Safety and Maintenance for Industrial Systems

Lecture 2

Elements of Safety Engineering

Contents and Goals

- Contents
  - Elements of Safety Engineering
  - Complex systems
  - Definition of “risk”
  - Prevention and protection
- Goals
  - To learn fundamental concepts and definitions
- Professional figures of reference
  - Safety Designer
  - Safety Supervisor
  - Safety Manager

Safety Engineering

- Safety is a discipline and a technical activity
- Safety of Industrial plants deals with every complex technical system
- Safety is tangible but even an intangible product = service
- Safety is a Company function = a complex of omogeneous (in contents and goals) Company activities

Complex Systems

- A **system** is a set of elements, variously connected to each other, designed to achieve a definite purpose.

- A **hierarchical** system (can be decomposed hierarchically) is composed of sub-systems in relation to each other, each of which, in turn, is hierarchical in its structure.

- The **control area** in a system is the portion of the system consisting in a number of elements which are directly dependent by one “**boss element**”.

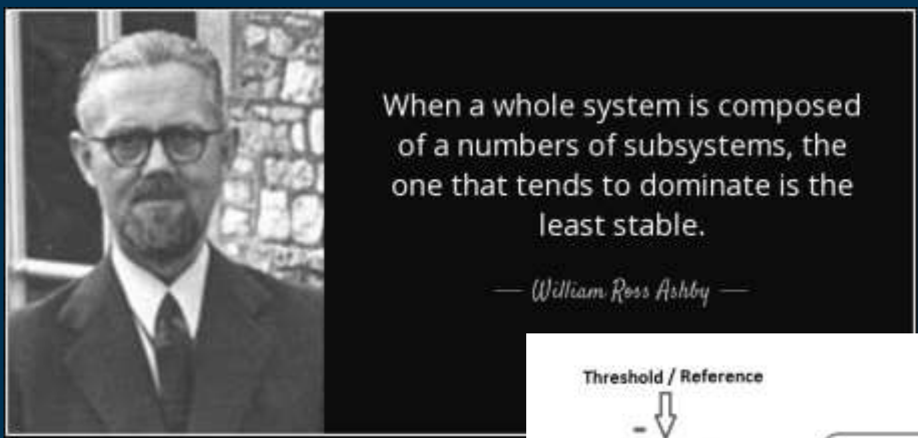
- At one level a system is said “**flat**”, if it has a very wide **control area (“span area”)** to that level.

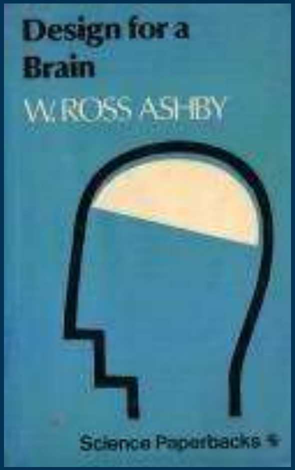
- There are many kinds of systems:
  - Social
  - Biological
  - Physical
  - Simbolic
  - …

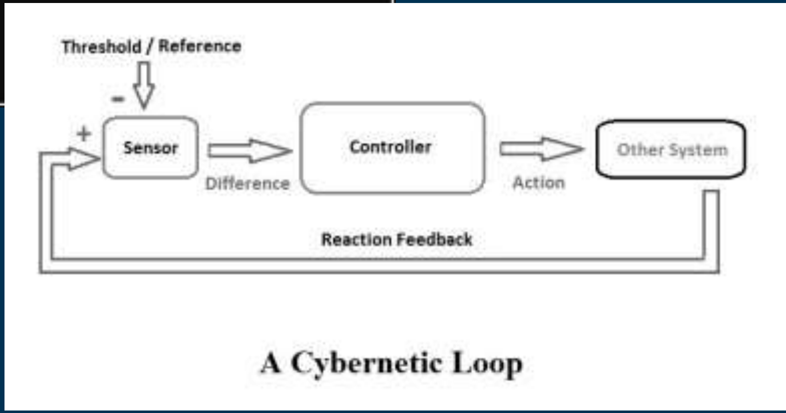
Complex Systems

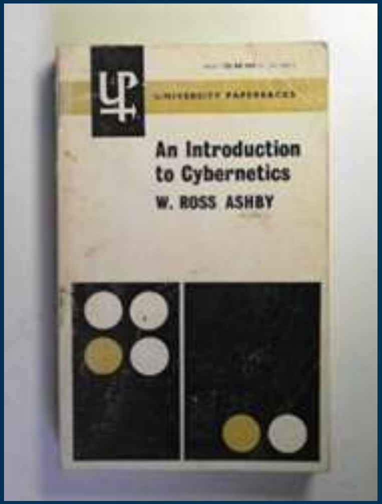
- The **variety** (or variance) of a system is the parameter representing the number of states that the system itself can take.

W. Ross Ashby (6 September 1903 – 15 November 1972) was an English neurologist and a pioneer in cybernetics









Complex Systems

- **Ashby's Law**:

$$\min V_S \geq V_R - V_C$$

V_S, variety of the system S (the lamp)
V_R , variety of the room R (the room lighting conditions, lighted/dark)
V_C , variety of the controller C (the switch of a lamp, or its dimmer)

⇒ To assume a very specific state to S
C must express a variety
at least equal to that of R

Complex Systems

- We say that a system is “**quasi-decomposable**” if it is a hierarchical system with strong relationships between the elements of each sub-system and weak interactions between sub-systems.

- In a quasi-decomposable system:
  - the **short-term behavior** of each sub-system is almost independent from the short-term behavior of the others
  - In a **long-term period**, the behavior of each system component only depends in an overall way from the behavior of the others

- The systems evolve towards hierarchical forms.

Complex Systems

- The complexity of a system depends on various factors:
  - abundance of the elements
  - number of relations
  - complication of the definition
  - …

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Complex Systems

SCIENCE AND COMPLEXITY

By WARREN WEAVER

Rockefeller Foundation, New York City

SCIENCE has led to a multitude of results that affect men's lives. Some of these results are embodied in mere conveniences of a relatively trivial sort. Many of them, based on science and developed through technology, are essential to the machinery of modern life. Many other results, especially those associated with the biological and medical sciences, are of unquestioned benefit and comfort. Certain aspects of science have profoundly influenced men's ideas and even their ideals. Still other aspects of science are thoroughly awesome.

How can we get a view of the function that science should have in the developing future of man? How can we appreciate what science really is and, equally important, what science is not? It is, of course, possible to discuss the nature of science in general philosophical terms. For some purposes such a discussion is important and necessary, but for the present a more direct approach is desirable. Let us, as a very realistic politician used to say, let us look at the record. Neglecting the older history of science, we shall go back only three and a half centuries and take a broad view that tries to see the main features, and omits minor details. Let us begin with the physical sciences, rather than the biological, for the place of the life sciences in the descriptive scheme will gradually become evident.

Problems of Simplicity

Complex Systems

A Mathematical Theory of Communication

By C. E. SHANNON

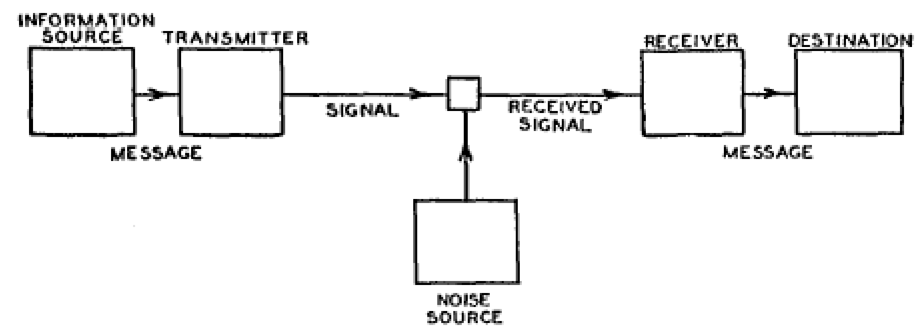


Fig. 1—Schematic diagram of a general communication system.

Complex Systems

THE ARCHITECTURE OF COMPLEXITY

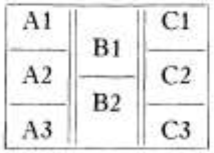
HERBERT A. SIMON*

Professor of Administration, Carnegie Institute of Technology

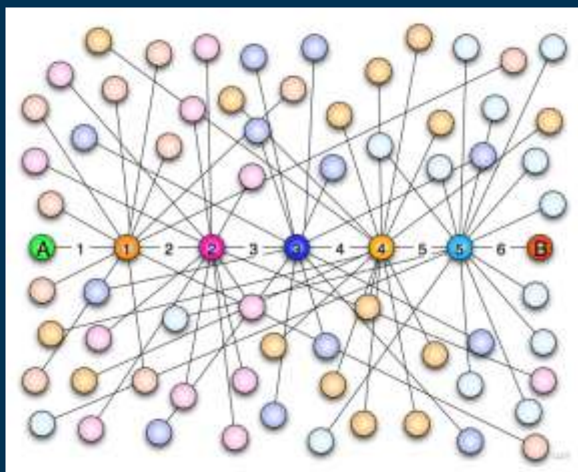
(*Read April 26, 1962*)

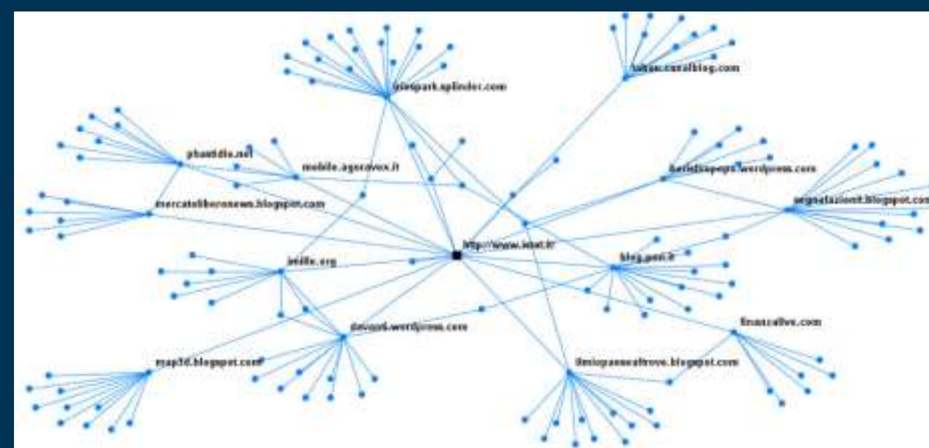
	A1	A2	A3	B1	B2	C1	C2	C3
A1	—	100	—	2	—	—	—	—
A2	100	—	100	1	1	—	—	—
A3	—	100	—	—	2	—	—	—
B1	2	1	—	—	100	2	1	—
B2	—	1	2	100	—	—	1	2
C1	—	—	—	2	—	—	100	—
C2	—	—	—	1	—	100	—	100
C3	—	—	—	—	2	—	100	—

FIG. 1. A hypothetical nearly-decomposable system. In terms of the heat-exchange example of the text, A1, A2, and A3 may be interpreted as cubicles in one room, B1 and B2 as cubicles in a second room, and C1, C2, and C3 as cubicles in a third. The matrix entries then are the heat diffusion coefficients between cubicles.



Complex Systems





Small Worlds Theory:

- What have in common some natural and artificial systems (fireflyes, internet, machines…) ?
- Low degree of separation
- High degree of accumulation
- Statistical distributions

Safety Engineering

- Safety has to be **designed**:
  - Risk analysis
  - Specific technical solutions
  - Organization
  - Planning of the safety activities (project management)
  - From an economic point of view: the costs for safety and non-safety (**SAFETY BUDGET**)

→ SAFETY TECHNICIAN

Safety Engineering

- Safety must be **implemented**:
  - Verification on the field of the adoption of the technical measures
  - Adoption of personal protective equipment (PPE)
  - Verification of tasks
  - New risks, new hazards
  - Serious and imminent hazards
  - Information/feedback to the employer

→ SAFETY SUPERVISOR

- Supervisor (DPR 547/55)
- Prevention and Protection Service (SPP) (DLgs 626/94)
- Safety representative (DLgs 626/94)

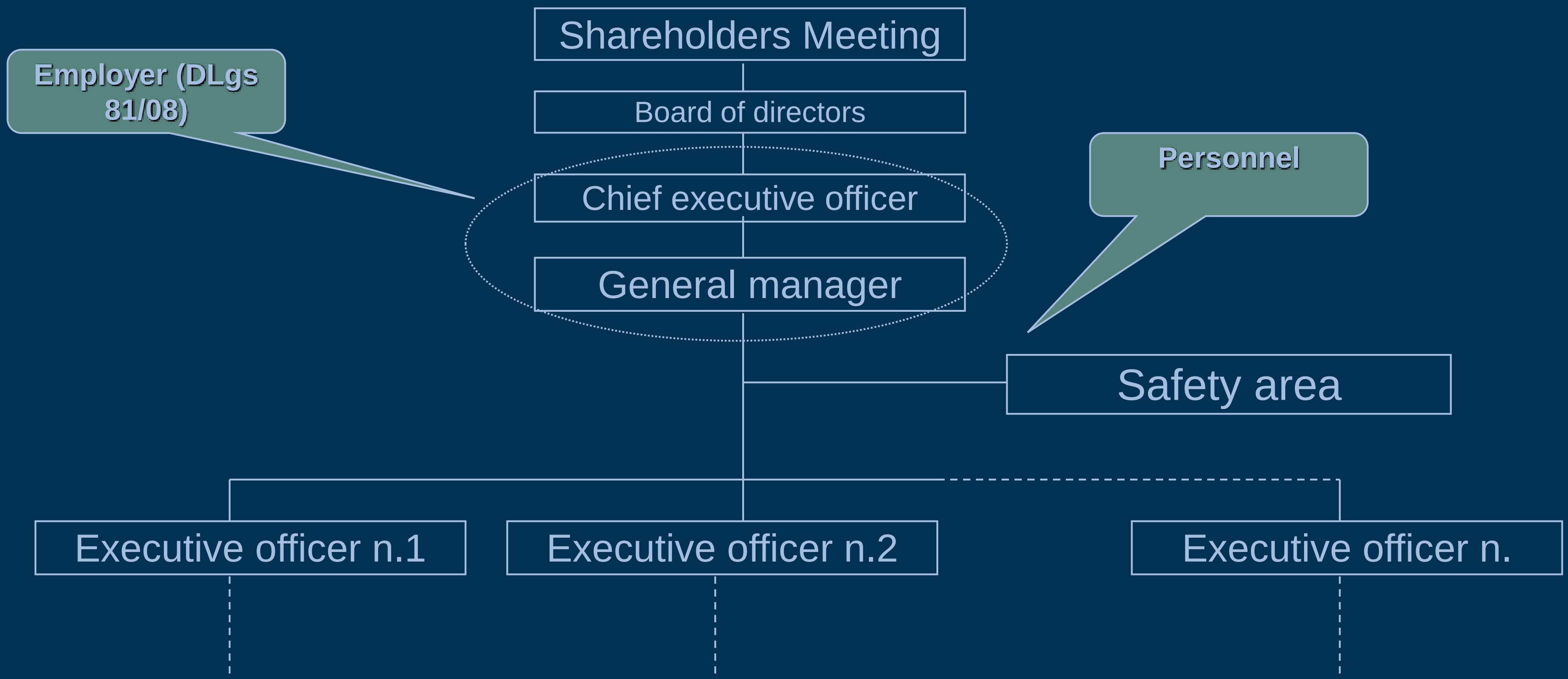
Safety Engineering

- Safety must be **managed**:
  - By updating the risk analysis, in accordance with
    - new works, new processes, modification of those existing
    - purchase of new techical resourses (machines, plants etc.)
    - new human resourses or relocation of those existing
  - From the point of view of the conservation / maintenance of the technical solutions
  - From the point of view of the technological update
  - From the point of view of the management of all the Company resources dealing with Safety (human and technical resources)

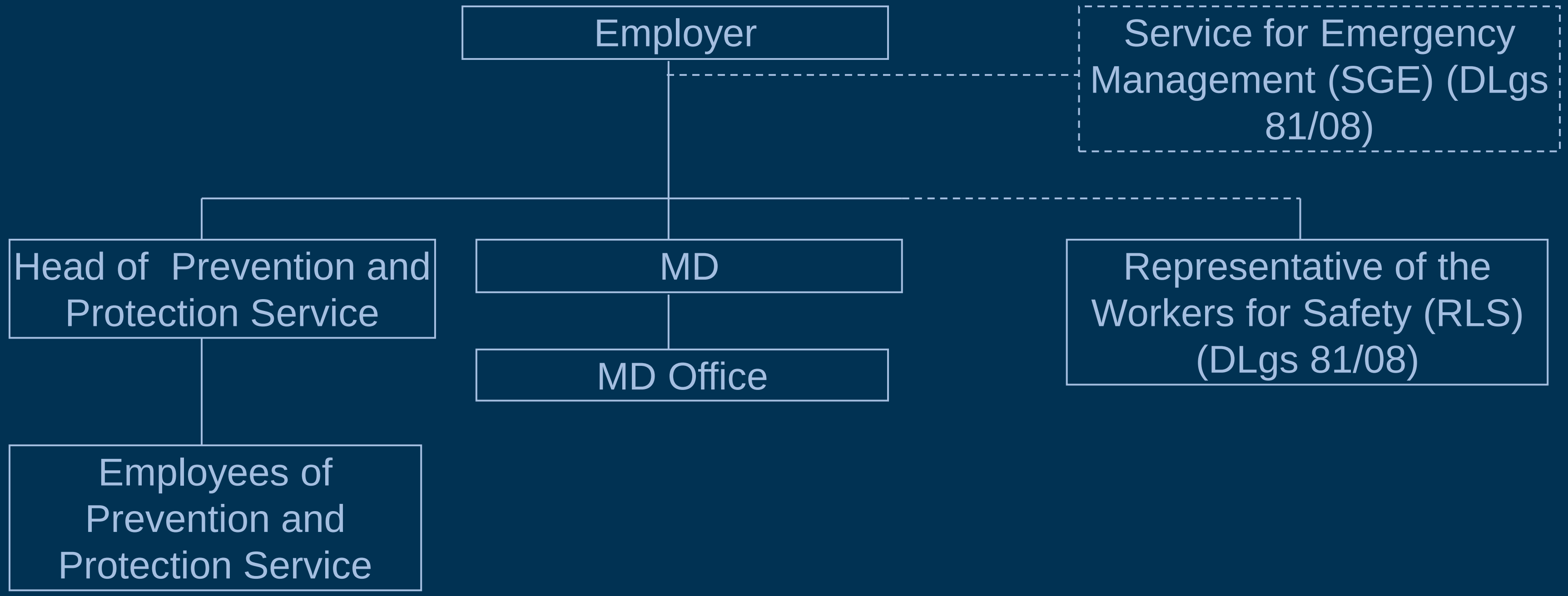
⇒ SAFETY MANAGER

- Executive (DPR 547/55)
- Employer (DLgs 626/94)
- Head of Prevention and Protection Service (RSPP) (DLgs 626/94)

An organizational example: a huge Company



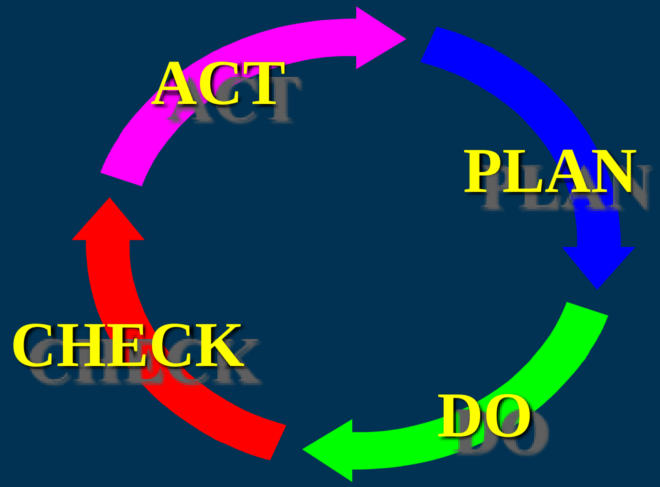
An organizational example: a huge Company



The Continuous Improvement

- Design / Plan
- Do
- Check
- Act

⇒ Quality of Safety ⇒ Satisfaction of stakeholders



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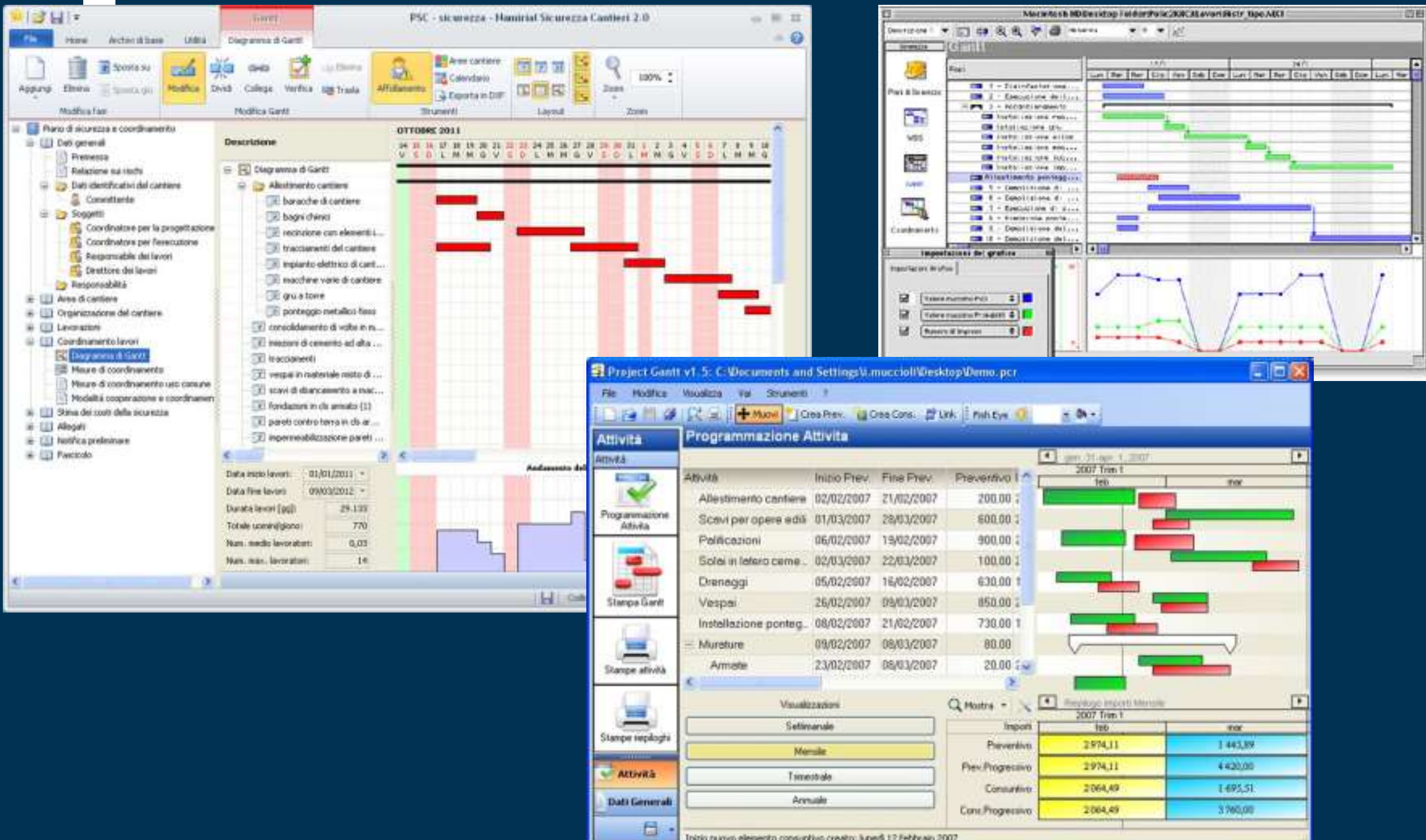
Planning

- Both Safety and non Safety have a cost
- Risk assessment should provide an indication of the urgency of the interventions
- Therefore, planning is essential
  - Timetable
  - Gantt chart
  - Programme and Evaluation Review Technique (PERT)
  - …

GANNT CHART

- The Gantt chart is characterized by the following input parameters:
  - Activities
  - Times
- To build the Gantt chart what follows is required:
  - identify all the activities (preferably hierarchically)
  - identify the order of the activities
  - identify the tasks lasting time
  - put each activity in the chart
- The chart allows to view at a glance:
  - Activities
  - Lasting time
  - Beginning and closing of each activity
  - Overlapping

GANNT CHART



PSC - sicurezza - Namirial Sicurezza Cantieri 2.0
OTTOBRE 2011
Descrizione
Project Gantt v1.5: C:\Documents and Settings\i.muccioli\Desktop\Demo.pcr
Attività
Programmazione Attività
Inizio Prev.
Fine Prev.
Preventivo
Allestimento cantiere
Scavi per opere edili
Palificazioni
Vespai
Murature
Armate
Programmazione Attività
Stampa Gantt
Stampe attività
Stampe riepiloghi
Dati Generali
Visualizzazioni
Settimanale
Mensile
Trimestrale
Annuale
Preventivo
Prev.Progressivo
Consuntivo
Cons.Progressivo

PERT

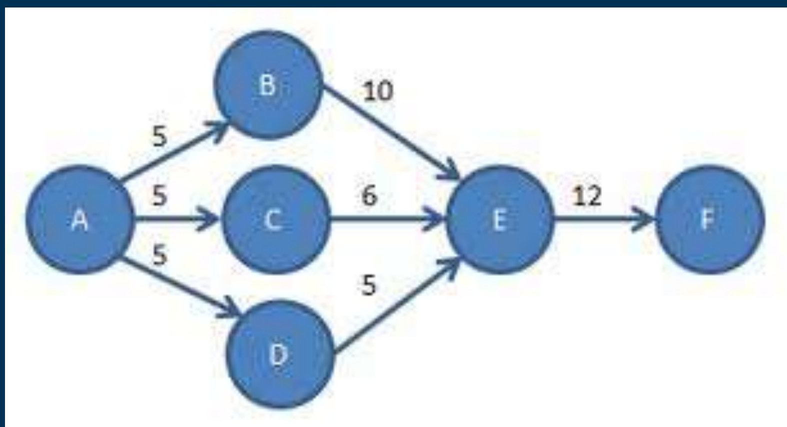
- The PERT Technique
  - Can be applied to a process consisting of several elementary activities
  - It is a reticular technique (based on graphs, formed by arcs and nodes)
  - It allows you to find the critical path, i.e. the sequence of activities that affect the total time of execution

- In the PERT Technique
  - The **elementary activities** are linked to the **arcs**
  - The **events** are linked to the **nodes** (an event corresponds to the occurrence of all the conditions necessary for the starting of the following activities)

PERT

- To apply PERT:
  - a list of the activities has to be provided
  - for each activity all those that must com before have to be identified
  - the estimated time for each activity (using statistical criteria and you can identify the most probable durations, or durations pessimistic or optimistic durations)
  - the graph is built (better to proceed backwards)
  - the durations of the activities are indicated in correspondence with each arc
  - in correspondence of each node they are indicated
    - the minimum time, considering the occurrence of the corresponding event (all previous activities concluded)
    - The maximum time, considering the deadline of the overall process
  - activities that can slip are identified, without delaying the process
  - the critical path is identified, corresponding to the path of activities that cannot slip

PERT


A
B
C
D
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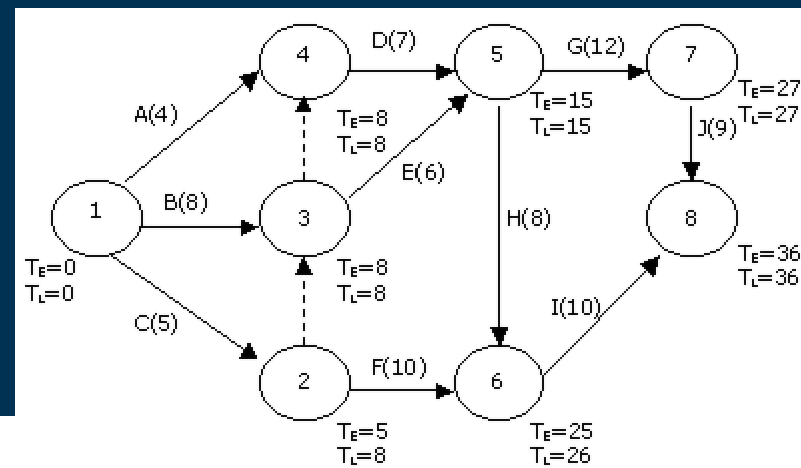
12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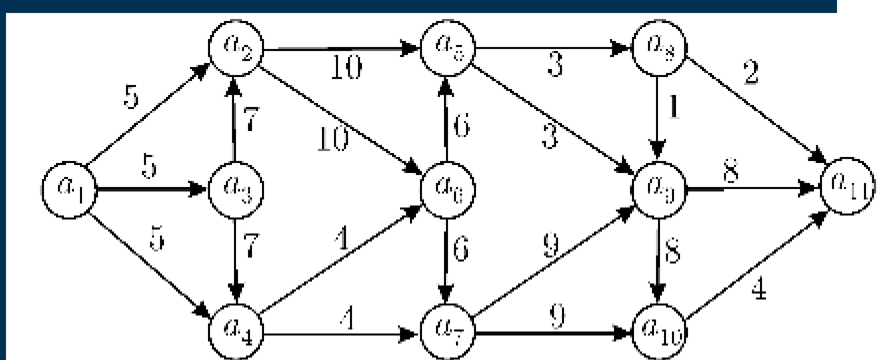
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4

Project management

- The planning of Safety activities (especially important in the case of yards) requires project management skills.

- Project management means a coordination activity of a process / project having as main objectives what follows:
  - planning of human resources to employ
  - planning of the deadlines (progress reports)
  - checking of the resources and the respect of the deadlines
  - the identification of variances and root cause analysis

Project management

Microsoft Excel - EasyProjectPlan.xls

File Edit View Insert Format Tools Data Window Help

EasyProjectPlan.com | Admin | Email | Version | Gantt | Delete Task | Insert Task | Group

I78 =

Version 1

%	Status	Flag	WBS	Tasks	Start	Finish	Duration	Owner	Priority	Milestone
			1	**Initiation**	**1/1/08**	**3/8/08**	**49 days**	Owner1,Owner2,Owner3		
100%	COMPLETED		1.1	Collect project ideas	1/1/08	2/1/08	24 days	Owner1,Owner2,Owner3		
100%	COMPLETED	⚑	1.2	Prioritize project ideas	1/2/08	2/4/08	24 days	Owner1,Owner2,Owner3	CRITICAL	Yes
100%	COMPLETED		1.3	Gather customer requirements	1/3/08	2/5/08	24 days	Owner1,Owner2,Owner3		
100%	COMPLETED		1.4	Select and justify a project	1/4/08	2/26/08	38 days	Owner1,Owner2,Owner3		
100%	COMPLETED	⚑	1.5	Submit and approve the Request for Proposal	1/5/08	2/5/08	22 days	Owner1,Owner2,Owner3	H	
20%	BEHIND SCHEDULE		1.6	Identify the project sponsor and project manager	1/30/08	3/8/08	28 days	Owner1,Owner2,Owner3		
30%	ON SCHEDULE	⚑	1.7	Get the project team in place	1/7/08	2/7/08	24 days	Owner1,Owner2,Owner3	M	
60%	ON SCHEDULE		1.8	Prepare the Requirements Document	1/8/08	2/8/08	24 days	Owner1,Owner2,Owner3		
10%	DATE TBD		1.9	Conduct project kickoff meeting		2/8/08	0 days	Owner1,Owner2,Owner3	L	
50%	CANCELLED		1.10	Conduct project brainstorming meeting				Owner1,Owner2,Owner3		
90%	ON SCHEDULE		1.11	Develop Statement of Scope	1/11/08	2/11/08	22 days	Owner1,Owner2,Owner3	NONE	Yes
			1.12	**WBS Development**	**1/13/08**	**2/15/08**	**25 days**	Owner1,Owner2,Owner3		
80%	ON SCHEDULE		1.12.1	Conduct Work Breakdown Structure meeting	1/13/08	2/13/08	23 days	Owner1,Owner2,Owner3	?	
30%	ON SCHEDULE		1.12.2	Build Work Breakdown Structure (WBS)	1/14/08	2/14/08	24 days	Owner1,Owner2,Owner3		
10%	ON SCHEDULE		1.12.3	Update WBS in Microsoft Project	1/15/08	2/15/08	24 days	Owner1,Owner2,Owner3		
100%	COMPLETED		1.13	Outline project plan	1/16/08	2/16/08	23 days	Owner1,Owner2,Owner3		
100%	COMPLETED		1.14	Assign resources to project plan tasks	1/17/08	2/17/08	22 days	Owner1,Owner2,Owner3		
			2	**Analysis**	**1/19/08**	**2/22/08**	**25 days**	Owner1,Owner2,Owner3		
0%	FUTURE TASK		2.1	Create Entity Relationship Diagram	1/19/08	2/19/08	22 days	Owner1,Owner2,Owner3		
100%	COMPLETED		2.2	Create Data Flow Diagram	1/20/08	2/20/08	23 days	Owner1,Owner2,Owner3		
0%	FUTURE TASK		2.3	Define data dictionary	1/21/08	2/21/08	24 days	Owner1,Owner2,Owner3		
0%	FUTURE TASK		2.4	Perform object-oriented analysis	1/22/08	2/22/08	24 days	Owner1,Owner2,Owner3		
			3	**Design**	**1/24/08**	**3/5/08**	**30 days**	Owner1,Owner2,Owner3		
0%	FUTURE TASK		3.1	Design data model	1/24/08	2/24/08	22 days	Owner1,Owner2,Owner3		
0%	FUTURE TASK		3.2	Write functional specifications	1/25/08	2/25/08	22 days	Owner1,Owner2,Owner3		
0%	FUTURE TASK		3.3	Design storyboards and/or prototypes	1/26/08	2/26/08	22 days	Owner1,Owner2,Owner3		
0%	FUTURE TASK		3.4	Write detailed design specifications	1/27/08	2/27/08	23 days	Owner1,Owner2,Owner3		
0%	FUTURE TASK		3.5	Write documentation plan	1/28/08	2/28/08	24 days	Owner1,Owner2,Owner3		
100%	COMPLETED		3.6	Write beta test plan	1/29/08	2/29/08	24 days	Owner1,Owner2,Owner3		
0%	FUTURE TASK		3.7	Write SQA test plan	1/30/08	3/1/08	23 days	Owner1,Owner2,Owner3		

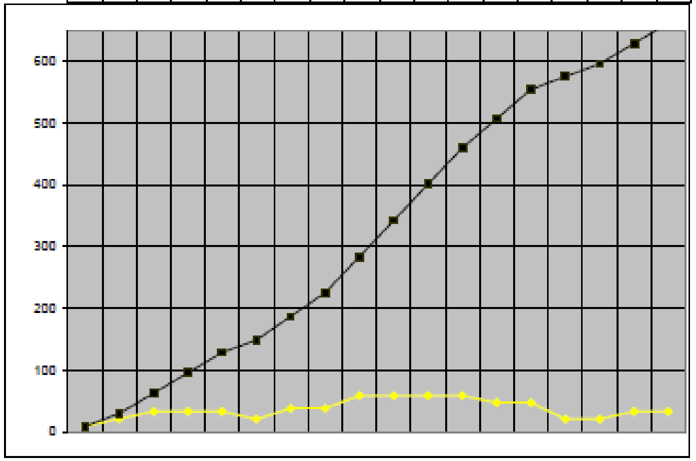
Ready

Project management

n.	Descrizione delle attività	Collaborazioni Previste PM (g.u.)	PMa (g.u.)	ES (g.u.)	Ea (g.u.)	Equipe (g.u.)	Costo per attività (ML)	durata (mesi)
a.	Definizione dell'equipe di Esperti e della relativa contrattualistica	5	5	5	5		17,25	1
1	Esame di pacchetti già realizzati	10	10	10	10	20	74,5	3
2	Suddivisione in macrofamiglie ed estrazione di un campione rappresentativo	5	5	5	5	10	37,25	2
3	Definizione di una scheda anagrafica per ciascuna macrofamiglia	15	15	15	15	30	111,75	5
b.	Riesame FS-CNIM per eventuali "messe a punto"							0,1
4	Definizione scheda ispezioni e "catalogo difetti"	25	25	20	20	70	215,25	4
5	Individuazione di un algoritmo di valutazione dei difetti	20	20	20	10	30	121	5
6	Test in campo sui campioni rappresentativi	18	18	10	10	20	84,5	5
	Costo totale delle attività (collaborazioni)						661,5	

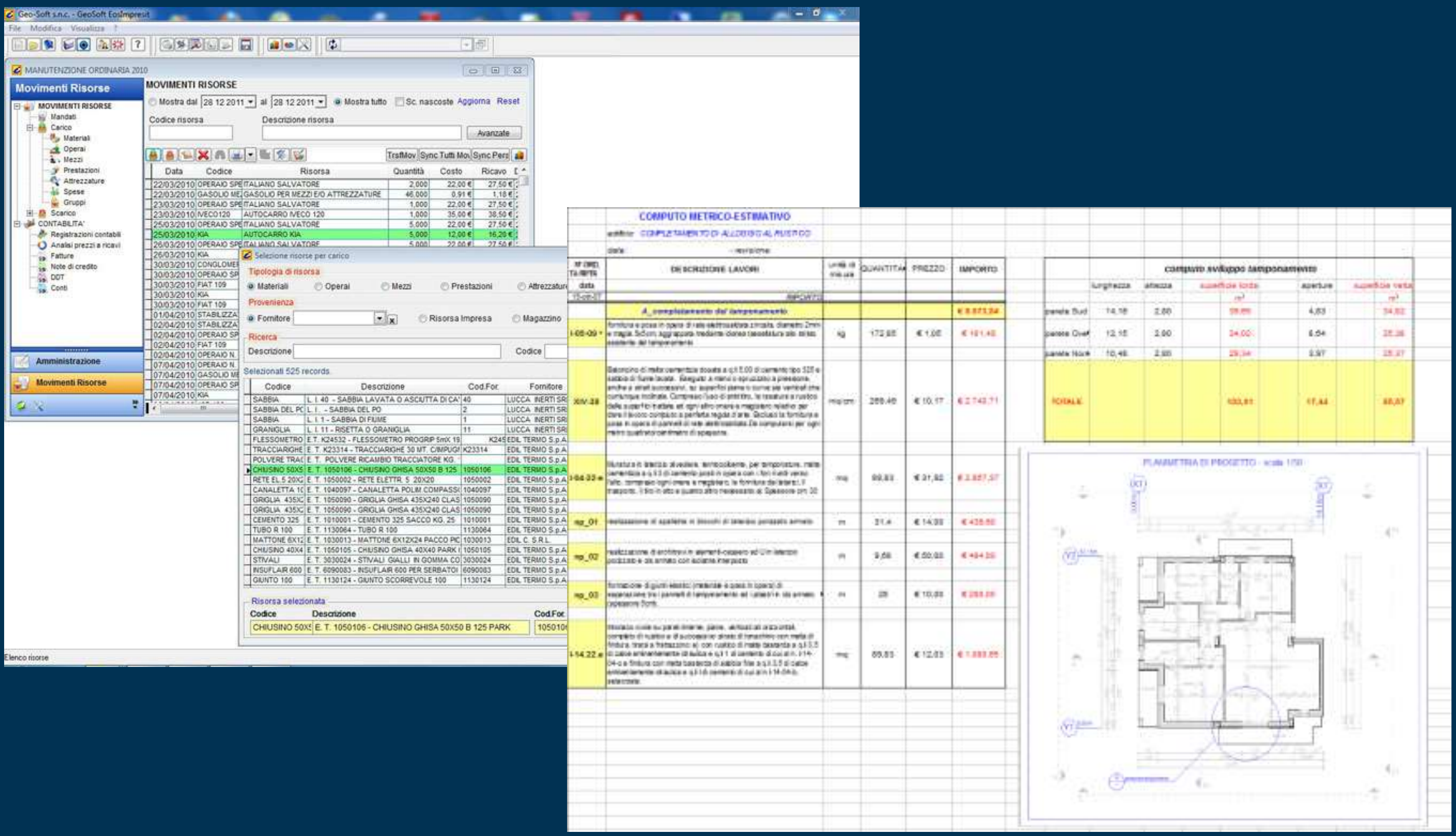
n.	mese 1 1	mese 1 15	mese 2 1	mese 2 15	mese 3 1	mese 3 15	mese 4 1	mese 4 15	mese 5 1	mese 5 15	mese 6 1	mese 6 15	mese 7 1	mese 7 15	mese 8 1	mese 8 15	mese 9 1	mese 9 15
a.	8,6	8,6																
1		12	12	12	12												12	12
2			9,3	9,3	9,3	9,3												
3			11	11	11	11	11	11	11	11	11	11						
b.																		
4							27	27	27	27	27	27	27	27				
5									12	12	12	12	12	12	12	12	12	12
6									8,5	8,5	8,5	8,5	8,5	8,5	8,5	8,5	8,5	8,5
quindicinali	8,6	21	33	33	33	20	38	38	59	59	59	59	47	47	21	21	33	33
progressivi	8,6	30	63	95	128	149	187	225	284	342	401	460	507	554	575	596	629	662

Figure professionali	PM	PMa	ES	Ea	Equipe	Totale
Costi unitari (in ML/g.u.)	1	0,25	1,4	0,8	2	
Totale impegno previsto (g.u.) per figura professionale	98	98	85	75	180	536
Totale costo previsto (in ML) per figura professionale	98	24,5	119	60	360	661,5



Costo collaborazioni	661,5
Costi coordinamento CNIM	50
Spese generali 20%	142,3
Totale (I.V.A. esclusa)	853,8

Project management



Safety Costs

- Human resources
- Individual protective equipment
- Collective protection
- Technical measures
- Organisational measures
- Consultancies
- Training
- Insurance
- …

Non Safety costs

- Material damage to the plant
- Insurance costs (Inail premium)
- Reduced production
- Reduced productivity
- Strikes
- Confiscations
- Social costs
- Immaterial damages
- …

Safety and Economic Balance

- The balance is the company document, required by law, which illustrates the economic and financial situation of a company.

- The balance must comply with a standard defined by law.

- Safety is not in the balance in a well defined way

ANYHOW

1. SAFETY IS AN INVESTMENT
2. SAFETY IS NOT A COST

Investment in Safety

- Investment in Safety is characterized by a return consisting of "missed costs.”

- Many Safety expenses are depreciable, therefore they allow the tax deductibility.

- Other Safety costs allow the deductibility from taxable income.

- Investments in Safety enhance the image of the company towards
  - The personnel
  - The customers / clients
  - The suppliers
  - The Society and the Country

Risks and Hazards

- Safety must be quantified.
- The Risk is the fundamental quantity through which we can evaluate the status of Safety.
- The risk is a quantity that refers to an immaterial object, although it refers to situations and material consequences, therefore

IT IS NECESSARY TO DEFINE MODALITIES AND EVALUATION TOOLS

Risks and Hazards

- The Hazard is the objectification of the risk in a particular situation
- Examples:
  - Risk of fire in an environment
  - Fire hazard due to the presence of barrels of oil

Risk estimation

- To estimate any physical quantity is necessary
  - define the unit of measure
  - define the scale, the zero, the full scale and sensitivity of the scale
  - define the measuring instrument and its precision

Risk estimation

- To estimate the risk the same criteria of a physical measurement have to be used.

- The risk estimation should lead to a quantitative assessment.

- Moreover, the risk estimation has to be:
  - Homogeneous between different environments
  - Systematic (i.e. repeatable)
  - Objective (not conditioned by external factors)

Risk Measure

- **Homogeneity** of risk estimation:
  - possibility of making in relations results for different situations and environments
  - Possibility of adopting omogeneous criteria of urgency

ENSURE THE SAME SAFETY TO EVERYBODY

Risk Estimation

- **Sistematic** Risk Estimation:
  - the risk estimation should be able to be repeated by returning the same results in less than predictable errors (based on the "tool" of measurement)
  - the risk estimation should be able to be repeated by different analysts without leading to differing results (based on the "tool" of measurement)

Risk Estimation

- **Objective** Risk Estimation:
  - the risk estimation should not be conditioned by facts which are not clearly objective
  - Avoid personal opinions
  - Avoid sporadic and / or random interviews
  - Avoid random inspections

Risk Estimation

- **Objective** Risk Estimation:
  - Risk analysis must be preceded by inspection activities (of places, projects, etc.)
  - Inspection activities must be designed and planned
  - The inspector has to be:
    - Indipendent in his/her judgement
    - not conditioned by economic factors
    - not influenced

Risk Estimation

- Risk estimation has to lead to **quantitative** results:
  - Numerical judgments
  - Linguistic judgments
    - linguistic judgments can have objective validity provided that they refer to well-defined scales
    - linguistic judgments better reflect the “fuzzy" way of man thinking

⇒ **FUZZY LOGIC**

Fuzzy Logic

- The Fuzzy Logic (introduced by the mathematician Zadeh in the 70s) introduces the degree of membership (IT: gda) of a variable to a certain set:
  - CLASSIC LOGIC

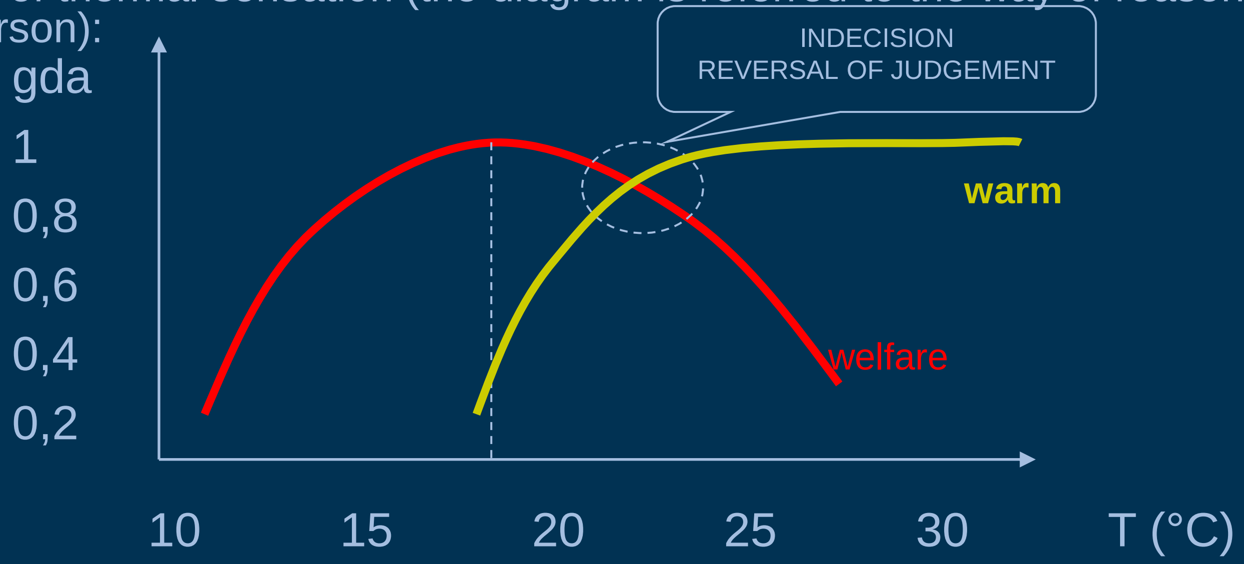
    $$\mathbf{x \in X \text{ or } x \notin X}$$

  - **FUZZY LOGIC**

    $\mathbf{x} \in \mathbf{X}$ with a certain "gda"

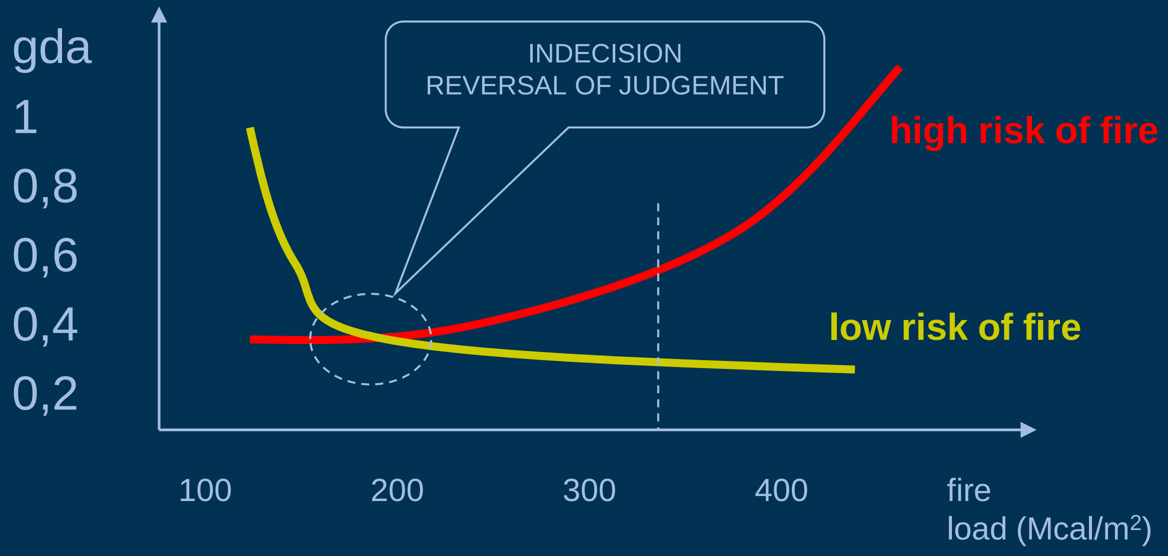
Fuzzy Logic

- the degree of membership (IT: gda) of a variable to a certain set is a variable parameter between **“0” and “1” with a certain law.**
- There are variables (professional judgments) that are better estimated in a fuzzy way**.**
- In the case of thermal sensation (the diagram is referred to the way of reasoning of a single person):



Fuzzy Logic

- **In the case of risk of fire:**



Risk: definition

- Risk is a quantity that has to do with the possibility of the occurrence of damaging events.
- Risk is a quantity:
  - statistical
  - fuzzy
  - refers to an immaterial object, leading to physical parameters

Risk: definition

- Analytically:

$$R = f\,(x_1, x_2 \dots x_n)$$

- It is necessary to:
  - Define fuction f
  - Define the parameters $x_1, x_2 \dots x_n$

Risks Classification

- Classification on the basis of the damaging event
- Classification on the basis of the physical phenomenon
- etc.

RISK ANALYSIS HAS TO BE COMPLETED AND EXHAUSTIVE

RISK ANALYSIS HAS NOT TO BE **“ENCYCLOPEDIC”**

Risks Classification

- on the basis of the damaging event:
  - Risks of injury
  - Environmental and hygiene risks
  - Organizational risks

Risks Classification

- On the basis of the physical phenomenon:
  - Mechanical risks
  - Electrical risks
  - Fire risks
  - Structural risks
  - Physical risks
  - Chemical risks
  - Biological risks
  - Hygiene risks
  - Environmental risks
  - ….

Risks Classification

- A cathegory of trasversal risks
  - Work organization
  - Working procedures
  - Workloads
  - Errors
    - Organizational
    - Individual

QUALITY MANAGEMENT	UNI EN ISO 9001
SAFETY MANAGEMENT	UNI ISO 45001
ERRORS MANAGEMENT	HUMAN FACTORS
DIVERSITY MANAGEMENT	gender, ethnicity, age, experience, character, handicaps, aptitudes, psychology, physicality, fears...

Faults and Exposure

- How does a productive system become hazardous?

- Two different events cathegories:
  - Fault phenomena
  - Exposure phenomena

- These phenomena are completely different, from different points of view: their genesis, their evolutions, their consequences and the treatment of the consequences.

Faults and Exposure

- Faults are complex phenomena (events) that determine a malfunction of the system in which they occur.
- Faults are studied by Reliability .
- There are different kinds of faults, in relation to the evolution of the way of functioning of the system[Fitch]:
  - Catastrophic failure - a condition of sudden and complete cessation of operations and a total deterioration of functions
  - Sudden failure - a condition of accelerated degradation both of the material and the performance, which becomes a partial weakening of the functions
  - Impending failure - a condition of perceptible degradation of the material in the presence of a serious deterioration of the performance
  - Incipient failure - a condition in which the use of appropriate means of detection allows to detect the early signs of degradation of the material, preserving the performance of the machine
  - Conditional failure - a condition in which early warning (degradation of the material or performance)has not yet occurred but if the situation persists, it will lead inevitably to a functional failure.

Faults and Exposure

- A single event of failure in a well-designed and well-managed / maintained system cannot lead to the occurrence of a seriously harmful event (Top Event).

- The occurrence of a series of fault events, chained together, lead to the occurrence of the Top Event.

- The chain of failures starts from a plurality of possible events (basic events), propagates through other events (fault propagation), up to the Top Event.

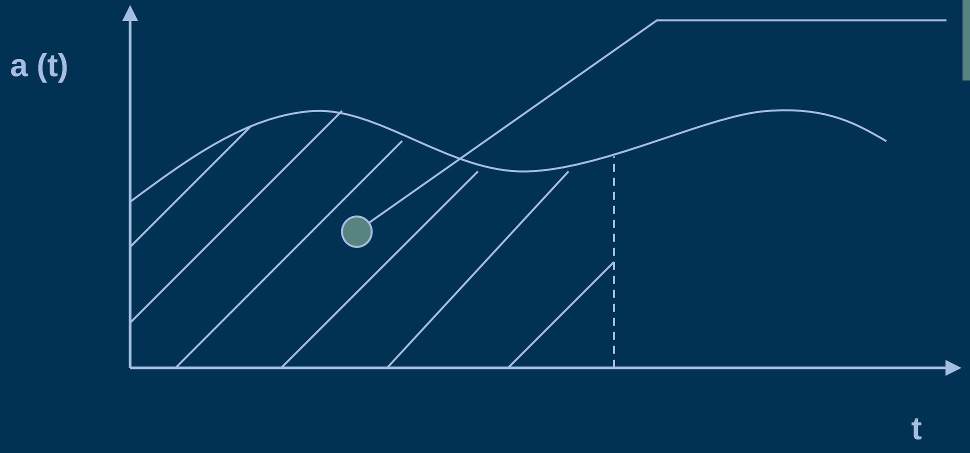
- The chain of failures can stop:
  - because it is adequately long
  - because improvement events occur

DESIGN TO SAFETY
DESIGN OF THE SAFETY

Faults and Exposure

- The phenomena of exposure are related to the presence of an exposure agent to which the workers are subject.

- The parameters to be taken into account are
  - Type of agent (a)
  - Concentration curve of the agent (a(t))
  - Exposure time
  - Absorbed dose (D)
  - Type of the workers activity



$D = \int a(t)\, dt$

Prevention and Protection

- Prevention

  Actions to reduce the probability of occurrence of adverse events

  - Maintenance
  - Information (even on the machine)
  - Training
  - …

- Protection

  Actions to reduce the damage caused by the occurrence of adverse events

  - Personal protective equipment (PPE)
  - Collective Protections

Prevention and Protection

$R_A = p_A * M_A$

$R_{B'} = R_{B''} = p_{B'} * M_{B'} = p_{B''} * M_{B''}$