phase-in

- ✓ ref. to ***managerial analyses***
  - make-or-buy analysis
  - financial
  - ...
- ✓ ref. to ***technological and organizational feasibility***
  - **calculations**
    - structural analysis
    - dynamics of machines
    - electrical parts (electric motors a, cables, IP levels etc.)
    - thermodynamics (heat exchange etc.)
    - reliability
    - DOE (Design Of Experiments)
    - ...
  - **prooves**
    - static and dynamic tests on materials properties
    - reliability and maintainability
    - environmental endurance (corrosion, high temperature resistance etc.)
    - materials recyclability
    - tests required by standards
    - ...
  - **organizational analyses**
    - individual and social variables
    - resources' needs
    - ...
- ✓ ref. to ***logistics and manufacturing***
  - suppliers' approval
  - technological variables
  - DFMA
  - Ishikawa diagram
  - ...

the three dots (...) means that, for a specific project, some other topics could be taken into account. In other words, **the listed items are not exhaustive**.

Important note: The listed items relate huge body of notions. In this course's context they're showed just in order to take into account possible activities whose development could be necessary in a project.

Engineering - **studies and trials** – managerial analyses

We used the expression «managerial analyses» in order to link it to the whole stake-holders, that's:

- employees,
- share-holders (and other financial actors like banks, may be stock exchange etc.)
- customers (end-users of the product you're developing)
- suppliers
- community (it could include both local community, that's the district where the company is, and business community as well).
- «others»

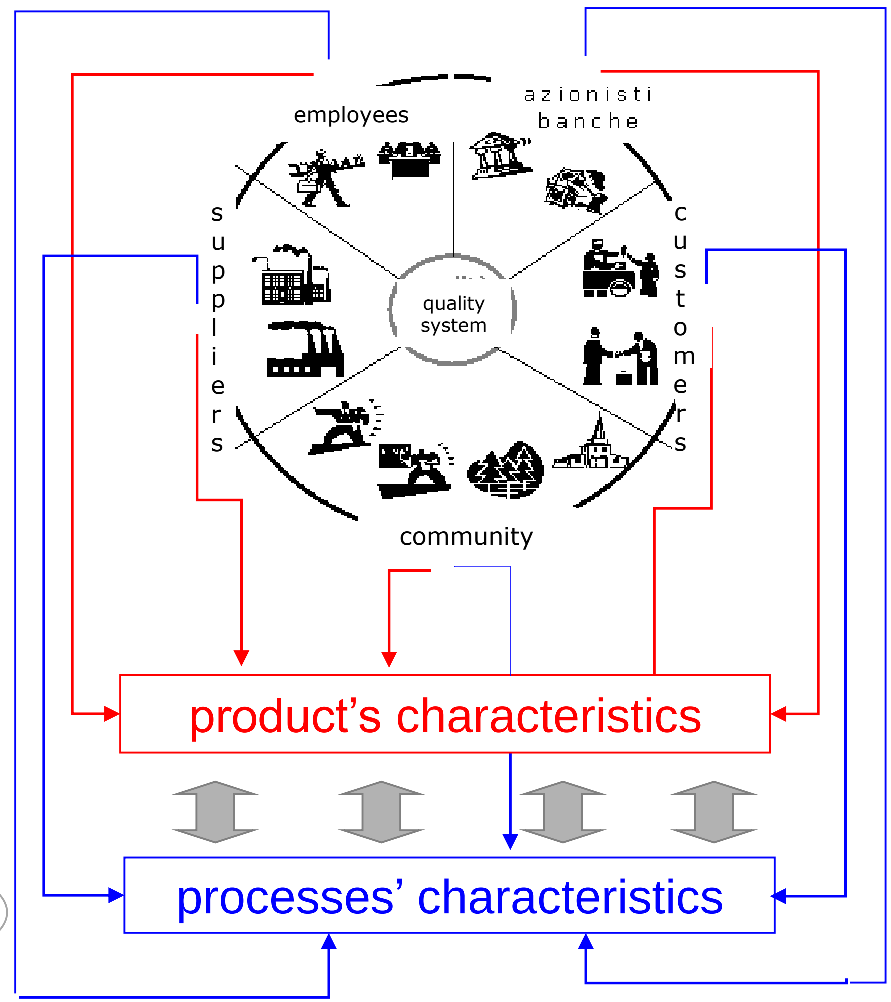
So, it's important to consider that, apart customers, **most of the stake-holders are more interested on the processes related to the product and not to the product itself.**

Indeed, processes are a source of employability and experience both for the employees and the community, again shareholders can get their reward from the righ level of processes' efficiency and effectivenees etc.

In the end, may be from the stake-holders expectations some musts will spring, and such musts will influence the project; so, they have to be suitably checked during the whole project. Typical ones are the product's cost (so the related profit) and outsourcing decisions.

By the way, the showed distinction on expectations and the link between product and processes prompt that there are two «branches» of engineering that's **product engineering** and **process (or manufacturing) engineering** (see pages 72-73 as well).

of course, **not all stake-holders have the same importance level**. Apart from customers, the significance of the other ones depends by their ability to influnece the company's decisions' process.



Engineering - studies and trials – technological feasability – calculations (structural analysis, dynamics of machines etc.)

About «calculations» it should be quite evident that an exhaustive work would pertain specialized people. Anyway, although someone's task could be limited to the design process' plan, she or he has to know the essentials of what is planning.

✓ ref. to **Technological and organizational feasibility**

- **calculations**
  - structural analysis
  - dynamics of machines
  - electrical schemes
  - reliability
  - DOE (Design Of Experiments)
  - ...

In other words, looking at the context of this course, one has to act as Project Manager, who isn't required to carry out specific technical job, but is asked to know the content of what is planning.

Just as additional and very concise information: the Project Manager functions are planning, organizing, leading, controlling.

So, that said let's start from structural and machine dynamics calculations.

Structural analysis

Structural analysis is the determination of the effects of loads on physical structures and their components. … . Structural analysis employs the fields of applied mechanics, materials science and applied mathematics to compute a structure's deformations, internal forces, stresses, support reactions, accelerations, and stability. The results of the analysis are used to verify a structure's fitness for use, often precluding physical tests. Structural analysis is thus a key part of the engineering design of structures.

[*abstract from* https://en.wikipedia.org/wiki/Structural_analysis]

Dynamics of machines

Dynamics of machines is a branch of the theory of machines and mechanisms that studies the motion of machines and mechanisms, taking into account the forces acting on them. The dynamics of machines and mechanisms deals with the following basic problems: definition of the laws of motion of the components of mechanisms, control of the motion of the components, determination of frictional losses, determination of the reactions in kinematic pairs, and balancing of machines and mechanisms.

[http://encyclopedia2.thefreedictionary.com/Dynamics+of+Machines]

It's to notice that both definitions mention the loads and forces acting on parts of a structure or of a machine (or a mechanism) and the related effects, that's deformations, frictional losses (then losses of energy in the form of heat) etc. Therefore one of the things to know is the ability of materials to undergo the aboove loads anf forces, namely the **materials properties**.

Engineering - **studies and trials** – technological feasability – **calculations** (structural analysis, dynamics fo machines etc.)

- **Physical properties**
  - ✓ **Mechanical properties**
    - **Stresses and strains behaviour** module of elasticity or Young module E: materials' strenght to the elastic deformation under tensile or compression stress – Pascal Pa = N/m²]
    - **Static resistance** (breakage tension) [Pa = N/m²]
    - **Hardness** [Brinell or Vickers numbers → permanent impression in a tested material left by a load]
    - **Resilience** (crashworthiness) [J/m³]
    - **Tenacity** (fracture toughness) [J → Izod impact testing]
    - **Fatigue resistance** [number od cycles necessary to the reaching of strain, breakage etc state]
  - ✓ **Thermal properties**
    - **Thermal expansion** [thermal expansion coefficient m³ /°K]
    - **Thermal capacity** [J/°K]
    - **Thermal conductivity** [W/m°K]
    - **Thermal shock resistance**
  - ✓ **Melting temperature** [°K]
  - ✓ **Density** [kg/ m³]
  - ✓ **Electrical properties**
    - **Resistivity** [ρ = m V/A]

First classification of materials properties is about the distinguishinig between physical and technological characteristics, that's to the characteristics respectively related to the ability of a material to be used in specific contexts and the one about its reaction in specific technological processes.

- **Technological properties**
  - ✓ **Ductility/malleability**

    Characteristic of a material to be cold-formed by plastic strain.
  - ✓ **Fusibility**

    Inclination of a material to pass from the liquid to the solid state.
  - ✓ **Hardenability**

    Capacity of a material to increase its hardness and mechanical properties when submitted to an hardening process (roughhy speaking: an hardening process consists in an heating to high temperature followed by a sudden cooling).
  - ✓ **Weldability**

    Inclination of a material to be welded.

Engineering - **studies and trials** – technological feasability – **calculations** (structural analysis, dynamics fo machines etc.)

- Looking at the mentioned properties, materials can be classified as:
  - **Metallic** (metallic nature elements) → crystalline structure, high density, high mechanical strain, malleabillity, good thermal and electrical conducibilities etc.
  - **Ceramic** (oxides and silicates) → crystalline structure, hardness and fragility, good thermal and electrical insulation characteristics, good resistance towards corrosion and wear etc.
  - **Polimeric materials – plastics** (macromolecular synthetic or natural organic compounds) → low density, low dimensional stability, high malleability etc.

- It's to take into account that excellent properties of a material can (of course) be poor in another one. For instance, hardness is high for ceramic material and not so high for metallic ones, viceversa for fragility, density (weight) is low for polimeric materials and high for metallic, viceversa for dimensional stability etc.

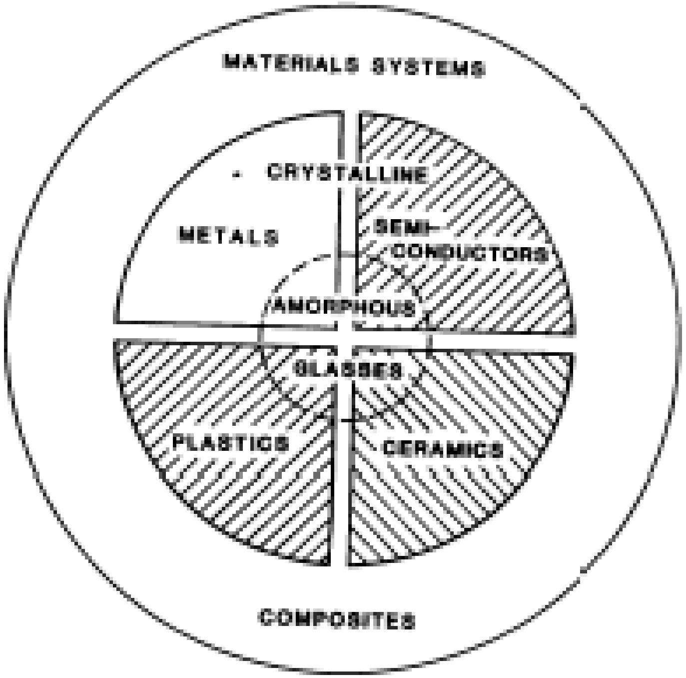


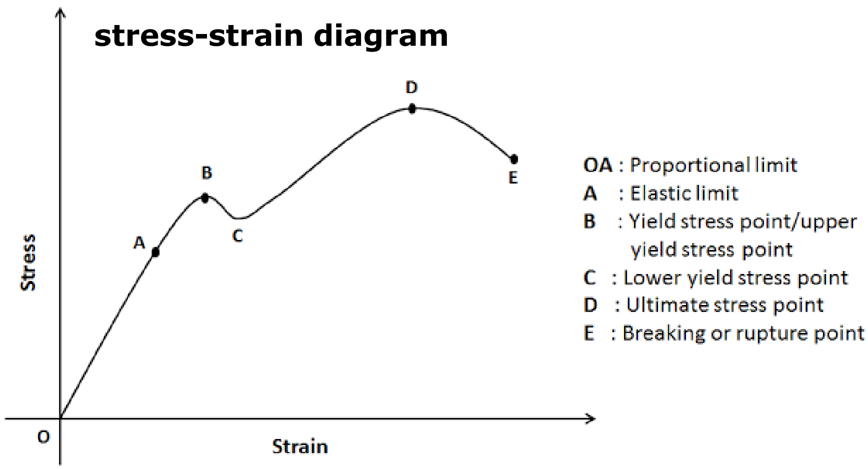
Figure 1. Simple pictorial classification of material and materials systems. The dotted circle is indicative of the fact that any of the four major classes can be regarded as glasses or as having glassy structures under certain conditions. Composites can be developed by a variety of combinations of ceramics in metals, ceramics in polymers, and so on.

[L. M. Murr – Material and Component Failure]

Engineering - **studies and trials** – technological feasability – **calculations** (structural analysis, dynamics fo machines etc.)

Just as *very basic notion* about dimensioning of a axial tensile stressed part, one should consider that:

- of course a no permanent strain or breaking are expected, so the part must work in its plastic limit (ref. to point A of the drawing), that's in a situation in which the strain caused by the tensile stress will disappear at the end of the tensile stress itself.
- the applied tensile strength (let's name it N) will act on all the portions of the stressed part, so, considering a beam whose section is A, the unit stress will be σ = N/A [kg/mm2]. Now, taking Young module E as characteristic of a material, the unit elongation ε is linked with the unit stress and **Young module** by the relation **σ = E · ε**

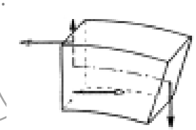


[www.mechanicalbooster.com]

That said, how one would compute the min sectional area which a certain part should have in order not to exceed its elastic limits? The answer is quite easy: after having choosed a specific material characterized by its Young module E and by a max admissible unit strength σ_{adm} the min area A_{min} will be

$$A_{min} = \frac{N}{\sigma_{adm}}$$

The example is related to the tensile strength. Anyway,, it's to consider that dimensioning related to compression and to bending comes from the same considerations. Indeed, one can see compression just as a strength having opposite direction than tensile one, while you can perceive bending effects by the below sketch, where some parts are compressed and some others elongated.



Engineering

- **studies and trials** – technological feasability – **calculations** (electrical parts - **motor**)

And now let’s spend some words on electrical parts, about which some very basic notions on the dimensioning of an electric motor, a cable an about IP level are proposed.

So, electrical motor: apart any consideration on the eletrical motor types (main differentiation is between alternating current AC motors, direct current DC motors), **the main parameters for an electric motor dimensioning** are:

- **number of revolutions (N)**
- **max torque (C_m)**

by which one can compute the **motor power P_m** by

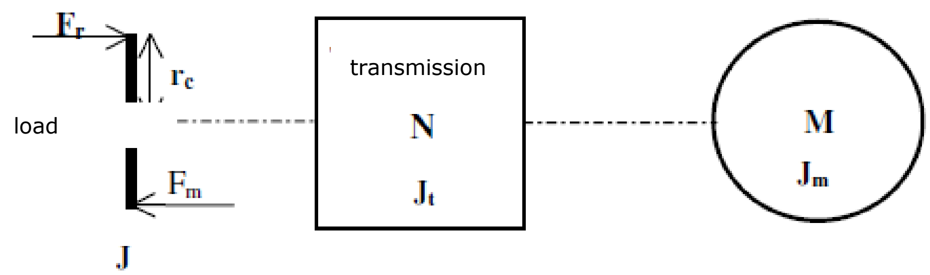
$$P_m = C_m \cdot \omega$$

where ω is the angular rate $\omega = N \cdot 2\pi/60$ [rad/sec]

That said, another key information for dimensioning is the application, which distinguishes between motor for translational (linear) movement and for rotating movement. More in details about translating movement: between the motor and the moved item there will be some devices finalized to translate the motion from translation to rotating or viceversa. The whole is named **cinematic chain**, below sketched.

Sketch’s legenda

- J: moments of inertia (which determines the torque needed for a desired angular acceleration about a rotational axis; similar to how mass determines the force needed for a desired acceleration).
- N: gear ratio
- M: motor.

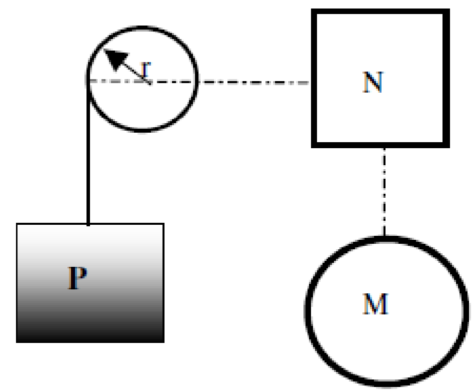


[*abstract from* PLC Forum www.plcforum.it]

Let’s see a summarized application next page.

Engineering - **studies and trials** – technological feasability – **calculations** (electrical parts - **motor**)

The sketch shows a lifting system constituted by a load P, a pulley whose radio is r, then a gear whose reduction ratio is N and a motor M.



[*abstract from* PLC Forum www.plcforum.it]

Looking at previous page formulas, in order to dimension the motor one must find its torque. Now considering that the torque applied to the pulley is $C_r = P \cdot r$, the theoretical couple of the motor should be the same, then $\mathbf{C_m = - C_r}$

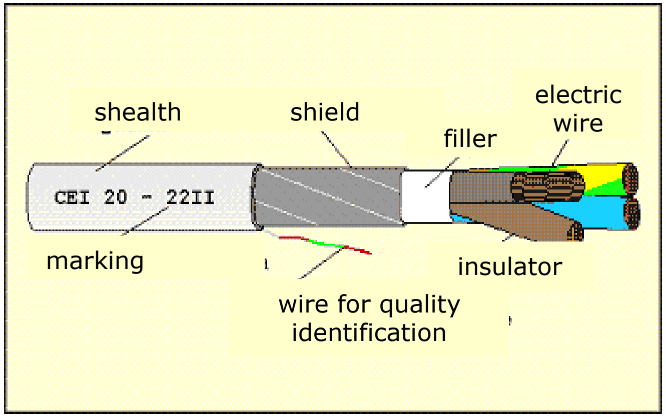
Now, **in a theoretical scheme** - that's *without considering the system efficiency, losses due to the friction (for instance between the rope hanging the load P and the pulley etc.), the moments of inertia of the pulley, the gear etc* – one could just compute the motor power. Indeed, if you define a certain number of revolutions N, the power will be given by $\mathbf{P_m = C_m \cdot N \cdot 2\pi/60}$.

Of course, a complete calculation must be real (not theoretical), so including the moment of inerzia of the load, the pulley, the gear and the motor itself one must consider an additional torque given by $\mathbf{C_a = J_t \cdot \delta\omega / \delta t}$, then the total torque will increase to $\mathbf{C_t = C_m + C_a}$ and consequently the power will rise as well.

As additional note: of course what showed by the above exercize is just a very basic element useful to address people to the choice of an electric motor. That said, at least one must consider the tipology of electric motors, about which first distinguishing is between DC motor (directcurrent motor) and AC motor (alternating current).

Engineering - **studies and trials** – technological feasability – **calculations** (electrical parts - **cables**)

Just as introduction to cables - and apart from the key function of a cable, that's to conduct a current at a defined voltage - let's consider that they must be protected by the working environment and, at the same time, they don't have to interfere on external systems (so cable must have a suitable dielectric or insulation strength, to be shielded for electro-magnetic effetcs etc.); that said a generic cable includes the parts showed by the picture.



[*abstract from* www.electroyou.it]

Anyway, cables configuration (just like several other things as their choice criteria, laying ways etc) are defined by IEC international standards. An important criteria is the cables classification accordingliy to their working voltage, that's distinguishes:

- Low voltage (L.T.) cables - operating voltage upto 1 kV
- High voltage (H.T.) cables - operating voltage upto 11 kV
- Super tension (S.T.) cables - operating voltage upto 33 kV
- Extra high tension (E.H.T.l cables - operating voltage upto 66 kV
- Extra super voltage power cables - operating voltage beyond 132 kV

Two further things: **I)** there are several other classifications criteria based on the insulation material, the number of strands, the conductor. **II)** apart from high and very high voltages, a common classfication splits 250/440 V (suitable for single phase or three-phase system where the voltage between each conductor and earth doesn't exceed 250V) and 650/1100V (suitable for single phase or three-phase system where the voltage between each conductor and earth doesn't exceed 650V).

Now, in order to dimensionate a cable (and besides any other, at any rate significant, consideration related to the cable configuration) **first thing is to find out its conductor dimensions, that's its sectional area,** about which main parameter is the **resistivity** of a material, that's a parameter which quantifies how strongly that material opposes to the flow of an electrical current (resistivity opposite is conductivity).

So, resistivy unit is Ωm (Ohm x m), the cable (that's what we have to dimension) has itsown resistance, so we must know both cable's resistivity and define its lenght. That said resistance is tied to resistivity by the relation. $\boldsymbol{R} = \boldsymbol{\rho} \times \frac{\boldsymbol{l}}{\boldsymbol{S}}$ where l is the lenght of the cable and S its section. that's our unknown parameter about whose definition one must know R. In the end, taking into account that the voltage drop (V_c) on the cable is about 2% of the voltage V applied to the load and taking that the related power is P, the cable resistance (Rc), the cable section is $\boldsymbol{S} = \boldsymbol{\varrho} \times \boldsymbol{l} \times \frac{\boldsymbol{P}}{\boldsymbol{0{,}02\ V^2}}$

Engineering - **studies and trials** – technological feasability – **calculations** (electrical parts - **cables**)

Anyway, let's consider an example, that's the parameters of the electric load are P=1000W and V=250V; we must compute the section of a cupper cable. So the current will be I=P/V=4A and the electric drop on the cable is Vc=0,02x250=5V; from such figures the cable resistance is $R=V_c/I=5/4=1{,}25\Omega$, then, taking that the cable's lenght is l=5m and knowing that the cupper resistivity $\varrho = 1{,}69\times10^{-8}$ Ohm m, the cable section will be $S=\varrho\times l/R=0{,}27mm^2$.

That said, two other things:

- first let's consider that the showed formula and example are referred to a DC current and to a unipolar cable. If you should consider AC current and multipolar cables, some other (light) consideration must be done.
- second: cables' section are standardized and provided by AWG table (as on the right one).

American Wire Gauge (**AWG**), is a logarithmic stepped standardized wire gauge system used since 1857, predominantly in North America, for the diameters of round, solid, nonferrous, electrically conducting wire. Dimensions of the wires are given in ASTM standard B 258.[1] The cross-sectional area of each gauge is an important factor for determining its current-carrying ampacity.

AWG	Diameter		Turns of wire, without insulation		Area		Copper wire							
							Resistance/length[7]		Ampacity,[8] at 20 °C insulation material temperature rating, or for single unbundled wires in equipment for 16 AWG and smaller[9]			Fusing current[10][11]		
									60 °C	75 °C	90 °C	Preece[12][13][14][15]	Onderdonk[16][15]	
	(in)	(mm)	(per in)	(per cm)	(kcmil)	(mm²)	(mΩ/m[a])	(mΩ/ft[b])	(A)			~10 s	1 s	32 ms
0000 (4/0)	0.4600[c]	11.684[c]	2.17	0.856	212	107	0.1608	0.04901	195	230	260	3.2 kA	33 kA	182 kA
000 (3/0)	0.4096	10.405	2.44	0.961	168	85.0	0.2028	0.06180	165	200	225	2.7 kA	26 kA	144 kA
00 (2/0)	0.3648	9.266	2.74	1.08	133	67.4	0.2557	0.07793	145	175	195	2.3 kA	21 kA	115 kA
0 (1/0)	0.3249	8.251	3.08	1.21	106	53.5	0.3224	0.09827	125	150	170	1.9 kA	16 kA	91 kA
1	0.2893	7.348	3.46	1.36	83.7	42.4	0.4066	0.1239	110	130	145	1.6 kA	13 kA	72 kA
2	0.2576	6.544	3.88	1.53	66.4	33.6	0.5127	0.1563	95	115	130	1.3 kA	10.2 kA	57 kA
3	0.2294	5.827	4.36	1.72	52.6	26.7	0.6465	0.1970	85	100	115	1.1 kA	8.1 kA	45 kA
4	0.2043	5.189	4.89	1.93	41.7	21.2	0.8152	0.2485	70	85	95	946 A	6.4 kA	36 kA
5	0.1819	4.621	5.50	2.16	33.1	16.8	1.028	0.3133				795 A	5.1 kA	28 kA
6	0.1620	4.115	6.17	2.43	26.3	13.3	1.296	0.3951	55	65	75	668 A	4.0 kA	23 kA
7	0.1443	3.665	6.93	2.73	20.8	10.5	1.634	0.4982				561 A	3.2 kA	18 kA
8	0.1285	3.264	7.78	3.06	16.5	8.37	2.061	0.6282	40	50	55	472 A	2.5 kA	14 kA
9	0.1144	2.906	8.74	3.44	13.1	6.63	2.599	0.7921				396 A	2.0 kA	11 kA
10	0.1019	2.588	9.81	3.86	10.4	5.26	3.277	0.9989	30	35	40	333 A	1.6 kA	8.9 kA
11	0.0907	2.305	11.0	4.34	8.23	4.17	4.132	1.260				280 A	1.3 kA	7.1 kA
12	0.0808	2.053	12.4	4.87	6.53	3.31	5.211	1.588	20	25	30	235 A	1.0 kA	5.6 kA
13	0.0720	1.828	13.9	5.47	5.18	2.62	6.571	2.003				198 A	798 A	4.5 kA
14	0.0641	1.628	15.6	6.14	4.11	2.08	8.286	2.525	15	20	25	166 A	633 A	3.5 kA
15	0.0571	1.450	17.5	6.90	3.26	1.65	10.45	3.184				140 A	502 A	2.8 kA
16	0.0508	1.291	19.7	7.75	2.58	1.31	13.17	4.016			18	117 A	398 A	2.2 kA
17	0.0453	1.150	22.1	8.70	2.05	1.04	16.61	5.064				99 A	316 A	1.8 kA
18	0.0403	1.024	24.8	9.77	1.62	0.823	20.95	6.385	10	14	16	83 A	250 A	1.4 kA
19	0.0359	0.912	27.9	11.0	1.29	0.653	26.42	8.051	—	—	—	70 A	198 A	1.1 kA
20	0.0320	0.812	31.3	12.3	1.02	0.518	33.31	10.15	5	11	—	58.5 A	158 A	882 A
21	0.0285	0.723	35.1	13.8	0.810	0.410	42.00	12.80	—	—	—	49 A	125 A	700 A
22	0.0253	0.644	39.5	15.5	0.642	0.326	52.96	16.14	5	7	—	41 A	99 A	551 A
23	0.0226	0.573	44.3	17.4	0.509	0.258	66.79	20.36	—	—	—	35 A	79 A	440 A
24	0.0201	0.511	49.7	19.6	0.404	0.205	84.22	25.67	2.1	3.5	—	29 A	62 A	348 A
25	0.0179	0.455	55.9	22.0	0.320	0.162	106.2	32.37	—	—	—	24 A	49 A	276 A
26	0.0159	0.405	62.7	24.7	0.254	0.129	133.9	40.81	1.3	2.2	—	20 A	39 A	218 A
27	0.0142	0.361	70.4	27.7	0.202	0.102	168.9	51.47	—	—	—	17 A	31 A	174 A
28	0.0126	0.321	79.1	31.1	0.160	0.0810	212.9	64.90	0.83	1.4	—	14 A	24 A	137 A
29	0.0113	0.286	88.8	35.0	0.127	0.0642	268.5	81.84	—	—	—	12 A	20 A	110 A
30	0.0100	0.255	99.7	39.3	0.101	0.0509	338.6	103.2	0.52	0.86	—	10 A	15 A	86 A
31	0.00893	0.227	112	44.1	0.0797	0.0404	426.9	130.1	—	—	—	9 A	12 A	69 A
32	0.00795	0.202	126	49.5	0.0632	0.0320	538.3	164.1	0.32	0.53	—	7 A	10 A	54 A
33	0.00708	0.180	141	55.6	0.0501	0.0254	678.8	206.9	—	—	—	6 A	7.7 A	43 A
34	0.00630	0.160	159	62.4	0.0398	0.0201	856.0	260.9	0.18	0.3	—	5 A	6.1 A	34 A
35	0.00561	0.143	178	70.1	0.0315	0.0160	1079	329.0	—	—	—	4 A	4.8 A	27 A
36	0.00500[c]	0.127[c]	200	78.7	0.0250	0.0127	1361	414.8	—	—	—	4 A	3.9 A	22 A
37	0.00445	0.113	225	88.4	0.0198	0.0100	1716	523.1	—	—	—	3 A	3.1 A	17 A
38	0.00397	0.101	252	99.3	0.0157	0.00797	2164	659.6	—	—	—	3 A	2.4 A	14 A
39	0.00353	0.0897	283	111	0.0125	0.00632	2729	831.8	—	—	—	2 A	1.9 A	11 A
40	0.00314	0.0799	318	125	0.00989	0.00501	3441	1049	—	—	—	1 A	1.5 A	8.5 A

a. ^ or, equivalently, Ω/km
b. ^ or, equivalently, Ω/kft
c. ^ a b c d Exactly, by definition

Engineering - **studies and trials** – technological feasability – **calculations** (electrical parts – **IP levels**)

A furher information that it's useful to consider for the design of eletric devices is the required capacity of bearing the impact of liquid or solid parts. Indeed, apart the mechanical damage (which of course can affect not electric device as well) the presence of such parts can reduce the dieletric characteristics of a product, so causing electrical discharge and/or short circuits.

About such risks, there are some standards, that's:

- IP (International Protection) levels, whose definition is provided by IEC 529 or EN 6052I standards. Such IP code includes two figures related to the protection from solid and liquid (the max is IP 68).
- IK, whose related standard is EN 50298, is about an enclosure's bumps strenght.

FIRST NUMBER Protection against solid objects		**SECOND NUMBER Protection against liquids**		**IK CODE Protection against mechanical impacts**	
IP	**TEST**	**IP**	**TEST**	**IK**	**TEST**
0	no protection	0	no protection	00	no protection
1	protected against solid objects over 50 mm e.g. accidental touch by hands	1	protected against vertically falling drops of water	01-05	impact < 1 joule
2	protected against solid objects over 12 mm e.g. fingers	2	protected against direct sprays of water up to 15 ° from the vertical	06	impact 1 joule
3	protected against solid objects over 2,5 mm (tools +small wires)	3	protected against sprays to 60° from the vertical	07	impact 2 joule
4	protected against solid objects over 1 mm (tools + small wires)	4	protected against water sprayed from all directions – limited ingress permitted	08	impact 5 joule
5	protected against dust – limited ingress permitted (no harmfull deposit.)	5	protected against low pressure jets of water from all directions - limited ingress permitted	09	impact 10 joule
6	totally protected against dust	6	protected against strong jets of water e g for use on shipdecks - limited ingress permitted	10	impact 20 joule
		7	protected against the affects of immersion between 15 cm and 1 m		
		8	protected against long periods of immersion under pressure		

[*abstract from* www.fibox.com]

Engineering - **studies and trials** – technological feasability – **calculations** (thermodynamics)

Here on the right you can find the scheme of an air conditioner. Now, apart from the dynamics and for the materials, there are **two main basic consideration: the heat exchange and the refrigerant characteristics**.

✓ About the heat exhange the obvious thing one has to do is the calculation of the exchanger surface area (ref. to the coil of the air conditioner and to its fins), whose magnitude is done by:

$$\mathbf{A} = \frac{\mathbf{E}}{\mathbf{U} \cdot \Delta\mathbf{T}}$$

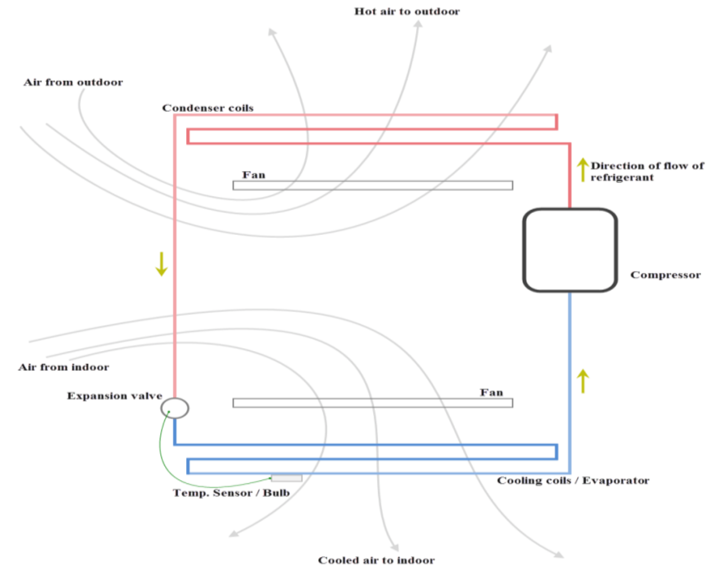
where:

- E: heat transfer rate [BTU/hr = 0,293 W]
- ΔT: difference of temperature [°K]
- U: heat transfer coefficient

… of course the key point will be to find a suitable U.

✓ Then the refrigerant characteristics which can be summarized as:

- vapor density (vapor density is the weight of a unit volume of gas or vapor divided by the weight of an equal volume of air or, sometimes, hydrogen).
- entalphy of vaporization (the enthalpy of vaporization, also known as the heat of vaporization or heat of evaporation, is the amount of energy that must be added to a liquid substance, to transform a quantity of that substance into a gas).
- thermal conductivity (the thermal conductivity of a material is a measure of its ability to conduct heat).
- dielectric strength (the maximum electric field that the material can withstand under ideal conditions without breaking down, that's without failure of its insulating properties).
- critical temperature (critical temperature is the highest temperature at which it is possible to separate substances into two fluid phases vapor and liquid).
- specific heat (the specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius).
- leak tendency (leak: accidentally loss or admit contents, especially liquid or gas)
- toxicity (toxicity is the degree to which a chemical substance or a particular mixture of substances can damage an organism).
- …



Every air conditioner has got a compressor inside it. It works to compress and pump the refrigerant gas. Compression of refrigerant produces heat. To dissipate this heat, compressed refrigerant is pumped to the condenser coils where a fan blows the heat out to outer atmosphere. During this process, refrigerant takes the liquid form. This liquid refrigerant is pumped towards expansion valve. Expansion valve has a temperature sensor connected to it which works in correlation with thermostat settings. Expansion valve releases the appropriate amount of refrigerant to evaporator (cooling coils) where liquefied refrigerant takes gaseous form. Conversion from liquid to gaseous state due to expansion causes cooling because energy is absorbed from the surrounding. Air when passes through fins (attached to coils) gets cooled and blown to the room. The gaseous refrigerant in cooling coils then enters the compressor and gets compressed once again. The cycle continues unless the compressor is shut down.

[*abstract from* https://benignblog.com]

Engineering - **studies and trials** – technological feasability – **calculations** (reliability)

First a definiion of reliabilty whiich can be meant as «**the ability of an apparatus, machine, or system to consistently perform its intended or required function or mission, on demand and without degradation or failure**”. [http://www.businessdictionary.com]

Reliability measurement units are

- **MTBF: Mean Time Between Failure**
- **Failure rate λ = 1/MTBF**

Of couse, the MTBF of a specific item can be guaranteed when the item works at the environmental and duty cycle conditions taken into account during the development of the item itself. (and anyway within the limit of the item’s expected life cycle).

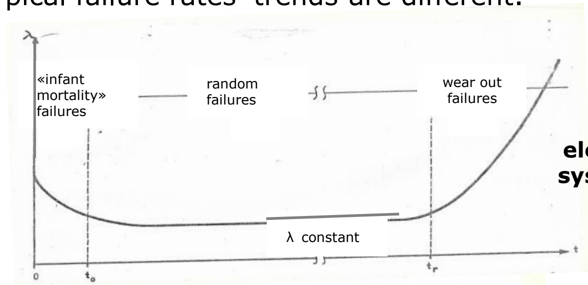
Now, of course the MTBF of a system (or its opposite, that’s the failure rate) will depend by the failure rates of any part of the system itself. Indeed and in rough words: one can easily get that if such parts are «strong» (and if they work at a proper running) the whole MTBF will be «high».
That said, and coming back to the previous pages cases, any system includes both electric (electronic) and mechanical (or electromechanical) parts, and such distinction is very important because their typical failure rates’ trends are different.

As a matter of fact: after the «infant mortality» phase (which, for any system, is a period characterized by a relatively high starting failure rate and by its lowering with the time):

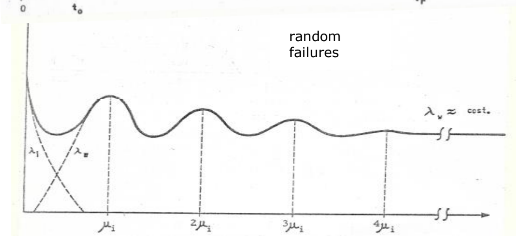
- the failure rate is quite constant for eletric system and isn’t for mechanical ones.
- the order od magnitude of the electronic parts’ failure rate is much lower (as rough indication let’s say 10^{-6} failure/hour) than the mechanical ones (let’s say 10^{-5} failure/hour).

With such premises, the probability of no failure R(t) at a certain period t can be computed by the following:

- ref. to electric devices $\mathbf{R(t)} = e^{-\lambda t}$ which is Poisson formula related to 0 event probability
- ref. to mechanical devices $\mathbf{R(t)} = e^{-\left(\frac{t}{\eta}\right)^{\beta}}$ which is Weibull distribution.



electric systems



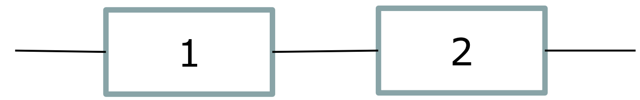
mechanical systems

Engineering - **studies and trials** – technological feasability – **calculations** (reliability)

Let's do some plain calculations **about the electric parts**: as instance, take two parts in series characterized by two failure rates $\boldsymbol{\lambda_1}$ and $\boldsymbol{\lambda_2}$. The probability that the system composed by such parts will survive till the time t is given by

$$R(t) = R_1(t) \times R2(t) = e^{-\lambda_1 t} \times e^{-\lambda_2 t} = e^{-(\lambda_1+\lambda_2)t}$$

so, comparing with previous page formula is easy to see that the whole failure rate of such system is given by $\boldsymbol{\lambda = \lambda_1 + \lambda_2}$



As additional information: in case of parts in parallel, one can get the whole failure rate following the same logic, so in this case multiplying the probability of failure F = 1- R(t), the by their multiplication one can get the above failure rate. .

Anyway, the arising question is «how to find λ values»? Now, there are several data bases and handbooks by which one can extract the necessary information. The most well-known is **MIL-HDBK-217-F** which is about electric discrete and integrated components (you can download it free of charge). The computing way is quite simple: for each component type MIL-HDBK-217-gives you an algorithm and some tables related to the algorithm's factors. For instance, here below you can see the algorithm related to the resistors.

$$\lambda_p = \lambda_b \pi_T \pi_P \pi_S \pi_Q \pi_E \text{ Failures}/10^6 \text{ Hours}$$

Just for completion of information:

- λ_b is a base failure rate related to the resistor's technology,
- π_T is the working temperature factor,
- π_P is the power level factor (see the table on the right)
- π_S is the duty cycle factor factor (see the table on the right),
- π_Q is a quality factor,
- π_E is the environmental factor.

Power Factor - π_P

Power Dissipation (Watts)	π_P
.001	.068
.01	.17
.13	.44
.25	.58
.50	.76
.75	.89
1.0	1.0
2.0	1.3
3.0	1.5
4.0	1.7
5.0	1.9
10	2.5
25	3.5
50	4.6
100	6.0
150	7.1

π_P = (Power Dissipation)$^{.39}$

Power Stress Factor - π_S

Power Stress	Column 1	Column 2
.1	.79	.66
.2	.88	.81
.3	.99	1.0
.4	1.1	1.2
.5	1.2	1.5
.6	1.4	1.8
.7	1.5	2.3
.8	1.7	2.8
.9	1.9	3.4

Column 1: $\pi_S = .71e^{1.1(S)}$

Column 2: $\pi_S = .54e^{2.04(S)}$

$$S = \frac{\text{Actual Power Dissipation}}{\text{Rated Power}}$$

Engineering - **studies and trials** – technological feasability – **calculations** (reliability)

About the mechanical parts:

- First let's consider the meaning of the two parameters showed by Weibull distribution:
  - η is named «characteristic life (or scale parameter)» and is the time value at which reaching the probability R gets the value R = 37%
  - β is named «shape parameter» because it defines the shape of the distribution (for β=1 the failure rate is constant, for β>1 the failure rate increases with the time, for β<1 the failure rate decreases with the time.
  - for Weibull as well there are some data base, like the showed one, which give η and β values.

Item	Beta Values (Weibull Shape Factor)			Eta Values (Weibull Characteristic Life--hours)		
	Low	Typical	High	Low	Typical	High
Components						
Ball bearing	0.7	**1.3**	3.5	14,000	**40,000**	250,000
Roller bearings	0.7	**1.3**	3.5	9,000	**50,000**	125,000
Sleeve bearing	0.7	**1**	3	10,000	**50,000**	143,000
Belts, drive	0.5	**1.2**	2.8	9,000	**30,000**	91,000
Bellows, hydraulic	0.5	**1.3**	3	14,000	**50,000**	100,000
Bolts	0.5	**3**	10	125,000	**300,000**	100,000,000
Machinery Equipment						
Circuit breakers	0.5	**1.5**	3	67,000	**100,000**	1,400,000
Compressors, centrifugal	0.5	**1.9**	3	20,000	**60,000**	120,000
Compressor blades	0.5	**2.5**	3	400,000	**800,000**	1,500,000
Compressor vanes	0.5	**3**	4	500,000	**1,000,000**	2,000,000
Diaphragm couplings	0.5	**2**	4	125,000	**300,000**	600,000
Gas turb. comp. blades/vanes	1.2	**2.5**	6.6	10,000	**250,000**	300,000
Gas turb. blades/vanes	0.9	**1.6**	2.7	10,000	**125,000**	160,000
Instrumentation						
Controllers, pneumatic	0.5	**1.1**	2	1,000	**25,000**	1,000,000
Controllers, solid state	0.5	**0.7**	1.1	20,000	**100,000**	200,000
Control valves	0.5	**1**	2	14,000	**100,000**	333,000
Motorized valves	0.5	**1.1**	3	17,000	**25,000**	1,000,000
Solenoid valves	0.5	**1.1**	3	50,000	**75,000**	1,000,000
Transducers	0.5	**1**	3	11.000	**20.000**	90.000
Static Equipment						
Boilers, condensers	0.5	**1.2**	3	11,000	**50,000**	3,300,000
Pressure vessels	0.5	**1.5**	6	1,250,000	**2,000,000**	33,000,000
Filters, strainers	0.5	**1**	3	5,000,000	**5,000,000**	200,000,000
Service Liquids						
Coolants	0.5	**1.1**	2	11,000	**15,000**	33,000
Lubricants, screw compr.	0.5	**1.1**	3	11,000	**15,000**	40,000
Lube oils, mineral	0.5	**1.1**	3	3,000	**10,000**	25,000

[*abstract from* www.barringer1.com

Example:

- Let's consider some suspension springs whose working is described by Weibull distribution and whose characteristic life and shape parameters are η=300.000 cycles and β=2. How many pieces will break before 100.000 cycles.

  So, applying Weibull the probability of surviving at 100.000 cycles $R(100.000) = e^{-\left(\frac{100.000}{300.000}\right)^2}$ = 89,48%, so the probability to fail before 100.000 cycles is F=(1-R)=10,52%.

- Now, let's enlarge the exercize: if a car should use the above suspension springs on both axles, which would be the whole characteristic life η_{tot}?

  The whole system could be considered a series system, indeed the breaking of just one of the suspension rings would damage the whole system, so the number of cycles would come working on the equation η_{tot} = $R_{spring1}$ x $R_{spring2}$. More in details it will be $\eta_{tot} = \frac{\eta}{4^{\frac{1}{\beta}}} = \frac{300.000}{4^{\frac{1}{2}}} = \frac{300.000}{\sqrt{4}}$=150.000 cycles

Engineering - **studies and trials** – technological feasability – **prooves**

Prooves purpose: a proof is defined as «the process of testing whether something is true or a fact», so one could say that **prooves are in order**:

- … **to verify if something you got** following some calculations or just as supposition is true,
- … or**, to check if a product (or parts of it) fits** some specific standards (a typical case is the matching with safety standards) or whatever in your project you need to take into account.

So, what in the following infere the two above cases. More in details:

- basic information are given on some of the subjects' calculations showed in the previous pages.
- general introduction on standards is given.

Engineering - **studies and trials** – technological feasability – **prooves** (physical anf technlogical properties)

First have a look to ***the physical and technological properties***, about which one can find a very high number of standards referred to different materials, tests and related conditions etc.

Just to better say: **ASTM** (American Society for Testing and Materials) has (as order of magnitude) about 1.500 standars (if one should browse the titles of such standards, he would find the word «steel» in 642 documents, «iron» in 147, «tensile» in 13, «hardness» in 17, «ductility» in 5 etc.).

That said, apart from ASTM one can find:

- some other international organization like **ISO** (International Standard Organization) or **EN** (European Norms).
- national ones, for instance **UNI** (Ente Italiano di Normazione) for Italy, **BS** (British Standards) for United Kingdom, **DIN** (Deutsches Institute für Normung) for Germany, **ANSI** (American National Standards Institute) for USA etc.
- others related to specific sectors and/or applications like **MIL-STD**, **IAEA** (International Atomic Energy Agency), **ASD** (Aerospace and Defense Industries Association) etc.
- forthemore, there are some standards tailored and issued by multinational corporations.

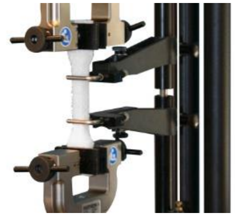
It''s also to say that most of the standars issued by different organizations are very similar. One shouldn't be astonished about, indeed the role of international organization is just standards' harmonizing.

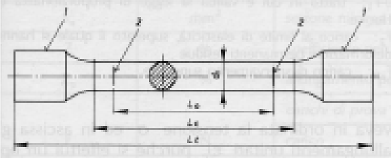
In the end: one has to choose itsown standards accordingly to what it wants to verify (and to its product's market as well)**. Anyway, on some characteristics mostly related to mechanical properties there are some «milestone standards» like the ones related to tensile strenght, hardness, resilience.**

Engineering

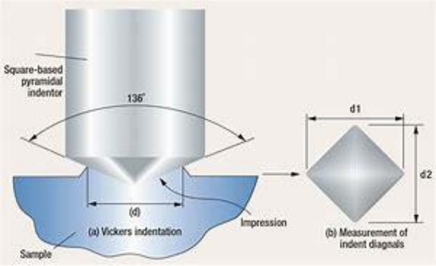
- **studies and trials** – technological feasability – **prooves** (physical anf technlogical properties)

- on **tensile strenght test** the strain is applied on a sample, whose dimensions are provided by specific standard, as well as the way of strain application (possible standards: ISO 68923, ASTM E8)

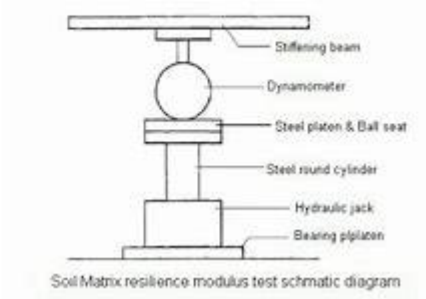




- **hardness test** is based on the impression left by a push rod whose shape is of course standardized (possible standards: ISO/TC 164/SC 3, ASTM A956).



- **resilience test** (is about the capacity of a sample to absorb the energy left by a pendulum (Izod or Sharpy pendulums), of course both sample and pendulum are standardized (possible standards for plastics: ISO180, ASTM D256).



Engineering - **studies and trials** – technological feasability – **prooves** (electrical parts)

With reference to ***electrical parts*** **one must distinguish between tests on components and on electrical devices** (indeed like motors, cables etc.).

- about components one will have to distinguish measurements both of electrical base properties (like resistance, capacitance, inductance etc.) and of some other derived characteristics, like dielectric strenght.
- on devices one will have some standards tests, which for instance could be insulation tests for cables, or some other customized ones, like the endurance of a electrical motor subjcted to an extra load etc.

Anyway, for electrical items as well there are plenty of standards issued by same organizations mentioned about physical and technological properties of materials, particularly by **IEC** (International Electrotechnical Commission) and by **IEEE** (Institute of Electrical and Electronic Engineers). Some rough figures on IEC publications: on about 1.200 standards you can find no. 77 for cables, no 12 for resistors, no. 21 for insulation properties, no. 10 for dielectric characteristics, no. 26 for capacitors etc.). Some other standards can be related to the application sectors, like

- railway (the side table shows some standards),
- domestic appliances (for instance the CSN EN 13203-6, which includes a paragraph related to «assessment of energy consumption of adsorption and absorption heat pumps" etc.).
- …

Electrical and control software:

[*abstract from* ABB Traction Engineering Training Course

EN 50163/IEC 60850	Railway applications. Supply voltages of traction systems
UIC 550	Power supply installations for passenger stocks
EN 50124-1	Railway applications - Insulation coordination – Part 1: Basic Requirements – Equipment and Creepage Distances
EN 50124-2	Railway applications - Insulation coordination – Part 2: Over Voltages and related Protections
EN 50121-1/IEC 6100-1	Electro Magnetic Compatibility - Part 1: General
EN 50121-2/ IEC 6100-2	Electro Magnetic Compatibility - Part 2: Emission of the whole Railway System to the Outside World
EN 50121-3-1/ IEC 6100-3-1	Electro Magnetic Compatibility - Part 3-1: Rolling Stock – Train and complete Vehicle
EN 50121-3-2/ IEC 6100-3-2	Electro Magnetic Compatibility - Part 3-2: Rolling Stock – Apparatus
EN 50126	Railway applications – The specification and demonstration of reliability, availability, maintainability and safety (RAMS)
EN 50155	Railway Applications - Electronic Equipment used on Rolling Stock
EN 50128	Railway applications – Communications, signalling and processing systems – Software for railway control and protection systems

Engineering - **studies and trials** – technological feasability – **prooves** (reliability tests)

On ***reliability and maintainability*** the prooves can be related to the whole system you're designing or, of course, to some parts of it. However, the key point of reliability prooves is the carry out them looking at **inferential statistics**, that's:

Inferential statistics provide a way of going from a "sample" to a "population" inferring the "parameters" of a population from data on the "statistics" of a sample.

[www2.stat.duke.edu/ Duke University]

In other words: about reliability what above means to extend the reliability data you can get from a sample of the part (or system) you're checking to the whole population. Now, beyond some other (important) considerations on inferential statistics, a basic one is on **confidence interval**, whose concept is quite easily understandable. Indeed if you should tell on a population's parameter θ you won't say that such parameter's value/level corresponds to an exact number but you'd (wisely) say you're quite confident that its value is inside a certain interval. In other words you'd say what by the following expression

$$P\{a \leq \theta \leq b\} = 1 - \alpha$$

where α represents your uncertainty and P your confidence; for instance if you would quantify the 5% the possibility that your assessment is wrong, you'd say that the probability that the paramenter your parameter θ is between a and b is = 100%- α = 95%

From such consideration, some further remarks would come, that's the **hyphotesis testing** which means that a certain H_0 hyphotesis is true while it isn't or to say that it isn't true while it is, so you have **two different risks α and β**.

using more accurate words, one should say Tipe I and Type II errors. Besides H_0, generally an alternative hypothesis H_1 is stated as well.

	True	False
Fail to reject H_0	Correct action	Type II error
Reject H_0	Type I error	Correct action

Engineering - **studies and trials** – technological feasability – **prooves** (reliability tests)

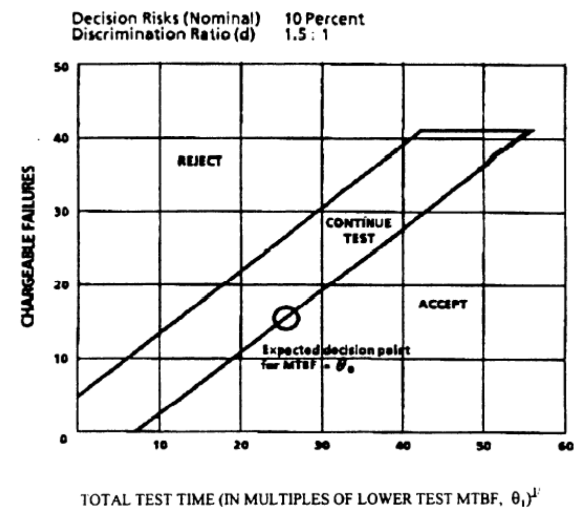
See App. 5 for the list of MIL reliability standards.

Being stated what in the previous page, there are some standards which provide reliability tests organization. On the right side you can see an example coming **from MIL-HDBK-781A** (Handbook for reliability test methods, plans, and environments for engineering, development qualification, production) and **MIL STD 781D**.

The showed test is a sequential test characterized by:

- 10% decision risks, which means - stated two MTBF values θ_0 and θ_1, that are the equivalent of the H_0 and H_1 hypotheses – that both the risk to accept an MTBF whose real value is lower than θ_1 and the risk to reject an an MTBF higher than θ_0 is the 10%.
- a discrimination ratio $\rho=\theta_0/\theta_1$ is 1,5:1 (the lower the discrimation ratio the longer is the test).

any test is fitted out with a test procedure which, at any stage of the experiment (at the n.th trial for each integral value n), gives a specific rule for one of the following three decisions: (1) to accept the hypothesis being tested (null hypothesis), (2) to reject the null hypothesis, (3) to continue the experiment by making an additional observation.



[abstract from MIL HDBK 781A]

Chargeable failures	Standardized termination time, t[2]		Chargeable failures	Standardized termination time, t[2]	
	Reject at $t_R \leq$	Accept at $t_A \geq$		Reject at $t_R \leq$	Accept at $t_A \geq$
0	N/A	6.95	21	18.50	32.49
1	N/A	8.17	22	19.80	33.70
2	N/A	9.38	23	21.02	34.92
3	N/A	10.60	24	22.23	36.13
4	N/A	11.80	25	23.45	37.35
5	N/A	13.03	26	24.66	38.57
6	0.34	14.25	27	25.88	39.78
7	1.56	15.46	28	27.07	41.00
8	2.78	16.69	29	28.31	42.22
9	3.9g	17.90	30	29.53	43.43
10	5.20	19.11	31	30.74	44.65
11	6.42	20.33	32	31.96	45.86
12	7.64	21.54	33	33.18	47.08
13	8.86	22.76	34	34.39	48.30
14	10.07	23.98	35	35.61	49.50
15	11.29	25.19	36	36.82	49.50
16	12.50	26.41	37	38.04	49.50
17	13.72	27.62	38	39.26	49.50
18	14.94	28.64	39	40.47	49.50
19	16.15	30.06	40	41.6g	49.50
20	17.37	31.27	41	49.50	N/A

Accept-reject criteria

[1] Total test time is the summation of operating time of all units included in test sample.

[2] To determine the actual termination time, multiply the standardized termination time (t) by the lower test MTBF(θ_1)

That said, the test works in this way: let's consider to have a sample of five machines and that the θ_0 is 1.500hs (so θ_1 is 1.000hs), in case of no. 8 failures (that's tested items' breakage) you'd reject the hypothesis of θ_0=1.500hs if the total test time is 2,78x1000=2780hs (that's 556hs for each unit) and accept θ_0=1.500hs in case it's 16,69x1000=16.690hs, that's about 3340hs per unit.

Engineering - **studies and trials** – technological feasability – **prooves** (maintainability, materials reciclability etc. + safety standards)

- Like the characteristics described in previous pages, **you can find several standards for maintainability and materials' reciclability, as well as for many different other issues**.

  such topics (logically) mean that a product development must include what about its operating life and its retirement disposals as well.

  The table on the right lists several standards. By the way it's interesting to note that they are mentioned by MIL STD 499B, that's, taking into account that MIL STD 499B as a «managerial» standard, the mentioning of technical standards (so a suitable care about) would mean that's «technical» considerations are a necessary condition for any engineering work.

- Apart from the prooves and the related standards which you'd like to carry out for your-own decision (that's because necessary for your product's development) **there are some standards usually related to safety, flammability etc.** coming from the specific business sectors or by **national authorities like:**
  - **UL** (Underwriter Laboratories) for USA,
  - **TŰV** (Technischer Überwachungsverein)
  - **SGS** (Societé General de Surveillance)
  - **CQC** (China Quality Certification Center)
  - …

  Some other requests can come from **CE** (European Community) about CE marking.

TABLE 2.1 Standards Cited in Mid-Std-499B

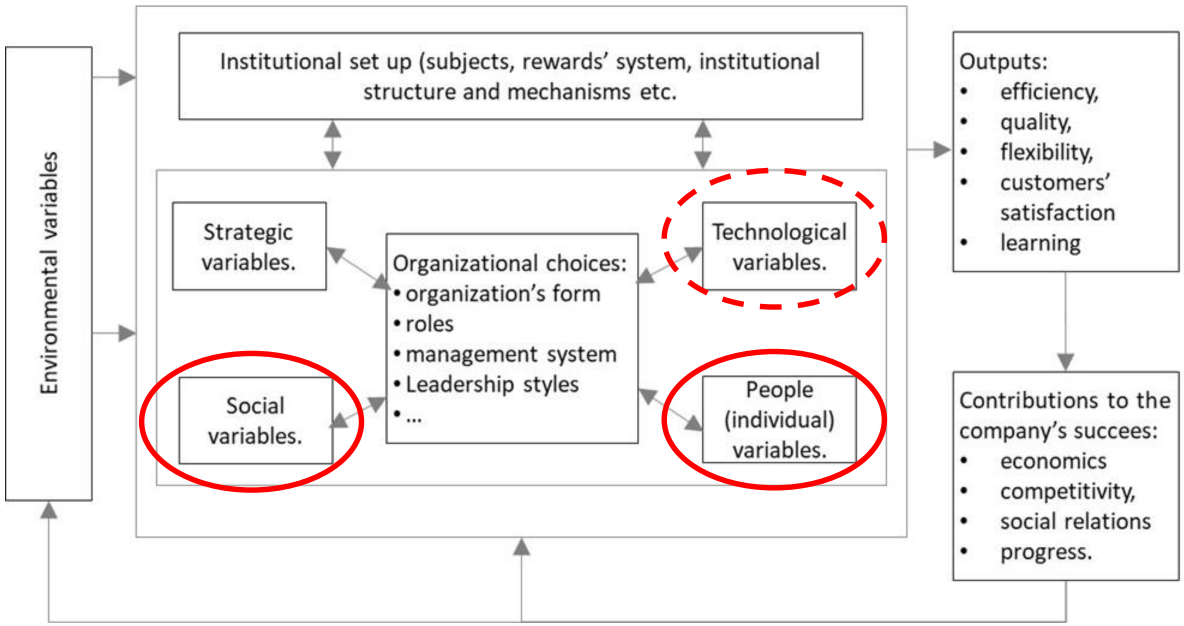
Technical Discipline	Reference	
Configuration management	MIL-STD-480/481/482/483	
Climatic Information	MIL-STD-210	
Computer-aided acquisition and logistics support	MIL-HDBK-59	
Corrosion prevention and control	MIL-STD-1250	MIL-STD-1568
Environmental analysis	MIL-STD-810	
Electromagnetic compatibility	MIL-STD-1541	MIL-STD-461
	MIL-E-6051	MIL-HDBK-237
Electrostatic discharge	MIL-STD-1686	
Human factors	MIL-STD-1472	MIL-STD-1794
	MIL-STD-1800	MIL-HDBK-763
	MIL-H-46855	
Maintainability	MIL-STD-470	MIL-STD-1843
	MIL-STD-2184	MIL-HDBK-791
Manufacturing	MIL-STD-1528	
Nondestructive inspection	MIL-HDBK-728	MIL-HDBK-731
	MIL-I-600	
Parts control	MIL-STD-965	
Producibility	MIL-HDBK-727	
Quality	MIL-Q-9858	MIL-I-45208
Reliability/durability	MIL-STD-785	MIL-STD-1530
	MIL-STD-1543	MIL-STD-1783
	MIL-STD-1796	MIL-STD-1798
	MIL-STD-2164	
System safety engineering	MIL-STD-882	
Software	DoD-STD-2167	MIL-STD-1803
	MIL-STD-1815	
	MIL-HDBK-287	
Software quality assurance	DoD-STD-2168	DoD-HDBK-286
Supportability	MIL-STD-1388	
Survivability	MIL-STD-1799	MIL-STD-2069
	DoD-STD-2169	MIL-HDBK-336
System security	MIL-STD-1785	
Telecommunications	MIL-STD-188-xxx	
Testability	MIL-STD-2165	
Thermal design/analysis	MIL-HDBK-251	
Transportability	MIL-STD-1367	MIL-HDBK-157
Value engineering	MIL-STD-1771	
Technical reviews and audits	MIL-STD-1521	
Work breakdown structure	MIL-STD-881	
Statement of work preparation	MIL-HDBK-245	
Technical data package	MIL-T-3100	
Specification practices	MIL-STD-490	MIL-S-83490

[H. Eisner - Essentials of project and system engineering management]

Engineering - **studies and trials** – organizational feasability – **individual and social variables**

All things considered, investigations on individual and social variables means to carry on an organizational analysys, about which the showed model could be suitable.

Indeed, by the definition of organization, and specifically taking into account that an organization must be suitably structured, **apart from the consistency between a specific product's development and the company strategy, it's necessary to verify if the resources are adequatly skilled and if there isn't any social constraint**.



[*abstract from* G.F. Rebora – Manuale di organizzazione aziendale]

Organizations are social entities that are goal-directed, designed as deliberatly structured and coordinated activity systems, and are linked to the external environment.
[R.L. Daft – Organization Theory & Design]

Technology variables of course must be taken into account for feasibility analysis. The drawing shows them with a dot line because they'll be considered in the «logistic and manufacturing» analysis,

Engineering - studies and trials – organizational feasability – individual and social variables

- **Technological variables**:
  - ✓ ... key variables affecting the operations and other operating activities. ...
  - ✓ ... attention to the ICT systems.
- **Individual variables**:
  - ✓ ... they characterize the employees: abilities and lacknesses, seniority, scholarity, personal disposition etc.
  - ✓ commitment, aptitudes for relationship, team working, cooperation etc.
- **Social variables**
  - ✓ ...they're related to the relationships among individuals and to the possible aggregations.
  - ✓ ... it's important to note that such aggregations can intervene between employees and the organization.

apart from specific specific technical skills, it's important to verify the «behavioural» skills. Indeed the development group must have an «organic culture».

Organic organization: the word «organic» refers to the evolutionary theory, that's the ability of an organism to face environmental modifications. So, in a company's context, it means the skill on news' managing.

... so, for any project it's mandatory to define the context of the project itself. ... you can choose if carry on or not some technical analysis, but you must do an organizational analysis.

... product design is yet another bastion of Taylorism: inputs from Manufacturing and Quality are perceived as distracting; those from Sales are considered downright irrelevant. Design quality is measured strictly in terms of technical specifications whose connections to customers requirements may be tenuous at best. ...

[J. B. ReVelle – Manufacturing handbook of best practices]

Engineering - **studies and trials** – logistics and manufacturing – **suppliers approval and partnership**

First let's state that, in the context of the course, the word «supplier» includes both the suppliers as normally meant (that's companies which provide raw material or parts or systems), and outsourcing providers. That said, the **two issues to be dicussed are suppliers' approval and partnership**

- **suppliers' approval**

  the words «supplier's approval» delineate the whole process of a supplier's homologation, that's the process related to check if a certain supplier could fit your expectations.

  The phases of a suppliers' approval process are quite similar for «normal supplies» and for outsourcing. Anyway they can differ in depth: its widening can vary accordingly to the relationship continuity between supplier and customer and by the transacted goods' worth as well.

  For extemporary transaction the whole process can just be outlined and suitably shaped for existing supplies (from which, for instance, you're considering to buy goods different by the ones you ususally bought)

- **partnership**

  A commitment to both customers and suppliers, regardless of size, to a long-term relationship based on clear, mutually agreed objectives to strive for world class capability.

  [Partnership sourcing Ltd – Making partnership sourcing happens]

  The concept of patnership, when got in the meaning of will of cooperation, is very next to the one od companies network. Indeed as network's definition one can take «**… plot of not competitive relationships which links legally independent entities, without any undermining of the formal authonomy and without any unitary management. So, companies' networks are organizational typologies based on the cooperation and the coordnation among companies or other organizations which are under interdependency's conditions.**

  [*abstract from* G. Soda – Reti tra imprese]

Engineering - **studies and trials** – logistics and manufacturing – **suppliers approval and partnership**

Phases of suppliers' approval

i. Scouting → Scouting phases can be summarized as the preparation of the list of possible suppliers. Sources about can be directories, consultants, other companies etc. Care must be given in order to list a «not too low» number of companies.

ii. First selection → First selection is just in order to focus the a priori most suitable suppliers. Attention must be done to include all possible operations themes (for instance and about logistics: the distance of the supplier's facilties) and anyway to take into account possible specificities (like scarcity of suitable suppliers).

iii. Request of Proposals issues → Request for Proposals (RfP) or for Quotations (RfQ) symbolizes an «official step» of contact between the possible supplier and the client; so, first one must care «communication rules». That said, the content of the RfP (expectations etc.) must be made plain.

iv. Second selection → Of course the reference for such selection is the consistency between the supplier's proposals and the upmentioned requests (that's the client's expectations). On such phase one must pay attention to the explanation of possible significant gaps among the suppliers proposals.

v. Final candidates focusing → Final candidates focusing could take into account some other factors, like suppliers' financial situation, the relationship between managing directors or other key actors, etc.

Phases of suppliers' approval

vi. Auditing → A priori an audit is in order to get more confidence about the potential supplier's ability to supply, anyway main purpose of the audit is to focus less strong issues and to agree improvement actions with the supplier. An audit must be carefully planned, an effective reference about is EN ISO 19011 standard (Guideline for auditing management systems).

vii. «chemistry» → «chemistry» is a peculiar phase which could be carried out in case two potential suppliers got the same ranking. Chemistry means the perception of cultural (behaviourial) reciprocity, so one will choose the supplier it feels more next.

viii. Contract → A contract - as document having legal validity which will rule any transaction between supplier and client - is suitable in case ypu forecast medium-long periods of supplying. That said, it's mandatory for outsourcing or in case of extemporary important transaction (like purchasing of machinery etc.), while for short period agreement on main factors (price, lead-time, quality, flexibility) could be enough.

ix. Managing relationship → Managing relationships is in order both for the solution of possible lacknesses (not conformities of the supplied goods or of the related services) and in order to plan improvement. A key aspect is to provide a suitable guide-line just for managing relationship.

Partnership

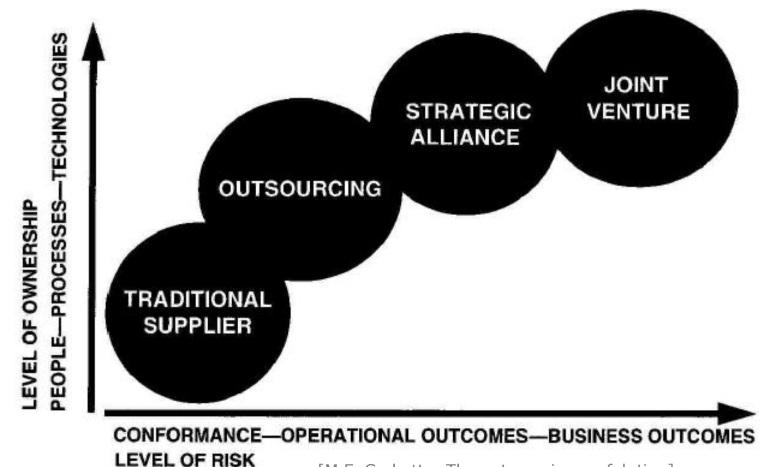
The concept of partnership is linked to the satisfaction of both parties’ (client and supplier) expectations, so, taking into account that such expectations come from the effectiveness’ and efficiency’s optimization of such parties’ processes, partnership can work when there is a mutual will of information sharing. Indeed such information will let the parties to act advisedly.

outsourcing is the act of transferring some of a company’s recurring internal activities and decisions rights to outside providers, as set forth in a contract.
[M.F. Greaver II - Strategic Outsourcing]

Anyway, when and how to carry out partnership?

- the sketch roughly shows the intensity of the partneship level compared with other relationships; of course the partnership’s level increases in case of long term relationship. Specifically, **taking into account the above meaning of partnership and that outsourcing means the transferring of internal process to an external organization, in such case the statement of partnership’s conditions is binding.**

FIGURE 10.1 USE OUTSOURCING’S RELATIONSHIP CONTINUUM TO GET THE RIGHT DEAL



[M.F. Corbett – The outsourcing revfolution]

- **About how to carry out partnership: which are the topics?** Such possible topics could be summed up in the **decision-making autonomy of the provider** (and conversely the client’s one as well) and should generally regard **factors of production, resources, operating processes, management, strategy.**

  An **important** ending note: starting by the thought that supplies are related to manufacturing, one could think that suppliers and outsourcing (make-or-buy) is a manufacturing subject. This is fully wrong, indeed **it would be too late** to work on such subject just before manufacturing starting.

Technological variables

Technological variables are the key variables affecting the operations, so:

- **production lines' organization** (continuous line, job shop etc.),
- **lines capacities**
- **lead time**
- **avalailability of specific machines** (technological systems)
- **planning and scheduling methodologies**
- … and again **workers and production technicians skills**
- **…**

> an organization's operations function is concerned with getting things done; producing goods and/or services for customers
> [cws.cengage.co.uk]

As in previous pages mentioned for logistics, **the above items must be investigated before production starting** (it's plain that it would be to late to work on them on production starting).

Anyway, some other items could be added at the above ones. A key one (ref. to the managerial analysis – page 31) is the production cost (ref. to direct costs) about which, and apart from purchasing costs, it's vital to carry on a rigorous **work study** analysys.

> the knowledge of purchasing costs is another reason for which the investigation on suppliers must be done before production start.

> work study is **"a term used to embrace the techniques of method study and work measurement which are employed to ensure the best possible use of human and material resources in carrying out a specified activity."** In other words, "work study is a tool or technique of management involving the analytical study of a job or operation." Work study helps to increase productivity.
> [International Labour Office]

DFM and Ishikawa

First, some questions:

- **why DFM and Ishikawa?**
- **are they the only tool to be taken into account?**

… and now the answers

- DFM and Ishikawa are tools useful to prevent any manufacturing matter, **so it's wise to take them into account during product development in order to guarantee a suitable fit between development's choices and manufacturing characteristics.**
- DFM and Ishikawa aren't the only tools, so **one can use what it likes**, may be customized versions of DFM and Ishikawa as well

⇩

A further **important** note: we're still in the «studies and trials» phase, so what above means that – in addition to the other mentioned topics (ref. to managerial analyses, all the ones belonging to «technological and organizational feasibility» etc.) – DFM and Ishikawa investigations have to be considered in the whole development activity.

DFM, DFA, DFMA

A very summarized definition of DFM (Design For Manufacturing) is **"DFM is the general engineering practice of designing products in such a way that they are easy to manufacture"**.

Traditional **DFM pillars** are:

- **reduction of the parts/components** related to a product,
- **standardization of parts and raw materials**

That said, an extension of DFM concept to assembly leads to **DFA (Design For Assembly)** which is pivoted on:

- **Minimizing number of assembly operations**
- **Reduce difficulties of assembly operations**

As a matter of fact, the two branches are now joint as **DFMA**, whose targets are

a. Simplify the design and reduce the number of parts.
b. Standardize and use common parts and materials.
c. Design for ease of fabrication.
d. Design within process capabilities and avoid unneeded surface finish requirements.
e. Mistake-proof product design and assembly (Poka-Yoke).
f. Design for parts orientation and handling.
g. Minimize flexible parts and interconnections.
h. Design for ease of assembly.
i. Design for efficient joining and fastening.
j. Design modular products.
k. Design for automated production.

[M. Hamidi, K. Farahmand Proceedings of The 2008 IAJC-IJME International Conference]

Anyway, of course some choices depend by the expected poduction volumes and, generally speaking, by the whole business.

A very simple example of DFA.

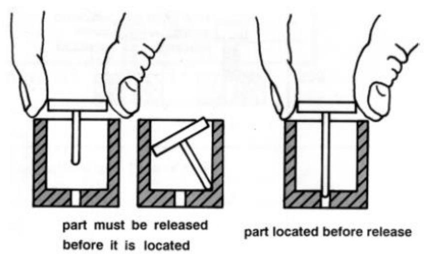


Figure 7. Some guidelines of design for ease of assembly

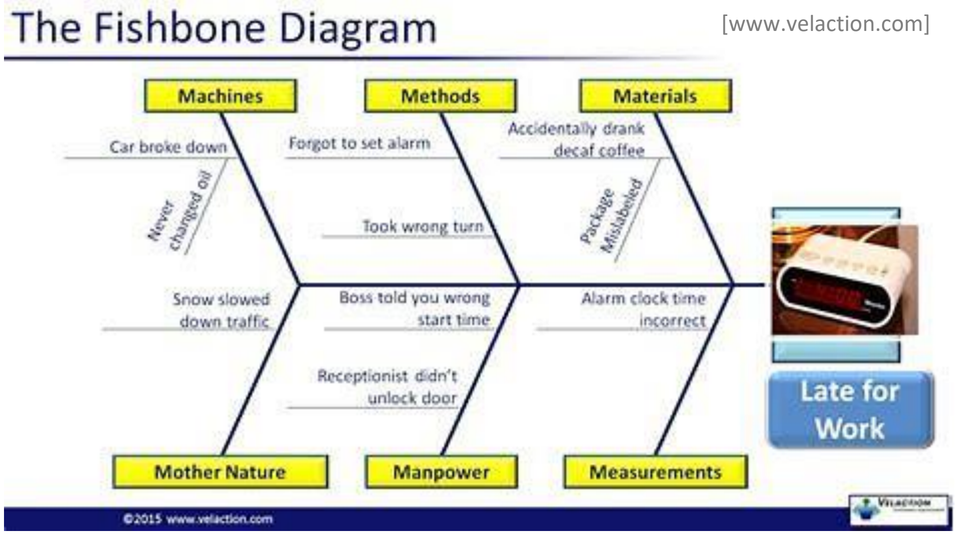
It's to note that, in order to apply DFMA, one needs to know technological variables.

Ishikawa diagram (Fishbone diagram)

Now, the well known Ishikawa diagram isn't proposed in its traditional role of "causes' investigation", but as effective tool in order to prevent possible unwelcomed effects (like quality's not conformities, inefficiencies, ineffectiveness etc.)

Indeed, if one would look at itsown experience, it would be able to list possible causes of unwanted things and so to prevent them.

[www.velaction.com]



Just as link with previous pages and in order to underline the importance of the organizational analysis: of course if you don't know your technologies, that's if you don't analyze your technological variables, you wouldn't have anything about the related branches of Ishikawa diagram (ref. to Machines, Methods etc.), same about individual and social variables (ref. to Manpower) etc.

As additional comment, it's to quote the **Murphy's law** as well, that's "**anything that can go wrong … will go wrong**" and its corollaries.

1. Nothing is as easy as it looks.
2. Everything takes longer than you think.
3. Anything that can go wrong will go wrong.
4. If there is a possibility of several things going wrong, the one that will cause the most damage will be the one to go wrong. Corollary: If there is a worse time for something to go wrong, it will happen then.
5. If anything simply cannot go wrong, it will anyway.
6. If you perceive that there are four possible ways in which a procedure can go wrong, and circumvent these, then a fifth way, unprepared for, will promptly develop.
7. Left to themselves, things tend to go from bad to worse.
8. If everything seems to be going well, you have obviously overlooked something.
9. Nature always sides with the hidden flaw.
10. Mother nature is a bitch.
11. It is impossible to make anything foolproof because fools are so ingenious.
12. Whenever you set out to do something, something else must be done first.
13. Every solution breeds new problems.

Engineering - **studies and trials** – final considerations

So, we've finished about «studies and trials», but some question could arise.

- 1° question: **are mentioned notions fully exhaustive for any project?**

  … answer: *of course they aren't. Besides we just gave very basic information (and abridged as well), nothing has been mentioned on a lot of some other subjects (for instance chemicals, IT etc.), whose knowledge could be indispensable for some projects. At the same time it's to day that likely some of the showed subjects are not useful for some projects.*

↓

An **important** consequence to the above answer is**: you're the only one who could take a decision on «study and trials» to be considered.**

- 2° question: **is there any priority about «studies and trials»?**

  … answer: yes, there is, indeed:

  - first: priority comes from yourown decisions (that's to what above mentioned) and about this you could decide what's absolutely necessary to carry on and what isn't (by the way, this could depend by your time-to-market, resources' availability as well etc.).
  - second: … anyway, and generally speaking you could need to have the results of some studies and trials before implementing new ones (for instance: it could be useless carry on DFMA before having a preliminary analysys on the components) .

↓

… and just in order to phase activities, a suitable plan about must be considered, that's the **«engineering process framework».**

Engineering

engineering process framework - introduction

Engineering Process Framework is a management tool targeted both to make clear company's rules on project and to progress control.

In other words: it puts into effect what provided by MIL-STD-499B (ref. Pages 7-9)

Here below two patterns of two different companies. About both it's interesting to note some specific steps whose achievement lets the prosecution to next process phase.

Such steps for instance are Develop Project Plan, Prepare Product Infrastuctue etc. (ref. to D2 phase of the first sketch), Technical Specification, FwSw/Hw/Me etc. (ref. to second sketch).

In the prosecution, such steps will be named «customer deliverables», «milestones» etc.

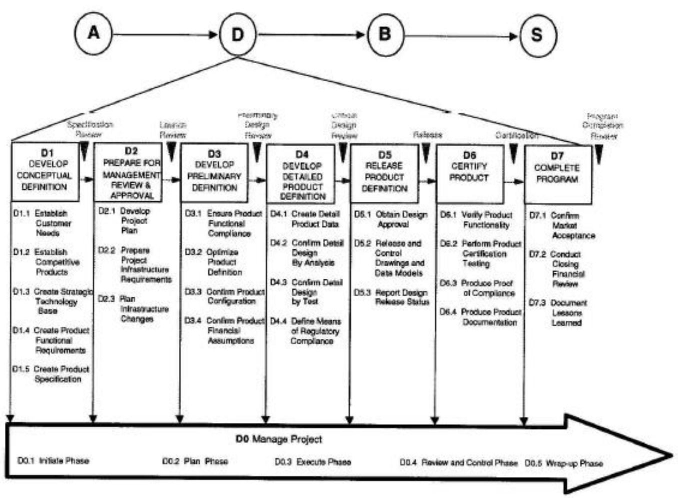
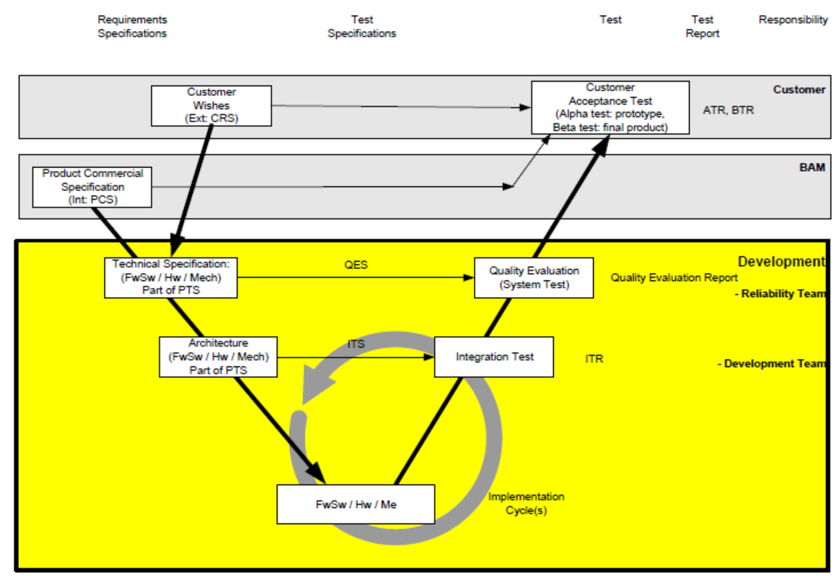


Figure 2-1: Process framework example 1 – Tier 1 processes (Courtesy Bombardier Aerospace – de Havilland Division)

[S.C. Armstrong – Engineering and product development management]



[*courtesy by* FIMI Philips (Development Manual)]

Didactic Note: looking at the ID course' Engineering module, care must be done on the «typical» development phases.

Engineering

engineering process framework - structure

So, which could be the rules mentioned by engineering framework definition? A major reference is given **by ISO 9000** standard, which (about design and development of products and services) points out the following steps:

- **Project Initiation Phases**
- **Design Inputs**
- **Design and Development**
- **Design and Development Review**
- **Design Verification**
- **Design Validation and Testing**
- **Project Assessment**

details about can ge got by ISO 9000:2015 – Quality Management Systems, Fundamentals and Vocabulary.

Legenda of main terms:

- **Project Initiation Phases**
  The first phase in any project management process is project initiation where the goal is to uncover the project's scope — the boundaries for resources, expectations, results, feasibility, the team, and your requirements — and produce a project charter. Now that you know the project's goals and scope and you have a project charter, you can move onto the next step: project planning.
  This is testing that ensures the *expressed* user requirements, gathered in the Project Initiation phase, have been met in the *Project Execution* phase. One way to do this is to produce a user requirements matrix or checklist and indicate how you would test for each requirement. For example, if the product is required to weigh no more than 15 kg. (about 33 lbs.), the test could be, "Weigh the object " does it weigh 15 kg. or less?", and note "yes" or "no" on the matrix or checklist.
- **Verification Testing**
  This is testing that ensures the *expressed* user requirements, gathered in the Project Initiation phase, have been met in the *Project Execution* phase. One way to do this is to produce a *user requirements matrix* or *checklist* and indicate how you would test for each requirement. For example, if the product is required to weigh no more than 15 kg. (about 33 lbs.), the test could be, "Weigh the object " does it weigh 15 kg. or less?", and note "yes" or "no" on the matrix or checklist.
- **Validation Testing**
  This ensures that any *implied* requirement has been met. It usually occurs in the *Project Monitoring and Control* phase of project management. Using the above product as an example, you ask the customer, "Why must it be 'no more than 15 kg.'?" One answer is, "It must be easy to lift by hand." You *could* validate that requirement by having twenty different people lift the object and asking each one, "Was the object easily to lift?"If 90% of them *said* it was easy, you *could* conclude that the object meets the requirement.

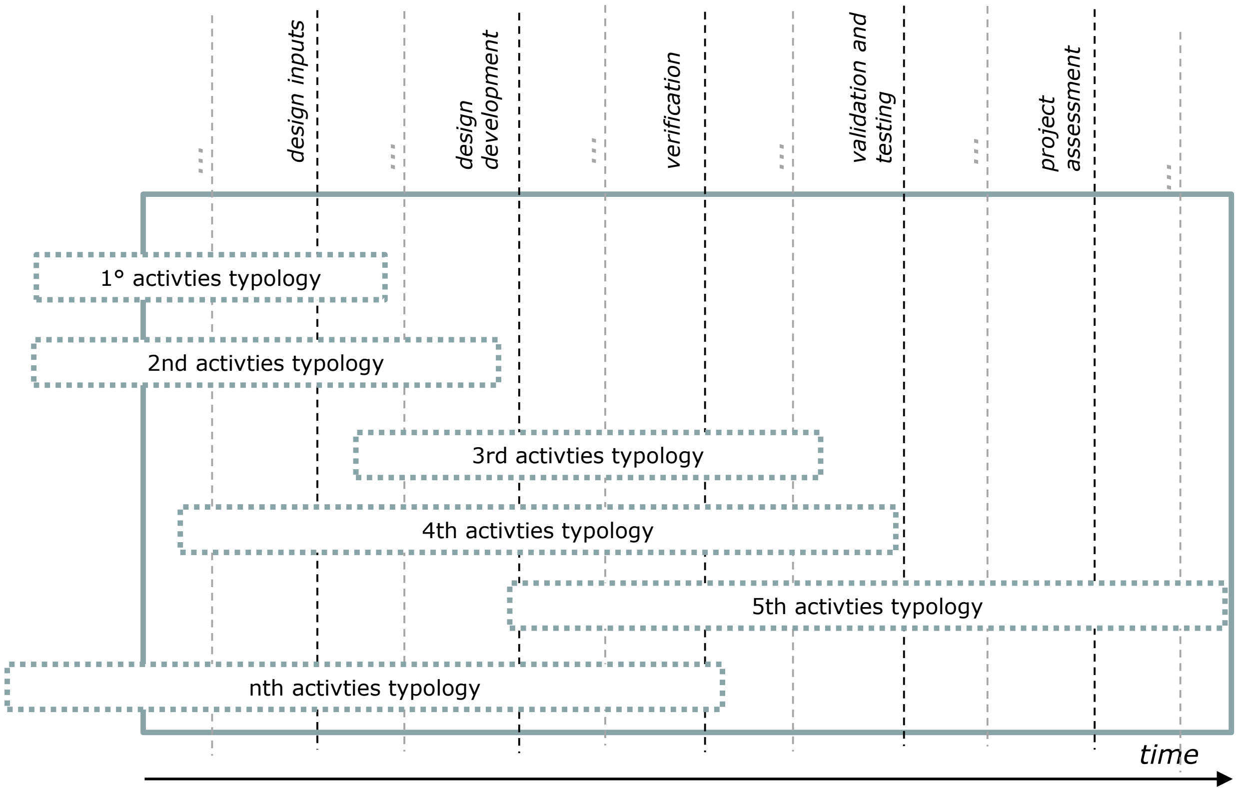
[*abstract from* www.bimanual.com)]

Engineering

engineering process framework - structure

In practice the engineerig process framework's shape will be very smilar to a Gantt. More in detail:

- on a Gantt horizontal axis usually one has just time, while now it must shown the **phases of the whole project**,
- on the vertical axis one will put the **activities to be carried out**.



«Is there any rule about the number of process' phases and the one related to the activities to be carried out?
«No, there isn't, but of course things must be suitably deployed».

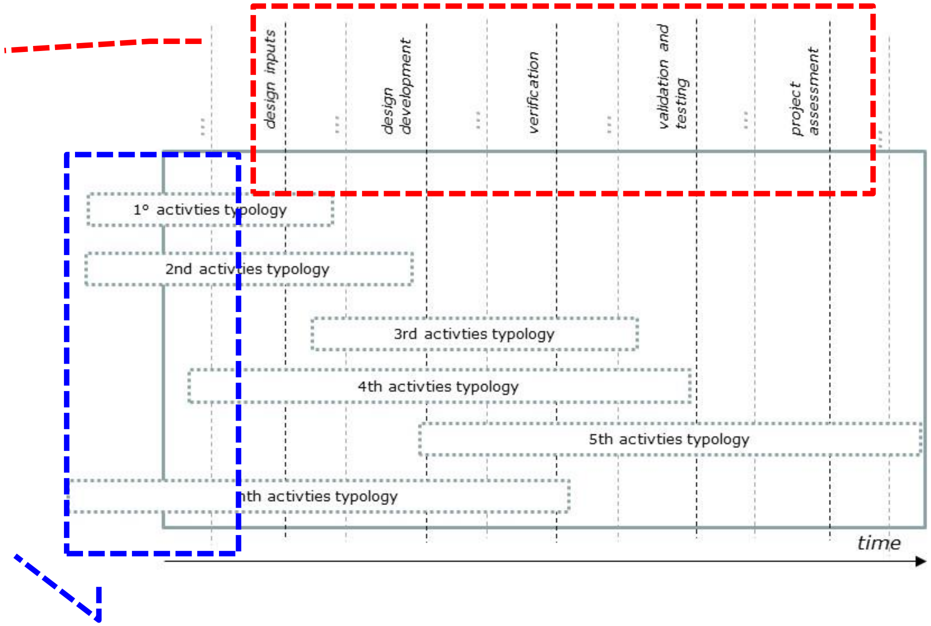
Engineering

engineering process framework - structure

«What does it mean that there isn't any rule, but things must be suitably deployed?»

About phases it means that you're the only one who can decide how many phases should be taken into account. Anyway, of course you should consider a certain number such to guarantee your project's effectiveness.

On «activities typologies»: looking at «studies and trials» you have several typology what mentioned it means that you're the only one who can decide how many phases should be taken into account. Anyway, of course you should consider a certain number such to guarantee your project's effectiveness.



Engineering

engineering process framework - phases

About phases, and besides ISO 9000 (ref. page 64), typical project management terminology refers specific phases named customer deliverables, maturity gates and milestones, that's:

- **customer deliverable** : the final work product at the highest level that results in a tangible item given to the final customer for approval.

  Some comments about:
  - A "tangible item" can be both a physical part and other things like calculations, analysis' or trials' results on specific subjects etc.
  - Furthermore it's to say that the word "customer" isn't (necessary) referred to the client meant as end user, indeed it includes the "internal customers" as well, that's any entity appointed to consider the deliverable itself both for its evaluation and as input for its work.
- **maturity gates** : as a product design is promoted through the design process, it requires that certain elements be in place before moving on the next phase. Maturity gates control this process.
- **milestones**: another term for maturity gates … Milestone are usually high-level events where top management decisions are made.

[S.C. Armstrong – Engineering and product development management]

the above phases can be meant as a WBS application (the Project Management Body of Knowledge (PMBOK5) defines WBS as "A hierarchical decomposition of the total scope of work to be carried out by the project team to accomplish the project objectives and create the required deliverables"). Just about see App. 5 for other engineering process framework examples.

That said, it's also to say that:

- a priori customer deliverables could be as much as the «studies and trials» you've taken into account. Anyway, if it's not so their number will be at least as much as the «activities typologies» you defined.
- of course the quantity of maturity gates will be less than the customer deliverables.
- the milestones generally include financial considerations as well.

Engineering

engineering process framework – «activities typologies»

On activities typologies: some different typologies have been mentioned in the «studies and trials» chapter, anyway the showed «thirty elements of system engineering» table can give you further (and important) hints.

The thirty elements of system engineering

- ✓ **Needs/goals/objectives**
- ✓ **Mission engineering**
- ✓ **Requirement analysis/allocation**
- ✓ **Functional analysis/allocation**
- ✓ **Architecture design/synthesis**
- ✓ **Alternative analysis/evaluation**
- ✓ **Technical Performance Meaurements**
- ✓ **Life Cycle costing**
- ✓ **Risk analysis**
- ✓ **Concurrent engineering**
- ✓ **Specification development**
- ✓ **Hardware/software/human engineering**
- ✓ **Interface control**
- ✓ **Computer tool evaluation and utilization**
- ✓ **Technical data management**
- ✓ **Integrated logistic support**
- ✓ **Reliability, Maintainability, Availability**
- ✓ **Integration**
- ✓ **Test and evaluation**
- ✓ **Quality Assurance and management**
- ✓ **Configuration management**
- ✓ **Specialty engineering**
- ✓ **Preplanned product improvement**
- ✓ **Training**
- ✓ **Documentation**
- ✓ **Production**
- ✓ **Installation**
- ✓ **Operations & Maintenance**
- ✓ **Operations evaluation/reengineering**
- ✓ **System engineering management** (planning, organizing, directing and modelling)

[H. Eisner - Essentials of project and system engineering management]

For instance:

- «mission engineering»: in rough words one could mean how much engineering activities must be studied in details (see pages 71-73 as well).
- «technical performance management»: apart from the analysis (studies and trials) you can carry out on some specific subjects, a key point is your ability to measure the system's (product's) performances you're designing.
- «concurrent engineering» which is a key way in order to match the expected time-to-market.
- «specification development + documentation»: it's to take into account that a project ends when its documentation is issued as well.
- «technical data management»: very seldom initial input don't change during the development, so it's vital to suitably check them and update the development's work.
- «integration»: it's particularly important in case of a modular project, which requires «integration and testing rules».
- «Quality Assurance and management»: beyond what provided by the process phases, specific check on quality and its fitting with the company Quality System must be foreseen.
- …

Engineering

engineering process framework – concurrent engineering

A further note on activities disposal in the time (that's on their planning) is the respect of time-to-market, which, generally speakin,g is increasingly shortening. A (a priori simple) way is to avoid any activities' serializing (which of course would extend the whole project time) is to put them in parallel, that's to adopt concurrent (or smultaneous) engineering criteria.

However, besides time-to-market, concurrent engineering is a way to reduce time and money waste. Indeed, by the advancing of potential matters, it would reduce (typical) development process' iterativity.

- **concurrent engineering** : a design process in which any functional area with an interest in the product has an opportunity to have input into the design up front before the detail product data are developed. The objective is to make the bulk of the product changes up front to eliminate surprises later in the life cycle when they are more expensive to fix.

[S.C. Armstrong – Engineering and product development management]

Function \ Phase	Conceptual Definition	Preliminary Definition	Detailed Definition	Production Build
Marketing	Partial	Partial	Full	Full
Design Engineering	Full	Full	Full	Partial
Manufacturing Engineering	Partial	Partial	Full	Full
Manufacturing	Inadequate	Partial	Partial	Full
Materials Management	Inadequate	Partial	Partial	Full
Business Management	Inadequate	Inadequate	Partial	Partial
Finance	Partial	Inadequate	Inadequate	Full
Customer Support	Inadequate	Inadequate	Inadequate	Full

- Full Involvement - Partial Involvement - Inadequate Involvement

Figure 4-8: Concurrency matrix

[S.C. Armstrong – Engineering and product development management]

Engineering

engineering process framework – development procedure

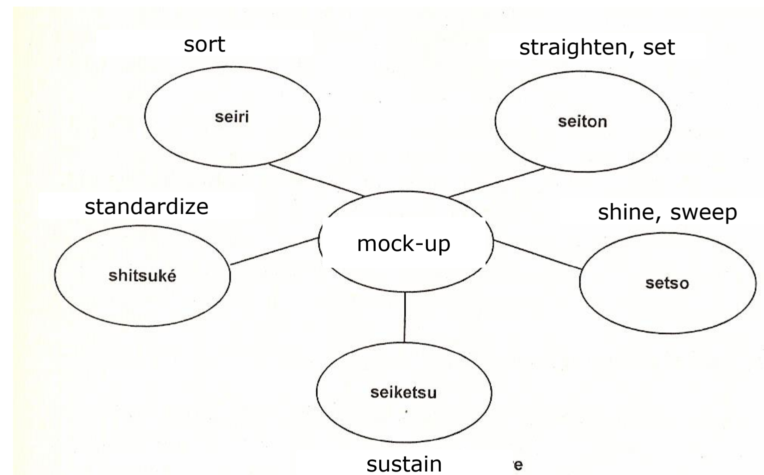
- In order to assure a suitable application, it's very useful to abstract what in the previous pages (ref. to «phases» and «activities typologies») in a suitable **development procedure**. If included in the company's Quality System, such procedure would guarantee consistency with the company strategy.

[https://the9000store.com/iso-9001-2015]

- A **process** states *what* needs to be done and why.
- A **procedure** states *how* the *process* needs to be done.
- A **work instruction** explains *how* to carry out the *procedure*.

- Anyway, taking into account complexity as well and specifically the usual modifications of the inputs which arise during the development process itself, it's also useful to keep the right flexibility. In other words «one must avoid to regiment the process, at any rate guaranteeing effectiveness and efficiency». A good reference about is the 5S model.

however, a successful 5S impementation must be rigorous, mostly about communication standard (that's bahviour's consistency).



[*abstract from* M. Langfelder – Engineering]

Engineering

engineering process framework – dimensioning of the engineering process framework

Now, an arising question could be «how much should one detail the engineering process framework?»

The answer can't be univocal, indeed it would depend by:

- the **company's culture**

  Indeed culture is «implicit behaviuru», so what a company or people are used to do because sure of its justness. Anyway, how to check it? A company's culture is a theme of an organizational analysis, specifically about its institutional set-up, that's the characteristic which is determined by the whole of the company's structure, powers and prerogatives of basic entities and roles. In other words: the institutional set-up fixes the basic rules which characterize the company's behaviour/»life style».

Culture definitions:

- the customs and beliefs, art, way of life and social organization of a particular country or group.
- the beliefs and attitudes about something that people in a particular group or organization share.

[Oxford Dictionnary]

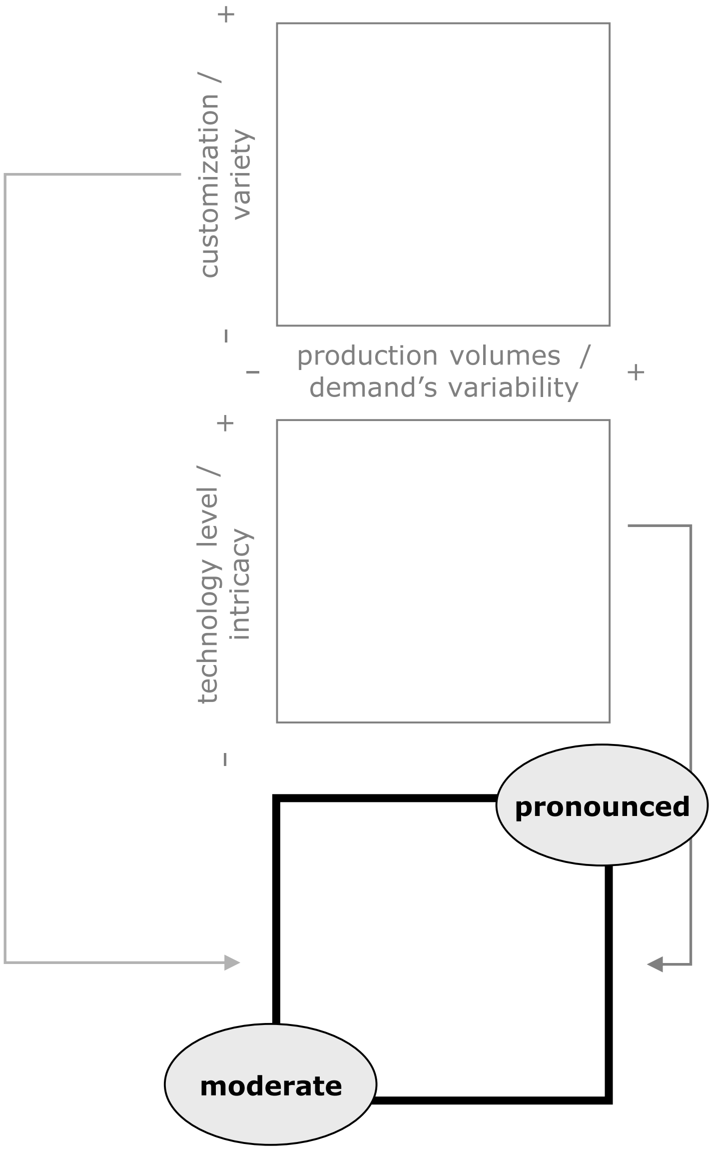
By the way, such comment on a company's culture underlines the need to be aware on the company organization as necessary condition for any project development.

- the **specific product characteristics**, that's the ones of the developping product.

  Such characteristics will be both about the differences existing with relation to other products and with such products' operations characteristics, that's to say the differences about production tecnologies, production volumes and their variability etc.

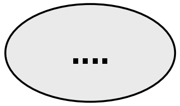
Engineering

engineering process framework – dimensioning of the engineering process framework



A possible tool about the engineering's depth level is given by the sketch. Of course in case of high customization and variety, high difference about the technological level required by the developping product (level of intricacy) and demands variability, the engineering process must be significantly pronounced, and viceversa.

.



: ... engineering depth

Engineering

engineering process framework – dimensioning of the engineering process framework

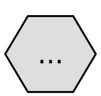
Anyway, taking into account the distinction between product and process engineering page 31) one will have to suitably differentiate them. In other words, may be it’ll have to give a suitable detail’s to logistics and manufacturing issues rather than to technological feasability (ref. page 31) or viceversa.

As additional note about the technology level/intricacy: leaving radical or incremental innovation models out of consideration, one could take into account other projects typologies, that’s:

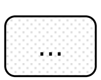
- adaptive
- of version
- original

which are respectively distinguished by:

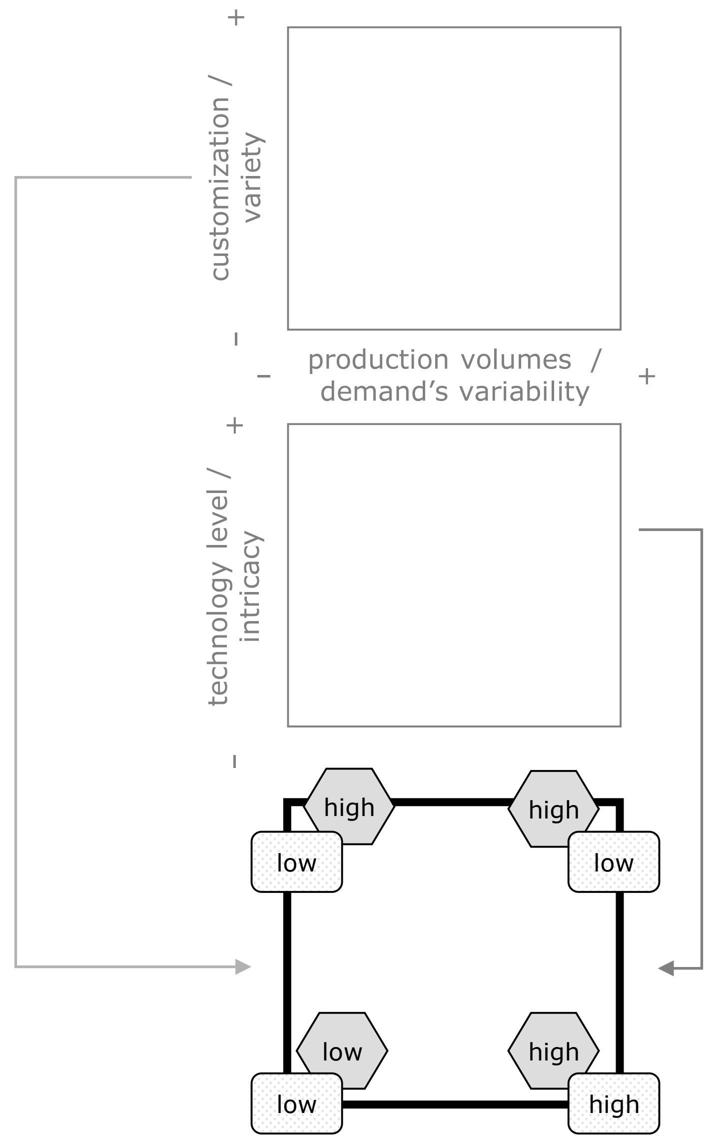
- the taking into account of new functions for an existing product,
- of new process or structural solutions without any change of previous functions,
- the search of new solutions related both to the product’s structure and to its functions.



: ... process engineering depth



: ... product engineering depth



Engineering

App. 1 – ref. to «holistic view»: bodies of knowledge definitions.

- **integrated product development (IPD)**: a management process that integrates all activities from product concept through production/field support. using a multifunctional team, to simultaneously optimize the product and its manufacturing and sustainment processes to meet cost and performance objectives.
  [Guide to integrated product and process development – U.S. Department of Defense]
- **project/program management**: a temporary endeavor undertaken to create an unique product or service. Temporary means that every projects have a definite beginning and definite end. Unique means that the product or service is different in some distinguishing way from all other similar product or services.
  [Guide to Project Management Body of knowledge – Project Management Institute]
- **process management**: an approach that involves thinking of the enterprise as a collection of processes rather than functions. Economic values is created vy completing business process. Process management involves studying, organizing and improving the business processes of an enterprise, often thought as a process reengineering.
  [S.C. Armstrong – Engineering and product development management]
- **organizational change/political management**: the body of knowledge that contains the tools and techniques that allow us to identify and systematically overcome resistance to change. Overcome resistance to change from all levels within an organization.
  [S.C. Armstrong – Engineering and product development management]
- **product data management** (PDM): a tool that helps engineers and the rest of the enterprise manage both the product data and the product development process. It provides a central repository for design data and documentation to ensure that all authorized personnel have access to the most current version.
  [S.C. Armstrong – Engineering and product development management]
- **systems engineering**: an interdisciplinary approach and means to enable the realization of successful systems.
  [International Council on System Engineering]

Engineering

App. 2 (i/ii) – Engineering standards overview

- **IEEE**: Institute of Electrical and Electronics Engineers
- **ANSI/EIA**: American National Standards Institute / Electronic Industries Alliance
- **ISO/IEC**: International Organization for Standardization/International Electrotechnical Commission
- **CMMI**: Capability Maturity Model Integration

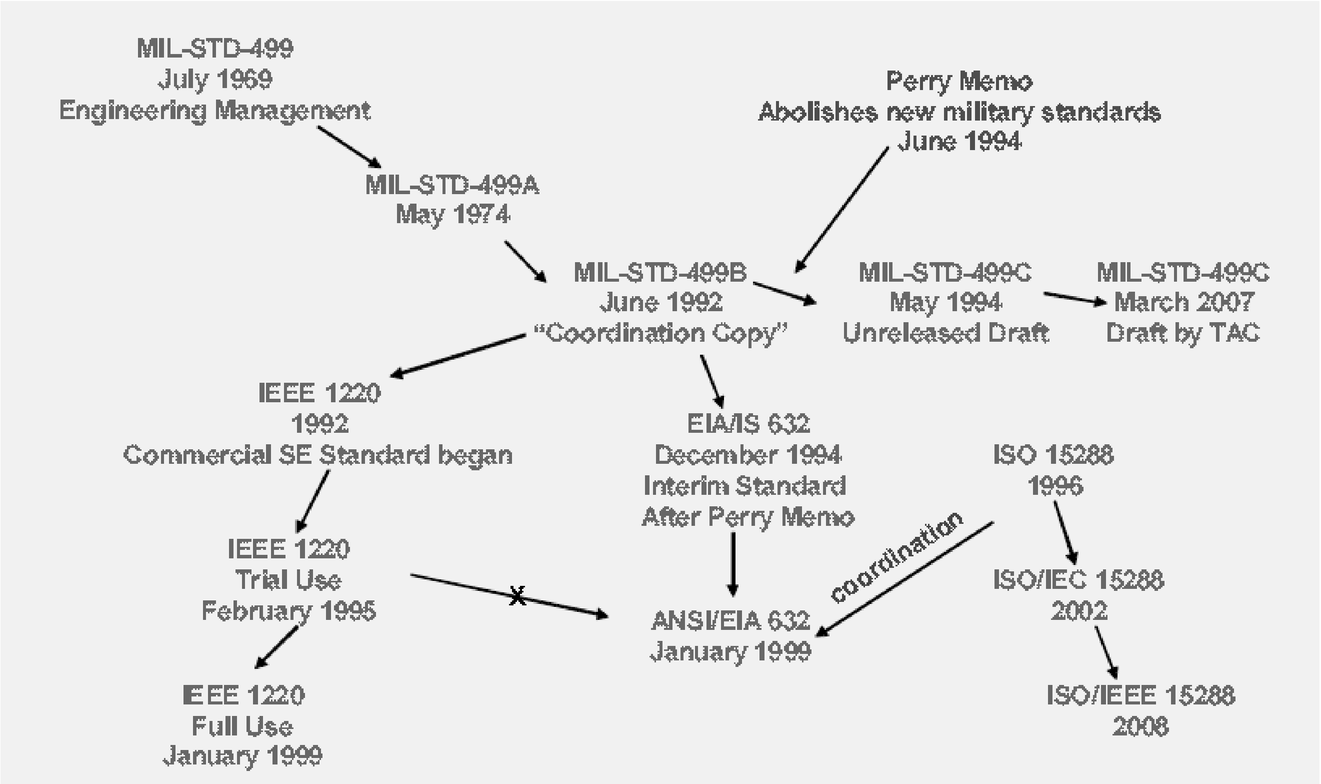


Fig. 1. The evolution of systems engineering standards.

[G.S. Chang et Al. – Journal of Biomecatronics Engineering , Vol 1 No. 1 2008]

Engineering

App. 2 (ii/ii) – Engineering standards overview

ANSI/EIA 632 Process Model

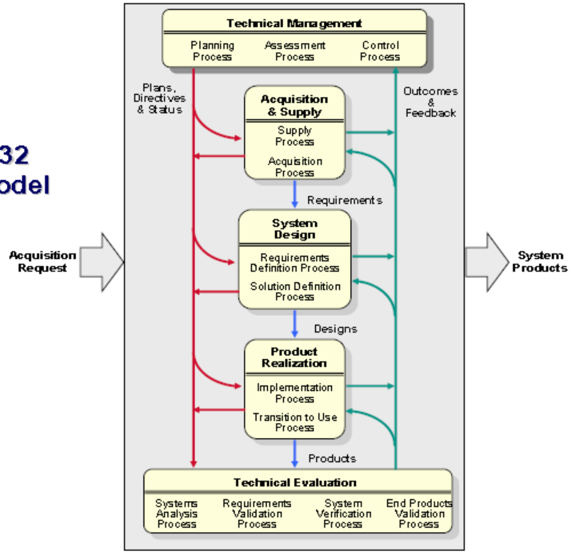


Figure 2: ANSI/EIA 632 Process Model

IEEE 1220 Process Model

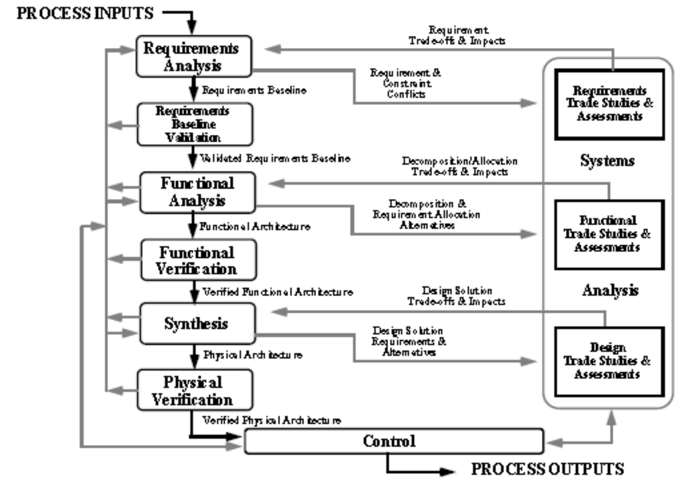


Figure 3: IEEE 1220 Systems Engineering Process

ISO/IEC 15288 Process Model

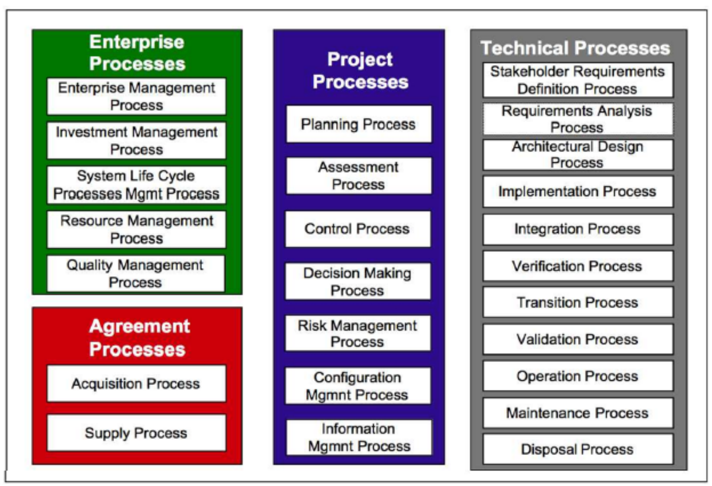


Figure 5: ISO/IEC 15288:2002 Process Details

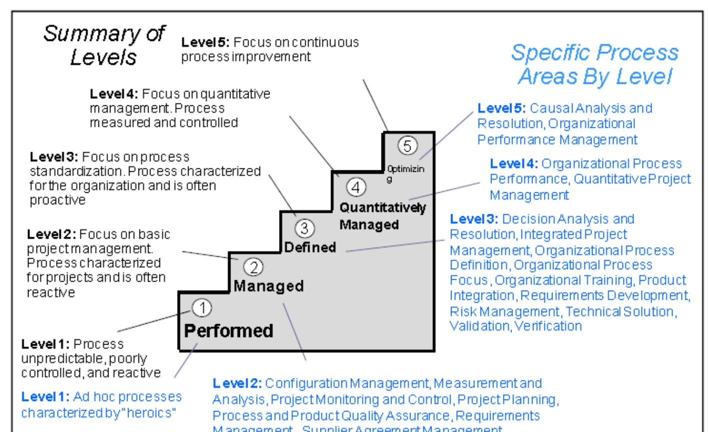


Figure 7. CMMI-DEV, version 1.3

[Systems engineering standards: a summary – www.acqnotes.com]

Engineering

App. 3 – MIL-STD-499B index.

MIL-STD-499B *DRAFT*

CONTENTS

Engineering **App. 4** – platform example.

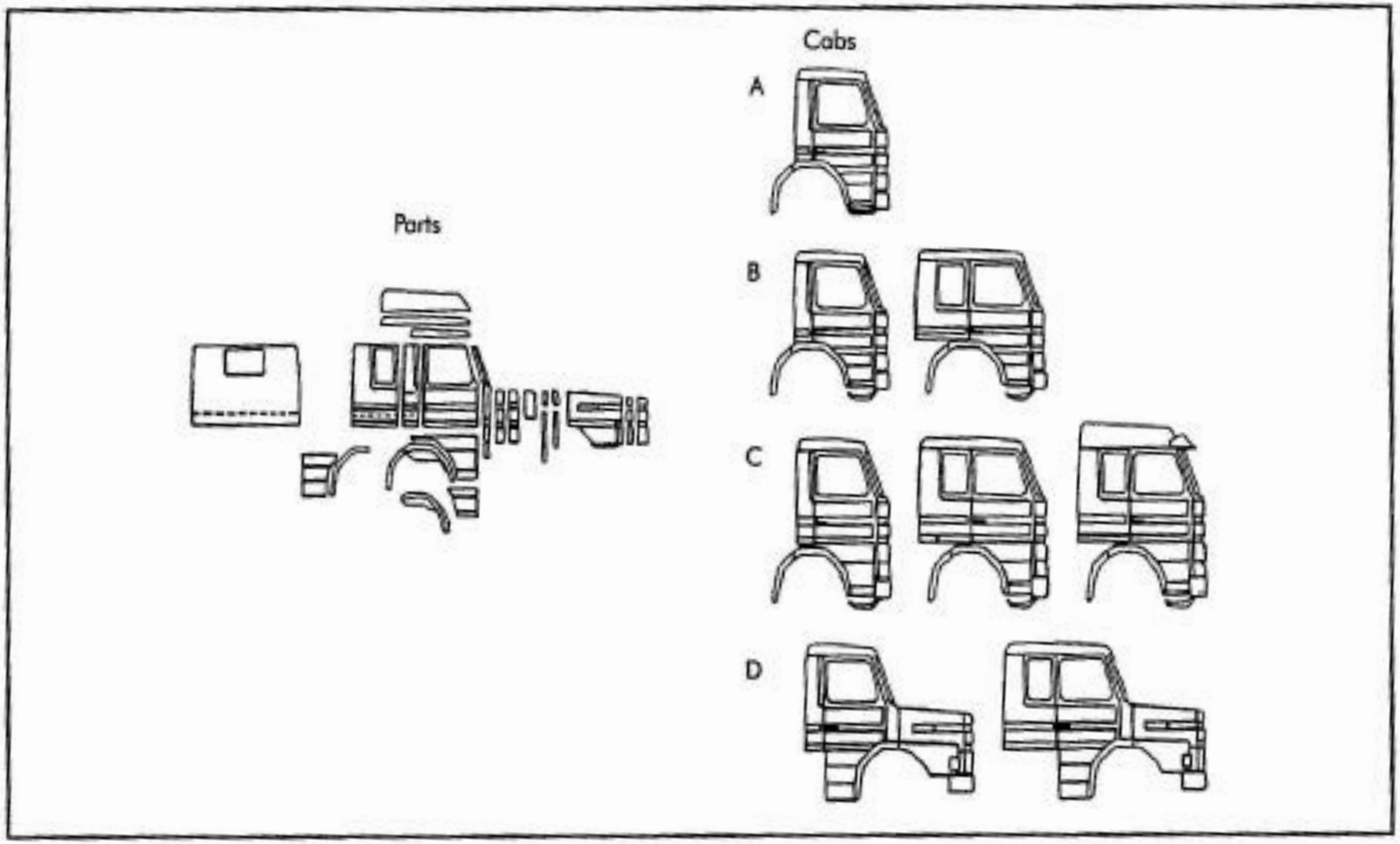


Figure 1-2. Scania's modular truck cab. With the modularized cab, Scania can offer their customers a wider range of products than previously and they now have fewer parts, fewer pressing tools, and shorter assembly time.

[A. Ericssson, G. Erixon – Controlling Design Variants (Modular Product Platforms]

Engineering

App. 5 (i/ii) – list of reliability MIL-STD.

up to 199

MIL-HDBK-61A(SE): Configuration Management Guidance (221 pages, 1.3 MB; updated 2/2001)

MIL-HDBK-108
Sampling Procedures and Tables for Life and Reliability Testing (Based on Exponential Distribution)
(77 pages, 6.09 MB)

- **MIL-HDBK-108(1)**: Notice 1 (1 page, 17 KB)

MIL-HDBK-189C: Reliability Growth Management (149 pages, 3.1 MB; updated 6/2011)

200-299

MIL-HDBK-217F
Reliability Prediction of Electronic Equipment - Notice F
(205 pages, 14.9 MB)

- **MIL-HDBK-217F(1)**: Notice 1 (37 pages, 2.78 MB)
- **MIL-HDBK-217F(2)**: Notice 2 (80 pages, 5.91 MB)

MIL-HDBK-251
Reliability/Design Thermal Applications
[This is a 40.5 MB WinZip file that contains the document in *.pdf format (697 pages, 53.8 MB)]

300-399

MIL-HDBK-338B
Electronic Reliability Design Handbook - Revision B
(1046 pages, 4.56 MB)

- **MIL-HDBK-338B(1)**: Notice 1 (1 page, 17 KB)

MIL-HDBK-344A
Environmental Stress Screening (ESS) of Electronic Equipment - Revision A
(102 pages, 4.51 MB)

- **MIL-HDBK-344A(1)**: Notice 1 (1 page, 17 KB)

400-499

MIL-HDBK-470A
Designing and Developing Maintainable Products and Systems - Revision A
(719 pages, 5.43 MB)

- **MIL-HDBK-470A(1)**: Notice 1 (1 page, 17 KB)

MIL-STD-471A
Maintainability Verification/Demonstration/Evaluation - Revision A
(64 pages, 707 KB)

- **MIL-STD-471A(1)**: Notice 1 (56 pages, 879 KB)
- **MIL-STD-471A(3)**: Notice 3 (1 page, 7.4 KB)

MIL-HDBK-472
Maintainability Prediction
(176 pages, 5.85 MB)

- **MIL-HDBK-472(1)**: Notice 1 (122 pages, 3.98 MB)

500-599

600-699

MIL-STD-690D
Failure Rate Sampling Plans and Procedures - Revision D
(43 pages, 673 KB)

700-799

MIL-STD-721C
Definition of Terms for Reliability and Maintainability - Revision C
(18 pages, 819 KB)

- **MIL-STD-721C(2)**: Notice 2 (1 page, 17 KB)

MIL-STD-750E
Test Methods for Semiconductor Devices - Revision E
(685 pages, 8.94 MB)

- **MIL-STD-750F**: With Change 1 (21 pages, 205 KB)

MIL-STD-756B
Reliability Modeling and Prediction - Revision B
(85 pages, 2.91 MB)

- **MIL-STD-756B(2)**: Notice 2 (1 pages, 3 KB)

MIL-HDBK-781A
Handbook for Reliability Test Methods, Plans, and Environments for Engineering, Development, Qualification, and Production - Revision A
(411 pages, 27.1 MB)

MIL-STD-781D
Reliability Testing for Engineering Development, Qualification and Production - Revision D
(47 pages, 1.46 MB)

- **MIL-STD-781D(1)**: Notice 1 (1 pages, 4 KB)

MIL-STD-785B
Reliability Program for Systems and Equipment Development and Production - Revision B
(88 pages, 12.9 MB)

- **MIL-STD-785B(1)**: Notice 1 (3 pages, 1.07 MB)
- **MIL-STD-785B(2)**: Notice 2 (9 pages, 760 KB)
- **MIL-STD-785B(3)**: Notice 3 (1 page, 4 KB)

MIL-STD-790F
Established Reliability and High Reliability Qualified Products List (QPL) Systems For Electrical, Electronic, and Fiber Optic Parts Specifications - Revision F
(17 pages, 834 KB)

- **MIL-STD-790F(1)**: Notice 1 (6 pages, 20 KB)
- **MIL-STD-790F(2)**: Notice 2 (3 pages, 15 KB)

800-899

MIL-STD-882C
System Safety Program Requirements
(117 pages, 8.29 MB) Please note that this standard was superseded by MIL-STD-882D.

- **MIL-STD-882C(1)**: Notice 1 (3 pages, 94 KB)

MIL-STD-882D
System Safety
(31 pages, 116 KB)

MIL-STD-882E
System Safety
(104 pages, 1,232 KB)

Engineering

App. 5 (ii/ii) – list of reliability MIL-STD.

1000-2000

MIL-STD-1543B
Reliability Program Requirements for Space and Launch Vehicles - Revision B
(100 pages, 10.3 MB)

MIL-STD-1543B(1): Notice 1 (1 pages, 3 KB)

MIL-STD-1629A
Procedures for Performing a Failure Mode Effects and Criticality Analysis - Revision A
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MIL-STD-1629A(1): Notice 1 (11 pages, 882 KB)

MIL-STD-1629A(2): Notice 2 (7 pages, 542 KB)

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MIL-PRF-19500P with Amendment 2
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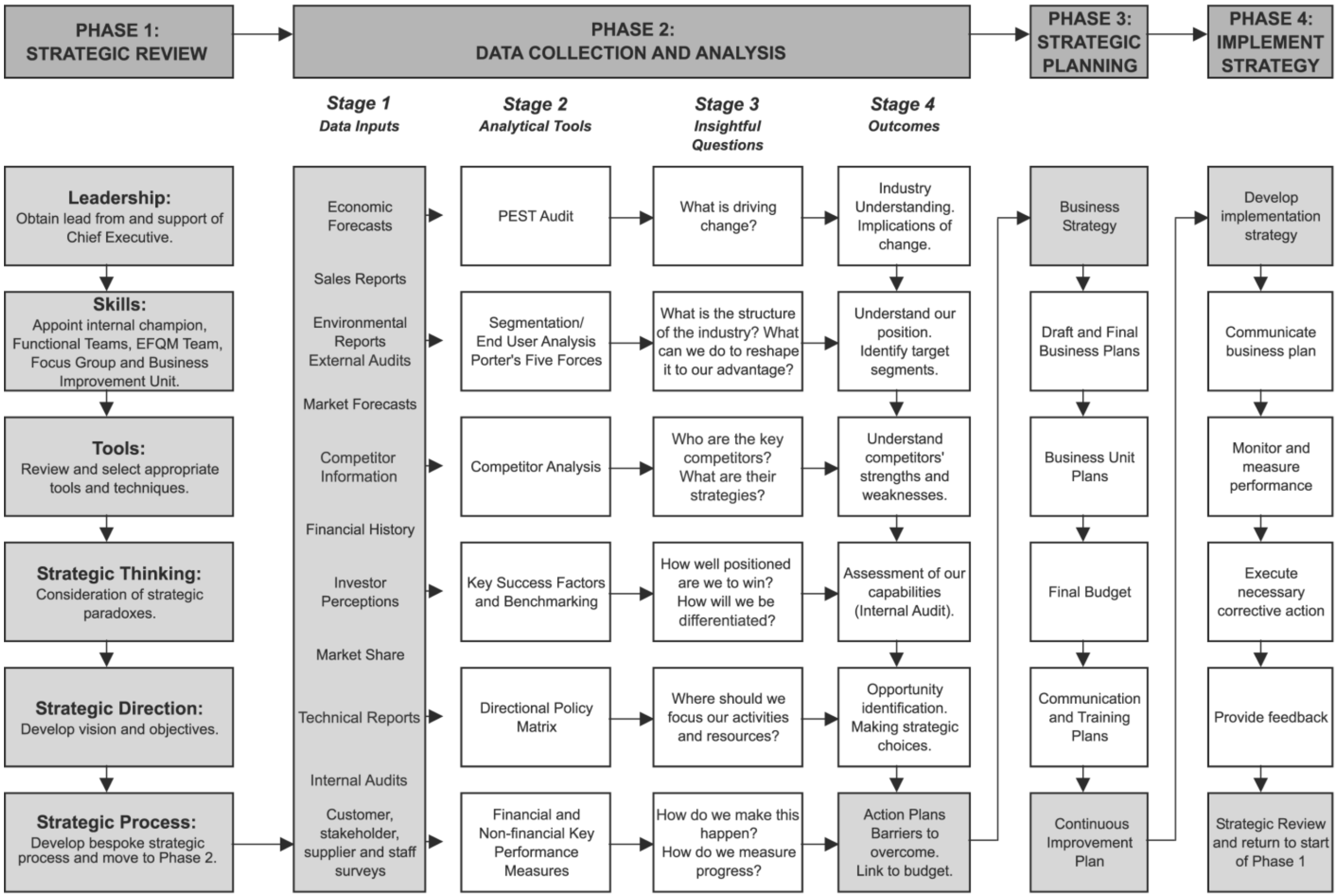
(174 pages, 1.15 MB)

Engineering - *App. 5* – (1/3) – esempi di process framework

gli esempi riportati sono **funzionali al solo obiettivo di comprendere come un process framework può presentarsi** (contenuti di tali esempi non hanno alcuna importanza).

... un esempio di process framework (ii)



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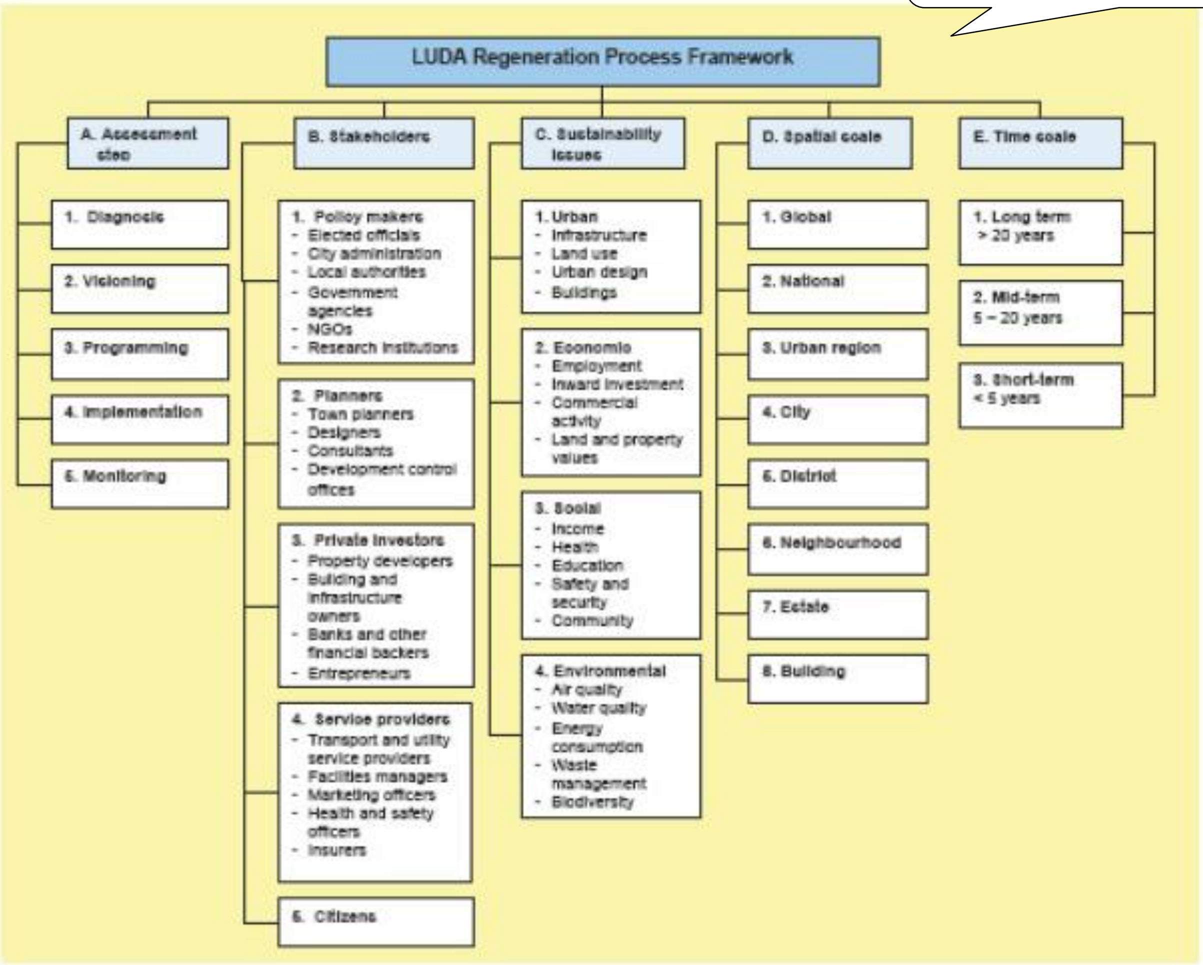
Engineering - *App. 5* – (3/3) – esempi di process framework

... un esempio di process framework (iv)

gli esempi riportati sono **funzionali al solo obiettivo di comprendere come un process framework può presentarsi** (icontenuti di tali esempi non hanno alcuna importanza).



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