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Safety and Maintenance for Industrial Systems

Lecture 3

Risks Analysis

Procedures and Methods

Contents and Goals

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  - Risks Analysis
  - Inspection procedures for risks analysis
  - Risks analysis methods
- Goals
  - Learning to perform risks analysis
- Professional Figures of reference
  - Safety designer
  - Inspector

Risks Analysis

- Risks analysis is the technical planning activity that aims at:
  - the assessment of the state of Safety of a technical system
  - the definition of safety measures

- Risks analysis, especially after the new European Standard, acts as an essential project activity when problems connected with safety arise:
  - workplaces
  - industrial processes
  - yards, construction sites
  - products, machinery and equipment
  - Etc.

- Risks analysis is performed:
  - On technical systems subject to design
  - On technical systems subject to realization
  - On existing / working technical systems
  - On technical systems subject to transformation
  - On technical systems subject to tests and maintenance

Risks Analysis

- The new emphasis on Risks Analysis as a tool for the planning and quantitative definition of the levels of safety offers many possibilities and ways out to the responsible subjects.

- At the same time, the responsibilities of these subjects have highly increased and they should have the following skills:
  - design skills in the field of accidents;
  - integration of safety in technical systems;
  - adoption of standards and technical rules.

- Risks analysis is the technical tool thanks to which we turned

FROM A STRICTLY IMPOSING STANDARDIZATION
TO
A SETTING BASED ON TECHNICAL KNOWLEDGE

- This will be clearer when we will talk about roles and responsibilities.

Risks Analysis Procedures

- The risks analysis has to be designed / planned and it cannot be improvised
- The main activities are as follows:
  - analysis of design specifications
  - definition of the analysis team
  - inspection planning
  - preparation of the inspection checklists
  - acquisition of the preliminary documents
  - execution of the inspections
  - analysis of the evidence
  - selection of the design method
  - application of the method and results analysis
  - identification of acceptability thresholds
  - schedule adjustments
  - analysis of safety costs
  - presentation of the results

The inspections activity

- Inspection (UNI CEI EN ISO/IEC 17020:2012):

EXAMINATION OF A PROJECT, A PRODUCT, A SERVICE, A PROCESS, A PLANT, AND CONSEQUENT DETERMINATION OF THEIR COMPLIANCE TO SPECIFIC REQUIREMENTS OR, ON THE BASIS OF "A PROFESSIONAL JUDGEMENT“, TO GENERAL REQUIREMENTS

  - The inspection of a process concerns personnel, facility, technologies and methodologies.
  - The inspection results can be used as a support of the certification (compliance).

The inspections activity

- The inspector activity has to be characterized by:
  - Indipendence
  - Impartiality
  - Integrity
  - Objectivity

- The standard UNI EN ISO 19011:2012 provides guidelines on planning modalities of the inspection audits.

Classification of risks analysis methods

- Inductive Methods
- Deductive Methods

- Analitycal Methods
- Synthetic Methods

- Quantitative Methods
- Qualitative Methods
- Semi-Quantitative Methods
- Multi-Criteria Methods

Risks Analysis Methods

- UNI EN ISO 12100:2010 former UNI EN ISO1050:1998
- UNI ISO/TR 14121-2:2013
- AISS - ISPESL
- MIL STD 882 E: 2012
- D.Lgs. 264/2006 “Analisi di rischio delle gallerie italiane”
- UNI EN ISO 14798:2013 “Ascensori, scale mobili e marciapiedi mobili - Metodologia di valutazione e riduzione dei rischi”
- UNI CEI EN ISO 14971:2012 “Dispositivi medici - Applicazione della gestione dei rischi ai dispositivi medici
- Hazard and Operability Analysis (HAZOP)
- Analytic Hierachy Process (AHP)
- Failure Modes Effects and Criticality Analysis (FMECA): MIL STD 1629 A
- Event Tree Analysis (ETA)
- Fault Tree Analysis (FTA)
- Minimal Cuts Sets (MCS)

UNI EN ISO 12100:2010

- The technical report UNI ISO/TR 14121:2013 "Safety of the Machinery – Risk assessment – Practical guidance and examples of methods" provides:
  - a guideline for the identification of hazards;
  - criteria for risk assessment and the selection of appropriate safety measures in relation to risks and constraints imposed by technical and economic factors.

THIS IS A SEMI-QUANTITATIVE METHOD AND IT WAS PROPOSED FOR RISKS ANALYSIS IN MACHINE TOOLS

UNI EN ISO 12100:2010

- The proposed analysis is mainly divided into three steps:
  - **Identification of risk factors;**
  - **Risks assessment;**
  - **Selection of safety measures.**

UNI EN ISO 12100:2010

- **Identification of risk factors**: it aims at identify all the risk sources in the different work phases
- The check lists can offer a valuable aid:
  - This means listing potential risk factors (eg. noise, dangerous substances, electrical contacts, etc.) and analyzing using a list that steps through all the most important issues related to safety.

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- The Checklists must be characterized by:
  - simplicity and versatility of use
  - easy updating
  - simplicity in the management of the data

And they also have to take into account:

  - specific requirements of the legislation
  - international standards of good practice
  - compliance to the "common good sense" from a technical-engineering point of view
  - standards and specific regulations of particular sectors

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- A great help in this survey phase, was offered from the list (even if not exhaustive) reported in the standard **UNI EN 414:2002** "Safety of machinery. Rules for the drafting and presentation of safety standards" (NOW REPEALED).

- The standard **UNI EN 414** contains a list of the main types of risks present in the use of machines.

- This list should be integrated with the reporting of events and situations that can cause damage (human errors, incorrect working procedures, damage to the safety devices, obstruction due to personnel carrying out the work activities, etc.).

UNI EN ISO 12100:2010

- In general the phase of hazards identification has to take into account:
  - visits to workstations, with visual sightings;
  - interviews with staff, the competent doctor, the head of the prevention and protection service;
  - analysis of historical data on accidents occurring in the company
  - …

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Risks assessment

- The measure of the risk associated with each hazard is expressed by :

R = f (D,A)

where:

R = risk magnitude

D = damage severity

A = probability of damage occurrence

- The determination modality of D and A takes into account the specific kind of risk considered.

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- To identify the function f (which allows the quantitative estimation of the risk R):

  The severity of the damage is considered as the function of two parameters:

Maximum predictable injury	DP
up to 3 days of invalidity	1
between 4 and 40 days of invalidity	2
More than 40 days of invalidity	3

DP measures the consequences caused by the event (in terms of the temporal effects of the accident)

Maximum extent of damage	ED
Single individual	1
Two or more individuals	2

ED measures the number of people involved

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- The probability of occurrence of the damage is considered function of four parameters:

Access to the sites	FA
occasional	1
frequent	2
continuous	3

FA, frequency of access to dangerous places

Staying time	TP
Up to 5 seconds	1
between 5 to 60 seconds	2
More than 60 seconds	3

TP, time of exposure to the hazard

Probability of event-cause	IO
low	1
medium	2
high	3

IO, index of occurrence of the unfavorable event

Prevention index			IP
Training	PPE	Avoidance of damage	
scarce	unsuitable	Very low	1
suitable	suitable	Limited	2

IP, evaluates how you can prevent the damage once the favorable event happened

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RISKS ASSESSMENT											
HAZARDS		HAZARDS LOCALIZATION	FACTORS DETERMINING THE SEVERITY OF DAMAGE			FACTORS DETERMINING THE OCCURRENCE OF THE DAMAGE				Occurence of the damage **A= f(FA,TP, IO,/IP)**	RISKS ASSESSMENT **R=F (D,A)**
			Max predictable damage **DP**	Max extent of damage **ED**	Severity of the damage **D=f(DP, ED)**	EXPOSURE INDICES		Index of occurrence **IO**	Prevention index **IP**		
						Frequency of access **FA**	Staying time **TP**				
1	**Mechanical hazards**										
1.1	crushing hazards										
1.2	hazards of entanglement										
1.3	hazards of slipping										
1.4	hazards of friction or abrasion										
2	**Electrical hazards**										
2.1	electrical contact										
2.2	electrostatic phenomena										
3	**Hazards from heat**										
3.1	radiant surfaces										
3.2	contact with flames										

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RISKS ASSESSMENT

	HAZARDS	HAZARDS LOCALIZATION	FACTORS DETERMINING THE SEVERITY OF DAMAGE			FACTORS DETERMINING THE OCCURRENCE OF THE DAMAGE				Occurence of the damage **A= f(FA,TP, IO,IP)**	RISKS ASSESSMENT **R=F (D,A)**
						EXPOSURE INDICES					
			Max predictable damage **DP**	Max extent of damage **ED**	Severity of the damage **D=f(DP, ED)**	Frequency of access **FA**	Staying time **TP**	Index of occurrence **IO**	Prevention index **IP**		
4	Hazards generated by noise										
5	**Hazards generated by vibrations**										
6	**Dangers from electromagnetic radiation**										
6.1	arc flash										
6.2	Lasers										
6.3	ionizing radiation										
7	**Hazards generated by materials and substances**										
7.1	contact or inhalation of fluids, gas fumes and dust										
7.2	fires or explosions										
8	**Hazards caused by failure of ergonomic principles**										
8.1	Bad posture or excessive efforts										
8.2	non-use of PPE										
8.3	insufficient lighting										
8.4	human factors										

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- The estimation of the risk related with each examined hazard will be obtained through the function f.
- These functions:
  - May be of different nature,
  - May be described by mathematical relations more or less simple.

- Based on these considerations, we can choose the most appropriate mathematical function to the data representation and, representing it in a graphic form, we can easily understand the immediate priorities per actions.

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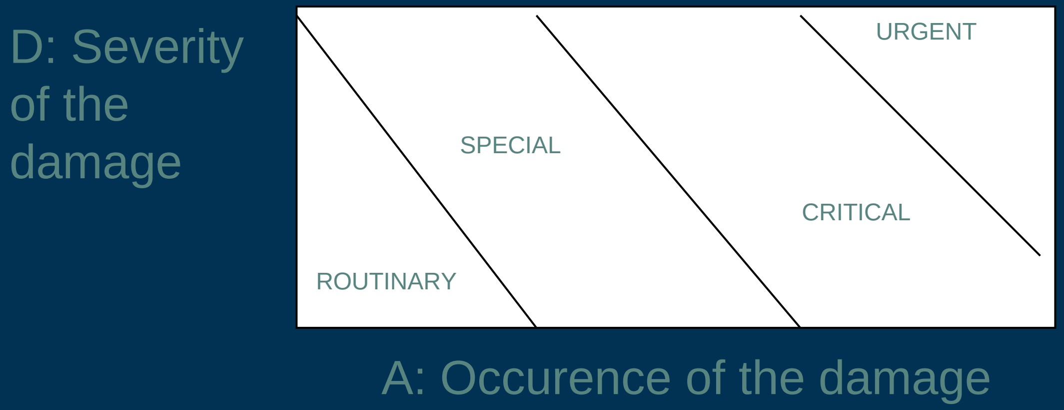
- In general, the function f enables to draw a risk / intervention matrix that allows to highlight the critical areas and signaling, thus, the degree of urgency of the interventions



matrix / risk intervention

UNI EN ISO 12100:2010

Selection of safety measures

- Once the risk assessment has been done and the priority of the actions to be performed has been analyzed, the risks reduction can occur in two directions:
  - The first one deals with reducing the probability of occurrence of the damage (prevention)
  - The other one deals with containing the possible consequences (protection)

UNI EN ISO 12100:2010

- Anyhow, the choice of the type of intervention to be taken will have to strictly follow the logical sequence:
  - elimination of the hazard;
  - reducing of the hazard;
  - hazard reduction at source;
  - optimal management of the hazardous situation;
  - collective protection;
  - individual protection;
  - information-training.

UNI EN ISO 12100:2010

- In general, the measures that reduce the risk at source are to be privileged.

- The standard 12100:2010 (former EN 292-1 “Safety of machinery. Fundamental concepts, general principles for design. Terminology, basic methodology”), devotes an entire section to what you can do to this regard in the phase of design.

- Concerning the hazards that cannot be eliminated or sufficiently reduced, there will be necessary to use "protection" (guards or safety devices).

UNI EN ISO 12100:2010

- Pros:
  - Simplicity
  - Possibility of integrating – in the assessment - factors that contribute to determine the heterogeneous damages (severity of the damage, staff training, extent of damage, probability of occurrence of the cause of the damage, etc.),
  - possibility of using graphical representations that guide the rational decision making by providing indications of priorities for a coherent prevention and / or protection plan actions.

UNI EN ISO 12100:2010

- Cons/Limits:
  - It is based on a "subjective" interpretation of probability (i.e. linked to the experience of the evaluator)
  - What follows is not taken into account:
    - risks arising from the workplaces (layout, lighting, noise, microclimate, etc.)
    - risks related to the human factors (physical and psychological adaptation of the employee assigned to the task, work organization).

This methodology is not very flexible because it was expressly designed to be applied to the risks associated with the use of machine tools.

MIL STD 882 E

- **MIL-STD-882 E** (2012) Standard identifies a set of requirements for the realisation of a safety program (System Safety Programme) which aims at providing design specifications and tools of operating control, capable of:
  - eliminate the identified hazards or otherwise
  - reduce the risks to acceptable levels
- **MIL-STD-882 E** (2012) Standard also proposes a semi-quantitative method for the identification and assessment of the hazards associated to a generic system.

MIL STD 882 E

- Risk assessment is based on the estimation, through the use of appropriate tables:
  - of the probability of occurrence

Class	Description	Frequency of occurrence	Possible relationship with quantitative data
(A)Frequent	Probability of frequent occurence	High	$>10^{-1}$
(B)Probable	repeated occurence		$10^{-2}<p<10^{-1}$
(C)Occasional	Limited occurence	Medium	$10^{-3}<p<10^{-2}$
(D)Remote	Improbable but possible		$10^{-6}<p<10^{-3}$
(E)Improbable	No occurrence during the life of the system	Low	$<10^{-6}$

MIL STD 882 E

- Of severity of the damage

Cathegory	Name	Description
I	Catastrophic	-Death -Loss of the system
II	Critical	-serious injury -serious damage to the system
III	Marginal	-minor injury -limited damage to the system
IV	Neglectable	-No injury -No damage

MIL STD 882 E

- The estimation method is particularly useful when quantitative data are at disposal
- The are 2 outputs of this methodology:
  - An Hazard Assessment Matrix

Frequence of occurence	Severity of the damage			
	I Catastrophic	II Critical	III Marginal	IV Neglectable
(A) Frequent	1A	2A	3A	4A
(B) Probable	1B	2B	3B	4B
(C) Occasional	1C	2C	3C	4C
(D) Remote	1D	2D	3D	4D
(E) Improbable	1E	2E	3E	4E

MIL STD 882 E

- An Hazard Risk Index (or HRI) through which is possible to identify the most critical conditions

	Hazard Risk Index (HRI)	Actions criteria
	I	Unacceptable
	II	Undesirable (management's opinion)
	III	Acceptable, control
	IV	Acceptable, monitoring

MIL STD 882 E

- Pros:
  - Up to date, this is the most widely used scheme, also in "personalized" forms by the user, because the scales of probability and severity or the different levels of risks can be changed time to time
  - simplicity of application
  - It provides intervention priorities through a risk index
  - very flexible: the factors which are considered with reference to the risks assessment are the probability of occurrence and the severity of the potential damage

MIL STD 882 E

- Cons/Limits:
  - the success or failure of the application is based on the expertise of the evaluator and on the degree of knowledge of all the factors involved
  - in the risks assessment factors such as workplaces, personal skills of the worker to master the risk, physical and mental adaptation of the worker, etc. are not taken into consideration.

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- At the basis of this method there is the consideration that the occurrence of an injury is due to a number of different factors, such as:
  - an improper design,
  - the poor condition of machinery,
  - poor cleaning or clutter floors,
  - individual behavior,
  - the lack of protective equipment,
  - improvisation and irrational organization of work,
  - room lighting, etc. .

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- All these factors can be grouped into three broad categories :
  - material or work equipment;
  - the workplace;
  - the individual and the work organization.

- The approach of this method takes into consideration a quantitative assessment of the risk of injury, carried out by assigning numerical values to the factors that fall into the three categories considered.

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- The proposed model consists on the following tasks:

<u>First phase</u>

comprehensive risks assessment of the workplace

Rg = MA * Amb

- MA, is the risk associated with "material" (machine);
- Amb, is the impact of the room/workplace

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- The factor MA is derived from the product of four factors:
  - Hazard events (Pd)
    - of minor consequences (impact, superficial cuts, etc.)
    - serious (fractures, deep lesions, etc.).
    - very serious and irreversible

PROPOSED QUOTATION

$$Pd = 1 \div 10$$

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- Frequency and duration of exposure during machine working (Ex)
  - occasional exposure reduced (eg. the automatic machines in good operating conditions, etc.).
  - frequent cyclical exposure (eg. intermittent presses, machine tools of production, etc.).
  - frequent or continuous exposure (eg. manual or automatic machines but in a state that requires frequent interventions, etc.).

PROPOSED QUOTATION

Ex = 1 ÷ 10

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- Probability of occurrence of a hazardous event tied to the "material“ factor (Pr)
  - low (complete inaccessibility to dangerous elements; practical and safe protection devices; etc.).
  - medium (full protective equipment in good working condition, even if they only provide partial protection; execution of some interventions in reduced safety conditions, etc.).
  - High (incomplete protection; removed or deactivated protection devices, etc.); occasional reduced (eg. automatic machines in good operating conditions, etc.).

PROPOSED QUOTATION

$$Pr = 0,5 \div 1,5$$

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- Probability of avoiding or limiting the injury (Ev)
  - The dangerous event is clearly perceptible and there is a chance to avoid it (person warned)
  - Sudden and unexpected occurrence of the hazard (complete inaccessibility to dangerous elements; practical and safe protective device; etc.).

PROPOSED QUOTATION

$Ev = 0,5 \div 1$

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- Therefore, you can calculate the material factor MA:

$$\mathbf{MA = Pd*Pr*Ex*Ev = 0{,}25 \div 150}$$

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- The factor Amb derives from the sum of three factors :
  - Location of the workplace (Qa)
    - The workplace and the different work areas are located
      - on the same level
      - with differences of permanent level
      - use of tools and accessories (walkways, ladders)
    - The work space and the passages are
      - mackerel and spacious
      - cramped and cluttered

PROPOSED QUOTATION

Qa = 0,5 ÷ 1

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- Workplace (Qb)
  - Lighting
    - correct (sufficient but not dazzling)
    - Insufficient
  - Noise
    - It does not disturb (good perception of signals)
    - It disturbs
  - Microclimate (temperature, dust, humidity, air currents)
    - Good
    - It bothers, it is stressful

PROPOSED QUOTATION

Qb = 0,3 ÷ 0,6

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- Ergonomic / Ergotechnic Aspects (Qc)
  - Arrangement of controls, signaling devices, indicators, areas of loading and refueling, etc…
    - Good
    - Poor coorect (sufficient, but not dazzling)
  - Physical stress (efforts, handling charges, work rate, etc.).
    - It does not disturb (good perception of signals)
    - It disturbs

PROPOSED QUOTATION

Qc = 0,2 ÷ 0,4

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- Therefore, you can calculate the environmental factor, Amb:

$$\mathbf{Amb = Qa + Qb + Qc = 1 \div 2}$$

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- The proposed model requires the application of the following second phase:

<u>Second phase</u>

evaluation of the individual's ability to dominate the risk

$$P = Q + \varphi + O$$

- Q, represents the qualification of employees;
- φ, represents the physiological factors of employees;
- O, represents the work organization.

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- The P factor is derived from the sum of three factors:
  - Qualification of personnel (in relation to the task assigned) (Q)
    - qualified person (professional training + general training in the workplace) and expert
    - qualified or expert person
    - unqualified and inexperienced person.

PROPOSED QUOTATION

Q = 10 ÷ 0

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- physiological factors (φ)
  - physical and psychic adaptability of the subject
    - Good
    - Poor

PROPOSED QUOTATION

$$\varphi = 3 \div 0$$

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- Work organization (O)
  - Procedures / operational modes / deliveries with reflections on safety
    - formally codified and strictly enforced
    - encoded, but not systematically observed
    - neither codified nor respected

PROPOSED QUOTATION

O = 5 ÷ 0

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- Therefore, you can calculate the individual's ability to dominate the risk, P

$$P = Q + \varphi + O = 18 \div 0$$

- Finally, the risk of accidents:

$$Rinf = Rg - k*P = MA*Amb - k*P$$

with k = MA/150

this weighting coefficient (k) represents the fact that the subject's ability to dominate the risk generally should vary depending on the level of risk associated with the material (for example, an apprentice will not have to work on a dangerous machine)

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- Pros:
  - It is complete: it takes into account risk factors also significantly different from each other
  - simplicity of application
  - It gives a synthetic and complete framework of the reality object of study
  - the obtained results allow to plan corrective actions (preventive or protective) based on a priority of interventions.

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- Cons/Limits:
  - the assessment is primarily based on the sensitivity and the experience of those who lead the analysis
  - somewhat not very flexible; it has been mainly designed to be applied to the risks arising from the "man-machine relationship"

Analytic Hierarchy Process (AHP)

- The Analytic Hierarchy Process
  - It is a methodology developed by Saaty in the eighties, whose robustness and flexibility make possible its use in several sectors even if very different from each other.
  - It is a method of multi-criteria decision analysis which assesses the priority of actions that can be taken with reference to different cases:
    - programs,
    - intervention strategies,
    - plans,
    - projects, etc.

Analytic Hierarchy Process (AHP)

- We have a multi-criteria decision-making process when decisions have to be made, taking simultaneously into account several factors, the criteria, on which alternatives should be evaluated

We cannot choose the alternative that optimizes only one factor, but <u>we have to take into account all the factors</u>

- In applying this method, the decision problem is organized in a **hierarchical structure** and the priorities of its elements with respect to a common attribute, at every level, are defined, comparing their mutual importance (or **verisimilitude**).

- Comparisons are made through a sequential process of pairwise comparisons, using a linguistic and / or numerical scale.

Analytic Hierarchy Process (AHP)

- The theme of this methodology is the increased reliability of the **relative** than absolute judgments.

- In this sense, the AHP facilitates the integration of objective and subjective, quantitative and qualitative evaluations, and takes advantage of a wide range of available information.

- Although the number of required pairwise comparisons appears redundant compared to what is strictly necessary, this redundancy of information allows to obtain a better classification.

Analytic Hierarchy Process (AHP)

- AHP application is divided into two phases each of which includes a series of successive steps:

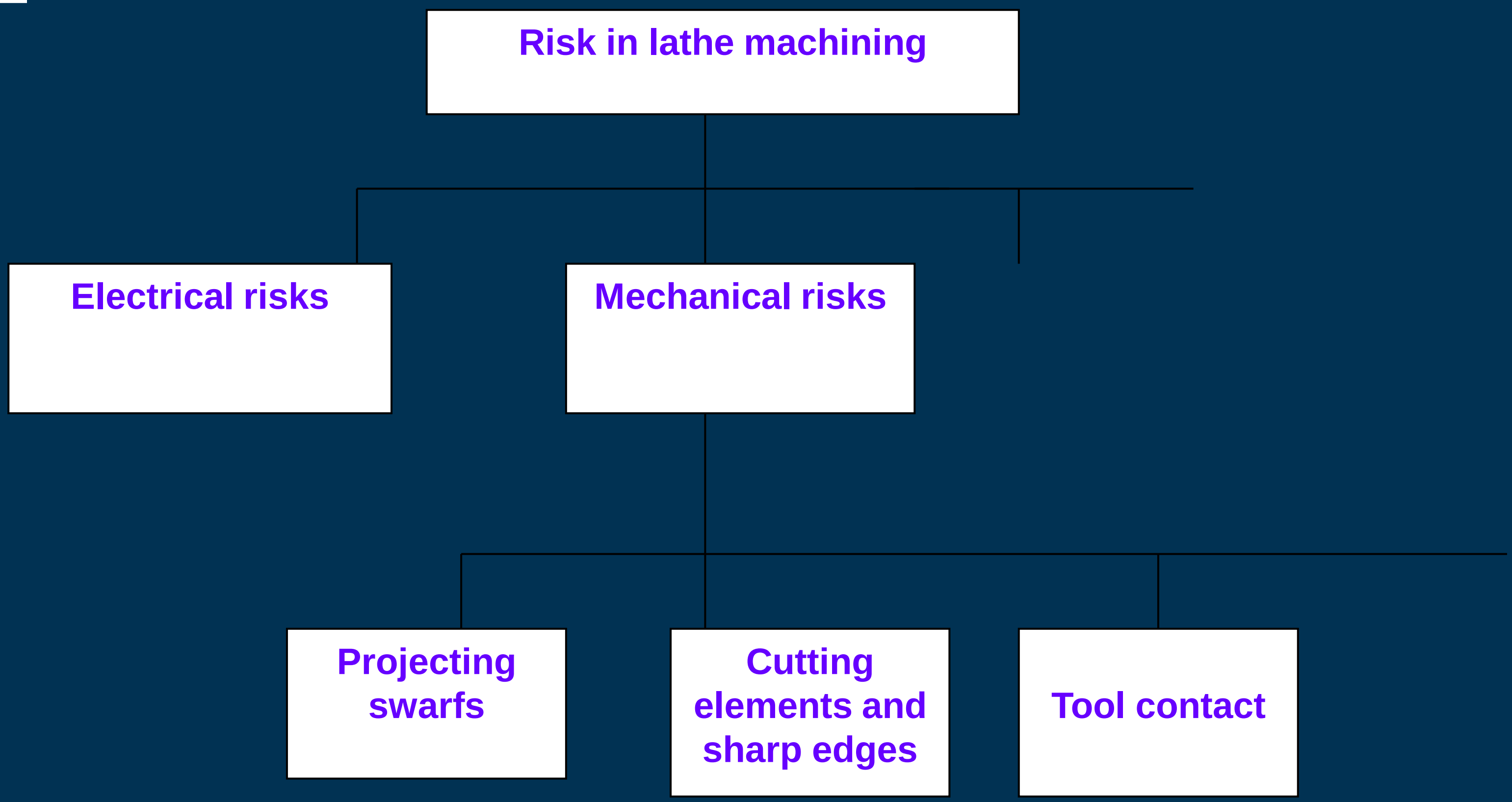
  - **Phase I: Risks assessment**
  - **Phase II: Risk causes assessment**

Analytic Hierarchy Process (AHP)

Phase I: Risks assessment

- First we proceed to the definition of the problem in terms of hierarchical structure, through a top-down decomposition of the objective of the upper level.
- The highest level of the hierarchy is the main goal (for example the risk in a work process).
- Elements of intermediate levels represent the types of risk (eg mechanical, electrical, chemical ...).
- The last level is formed by the sources of risk or hazards (for example: cutting elements and sharp edges, projection of swarfs ...).

Analytic Hierarchy Process (AHP)



Hierarchical determination of the problem: exemplification

Analytic Hierarchy Process (AHP)

- We go on identifying the relative importance of the elements belonging to a certain level with respect to a certain property.

Linguistic Evaluation	**Degree of importance or verisimilitude**
Equally important / probable	1
Moderately more important / probable	3
Significantly more important / probable	5
Much more important / probable	7
Extremely more important / probable	9

Intermediate values may be used to generate additional levels of discrimination

Analytic Hierarchy Process (AHP)

- With reference to the hierarchy illustrated above, we have for example :

Risk	Tool contact	Projection swarf	Z
Tool contact	1	2	1.7
Projection swarf	1/2	1	1.2
Z	1/1.7	1/1.2	1

where with z we indicate a generic source of risk.

Analytic Hierarchy Process (AHP)

- Information resulting from the comparison in pairs, which provide the relative importance between the elements, are organized in a matrix structure (A) and used to obtain the weights, corresponding to the absolute priorities (components of the vector W), which will be used to calculate the overall ranking of the alternatives.

$$\begin{bmatrix} 1 & & & & & & \\ & \dots & & & & & \\ & & 1 & & a_{ij} & & \\ & & & \dots & & & \\ & & 1/a_{ij} & & 1 & & \\ & & & & & \dots & \\ & & & & & & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ \\ w_i \\ \\ w_j \\ \\ w_n \end{bmatrix} = AW$$

Analytic Hierarchy Process (AHP)

- We can determine the values of the weights corresponding to the priorities, solving the system:

  $$A*W = l_{max}*W$$

  where

  l_{max}, maximum eigenvalue of the matrix A

  W, eigenvector corresponding to l_{max}

Analytic Hierarchy Process (AHP)

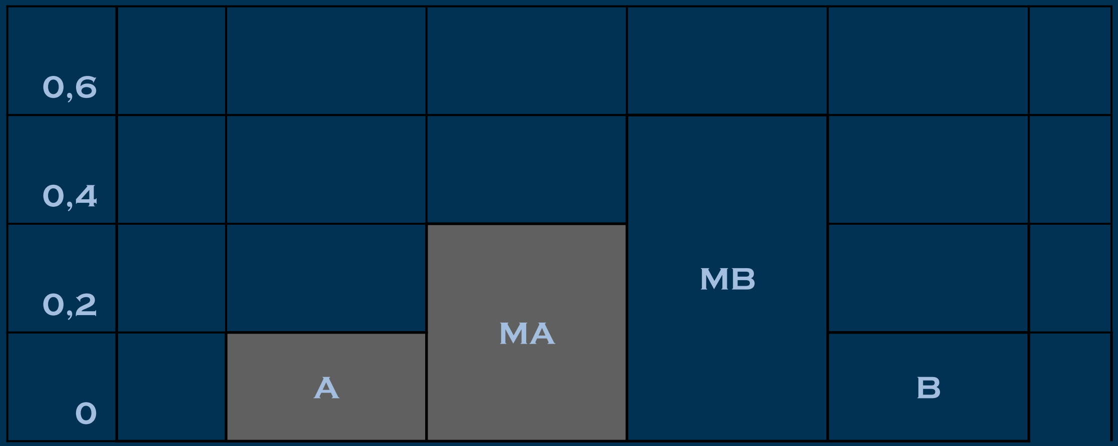
- Each element of the vector W represents the degree of influence of the single element, to the level to which it belongs, compared to the other elements for determining the final risk index.

Risk	Contact tool	Projection swarf	Z	weights
Contact tool	1	2	1.7	0.479
Projection swarf	1/2	1	1.2	0.283
Z	1/1.7	1/1.2	1	0.238

Analytic Hierarchy Process (AHP)

- For each source of risk, the verisimilitude of risk levels is estimated (A = high, MA = medium / high, MB = medium / low, B = low) by comparing pairs as described above.

- We can therefore understand the level of risk of each individual source of risk getting the verisimilitude function.

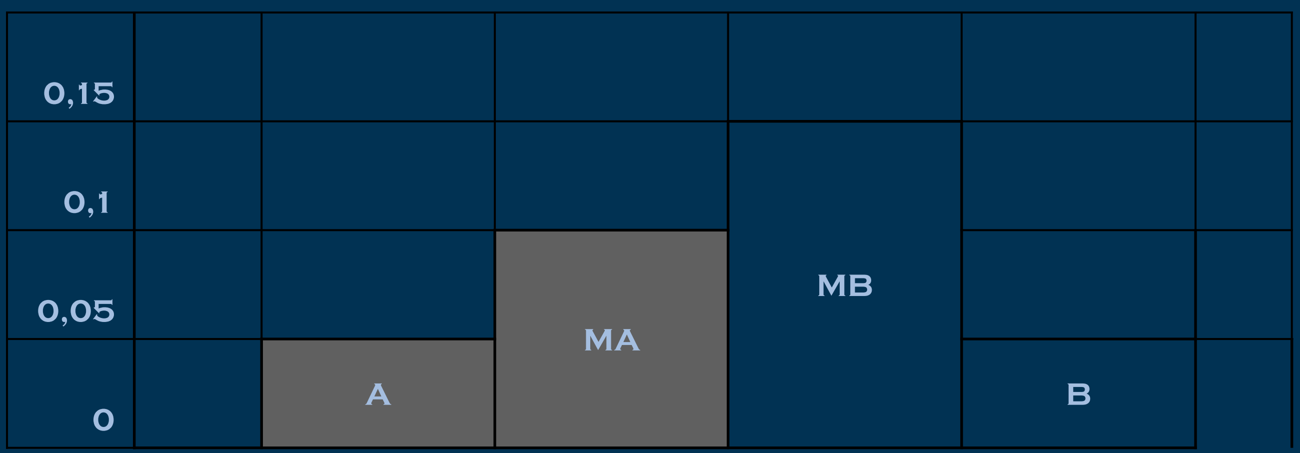


Projection swarf

- Function of verisimilitude of risk

Analytic Hierarchy Process (AHP)

- Multiplying the function of verisimilitude for the relative weight to each source of risk (obtained by the method of the eigenvalue) we obtain the function of risk of each source.



Projection swarf

- Function of risk

Analytic Hierarchy Process (AHP)

- The functions of risk of each source of risk <u>related to each type of risk</u> are <u>**summed** between them</u>. It is thus obtained a function of risk for each risk type at intermediate levels.

- The same operation is repeated on the upper levels in an iterative manner, until we have the function of risk of the entire activity.

- The functions of risk <u>do not allow a direct comparison between different risks</u>; for this reason the evaluator must define a scale of weights through which attribute, according to his perception, a weight of importance to the individual risk levels (A, MA, MB, B); in this way we obtain the **risk index**.

Analytic Hierarchy Process (AHP)

Risks scale	A	MA	MB	B	Weights
A	1	1.2	2	6	0.402
MA	1/1.2	1	2	5	0.350
MB	1/2	1/2	1	2	0.174
B	1/6	1/5	1/2	1	0.074

- Finally we build the ranking of risks based on the index of risk, **multiplying** the weights assigned to individual risk levels for the respective weights of the risk function and **adding** to each other the obtained results.

Analytic Hierarchy Process (AHP)

Second Phase
Risk causes assessment

- This phase is used to estimate the degree of influence of the causes of risk in order to ensure the effective and consistent selection of the prevention and protection actions to be undertaken.

- Similarly to the development phase of the functions of verisimilitude of the risk we proceed to the determination of the functions of verisimilitude of the risk causes. This analysis can be developed on four main causes:
  - **M**: intrinsic characteristics of the machinery or equipment;
  - **O**: skills and abilities of the operator;
  - **P**: working procedures used (including PPE);
  - **A**: characteristics of the workplace where the activity is developed

Analytic Hierarchy Process (AHP)

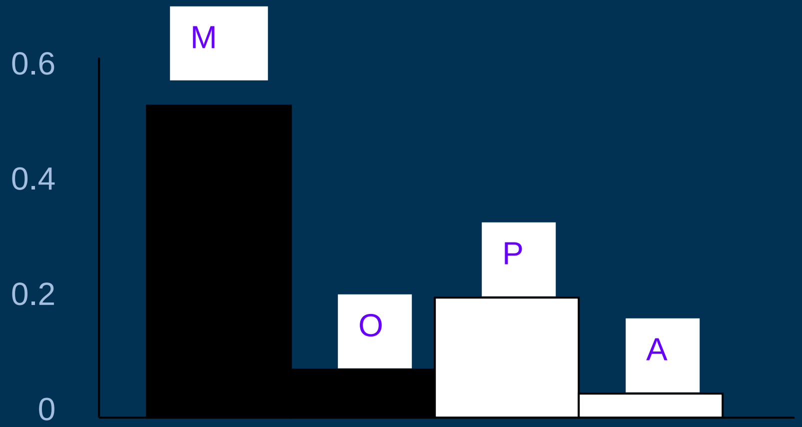
- The following is an example:

Projection swarf	**M**	**O**	**P**	**A**	**weights**
M	1	5	2	8	0.548
O	1/5	1	1/1.5	3	0.145
P	1/2	1.5	1	5	0.242
A	1/8	1/3	1/5	1	0.055

Determination of the verisimilitude function of the causes

Analytic Hierarchy Process (AHP)

- Multiplying the verisimilitude functions of the causes with their risk indices, we obtained the cause functions of the risk for each hazard / risk.
- The cause functions are calculated for each level in the hierarchy by summing for each single cause the contributions of the elements of the lowest levels in the hierarchy.
- When you reach the top level of the hierarchy you get a complete view of the importance with which the various causes contribute to the risk determination.



Analytic Hierarchy Process (AHP)

- Pros:
  - Possibility of integrating objective and subjective factors, qualitative and quantitative factors.
  - Possibility of simultaneously considering various factors which makes more effective the perception of risk
  - It gives greater reliability to the opinions expressed in compared form than those stated in absolute form. This reflects a deeper correspondence with the mental categories of mankind.

Analytic Hierarchy Process (AHP)

- Pros:
  - great flexibility: AHP applications can work even in fields very different from each others.
  - The risk level estimation is achieved by a hierarchical and competitive model between different hazards. This allows to get a synthetic judgment on the overall risk of the activity taken into consideration.
  - The estimations are made through distributions of values and not by point values: this makes the process more transparent

Analytic Hierarchy Process (AHP)

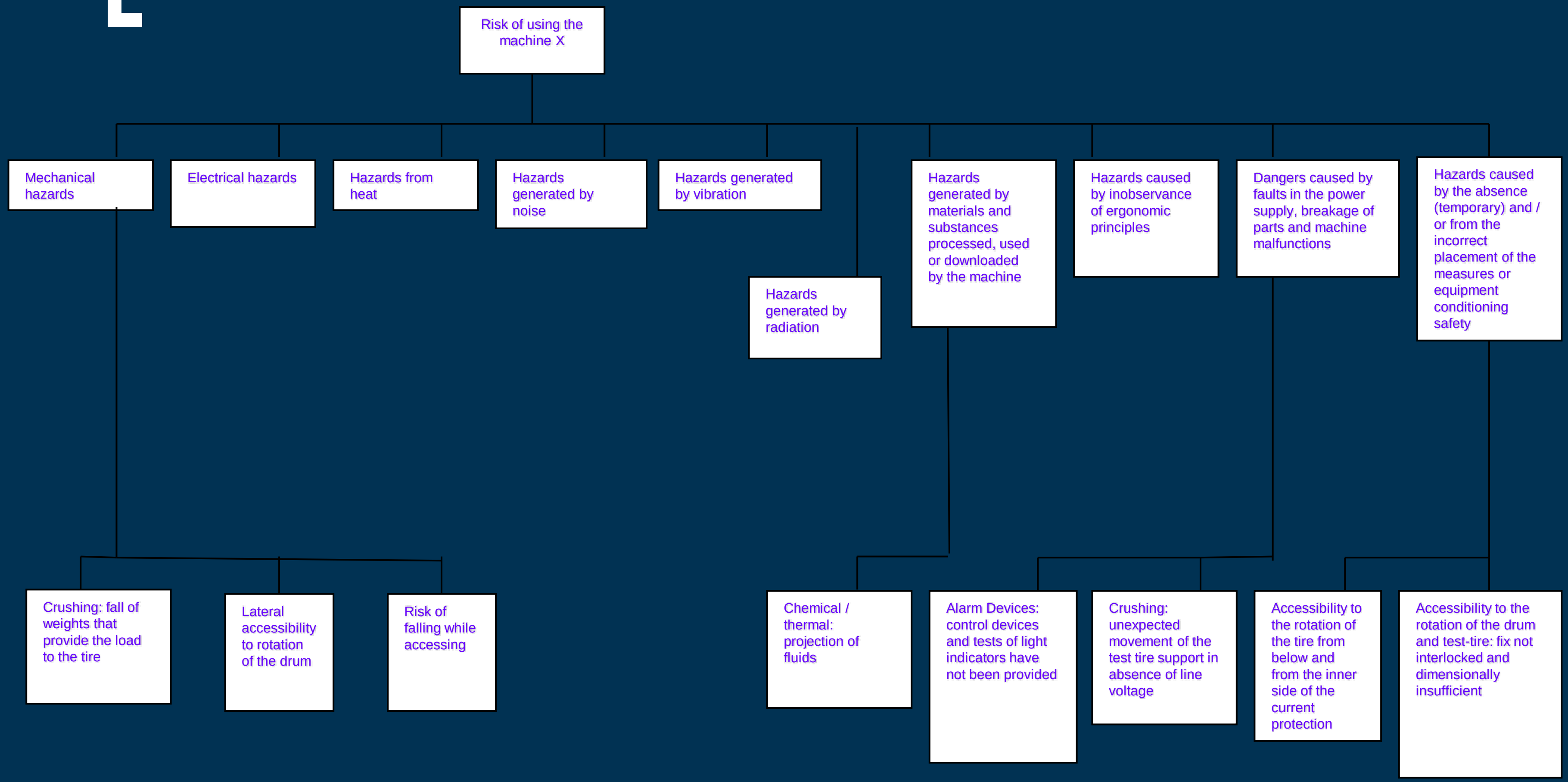
- Cons/Limits:
  - Rather high difficulty of application and strongly linked to the preparation of the evaluator.
  - **If we change the hierarchical structure, the results change** : this seems to be the most critical phase of the entire evaluation process.
  - If we operate an application to complex systems, there might be necessary to have an IT support.

AHP: an example

- The machine taken as an example deals with “tests on wheel-road system“. It is essentially made by a drum, which can rotate at the desired speed, to which different tires, with adjustable load, are pushed together.

- In all the applications, we refer to all the 10 types of hazards listed in the standard UNI EN 414 (Enclousure 1).

AHP: an example



AHP: an example

RISK Dangers caused by faults in the power supply, breakage of parts and machine malfunctions	Alarm Devices: control devices and tests of light indicators have not been provided	Crushing: unexpected movement of the test tire support in absence of line voltage
Alarm Devices: control devices and tests of light indicators have not been provided	1	1/2
Crushing: unexpected movement of the test tire support in absence of line voltage	2	1

Pairwise comparison between the sources of hazards to the type “hazards caused by failures in the power supply, breakage of parts of the machine and dysfunctions "

AHP: an example

- the maximum eigenvalue is calculated:

$$\begin{pmatrix} 1 & 1/2 \\ 2 & 1 \end{pmatrix} = A_2$$

$$\det(A - \lambda I) = 0$$

$$\begin{pmatrix} 1 & 1/2 \\ 2 & 1 \end{pmatrix} - \begin{pmatrix} \lambda & 1 \\ 1 & \lambda \end{pmatrix} = \begin{pmatrix} 1-\lambda & 1/2 \\ 2 & 1-\lambda \end{pmatrix} \quad \rightarrow \quad A - \lambda I$$

$$\begin{vmatrix} 1-\lambda & 1/2 \\ 2 & 1-\lambda \end{vmatrix} = [(1-\lambda)*(1-\lambda)] - 2*1/2 = 1 - 2\lambda + \lambda^2 - 1 = \lambda^2 - 2\lambda \quad \rightarrow \quad \det(A - \lambda I)$$

$$\begin{cases} \lambda = 0 \\ \lambda = 2 = l_{\max} \end{cases}$$

AHP: an example

- We can calculate the eigenvector corresponding to the maximum eigenvalue:

$$A * W = l_{max} * W$$

$$\begin{pmatrix} 1 & 1/2 \\ 2 & 1 \end{pmatrix} \cdot \begin{pmatrix} w_1 \\ w_2 \end{pmatrix} = 2 \cdot \begin{pmatrix} w_1 \\ w_2 \end{pmatrix}$$

$$\begin{cases} w_1 + \frac{1}{2} w_2 = 2w_1 \\ 2w_1 + w_2 = 2w_2 \end{cases} \rightarrow \quad \{2w_1 = w_2$$

- With w1 = 1

$$W = \begin{pmatrix} 1 \\ 2 \end{pmatrix}$$

AHP: an example

- Normalizing w on the sum of its elements:

$$W \rightarrow \begin{pmatrix} 1/3 \\ 2/3 \end{pmatrix} = \begin{pmatrix} 0.33 \\ 0.66 \end{pmatrix}$$

RISK	Alarm Devices: control devices and tests of light indicators have not been provided	Crushing: unexpected movement of the test tire support in absence of line voltage	**WEIGHTS**
Alarm Devices: control devices and tests of light indicators have not been provided	1	1/2	0.33
Crushing: unexpected movement of the test tire support in absence of line voltage	2	1	0.66

AHP: an example

- Once Calculated the weights for each source of risk is necessary to determine the risk level of each source:

Alarm Devices…	A	MA	MB	B
A	1	1/2	1/5	1/6
MA	2	1	1/4	1/4
MB	5	4	1	1/2
B	6	4	2	1

Crushing: unexpected movement …	A	MA	MB	B
A	1	1	1/7	1/5
MA	1	1	1/5	1/4
MB	7	5	1	3
B	5	4	1/3	1

AHP: an example

- The application of the method of Saaty’s eigenvalue leads to the definition of the following weights representing the **verisimilitude function of the risk**:

Functions of verisimilitute of the risk	**Alarm Devices…** (0,33)	**Crushing: unexpected movement …** (0,66)
A	0.068	0.073
MA	0.113	0.084
MB	0.344	0.577
B	0.474	0.264

AHP: an example

- From the obtained functions of verisimilitude of risk, we can have the functions of risk of the considered level, source by source.

- This step is performed by multiplying the weights of the functions of verisimilitude of each hazard source, for the relative weight obtained by the pairwise comparison between elements of the same level of the hierarchy (the initial comparison).

- To switch to the higher hierarchical level , we can make the sum of the risk functions of each source, which belongs to a type of danger (TOT).

Risk functions	**Alarm Devices…** (0,33)	**Crushing: unexpected movement …** (0,66)	TOT
A	0.068*0.33=0.022	0.073*0.66=0.048	0.070
MA	0.113*0.33=0.037	0.084*0.66=0.055	0.092
MB	0.344*0.33=0.113	0.577*0.66=0.380	0.493
B	0.474*0.33=0.156	0.264*0.66=0.174	0.330

AHP: an example

- At this point we make the pairwise comparison between the elements of the second level of the hierarchy and we obtain the weights:

Types of Hazards	Mechanical hazards	Electrical hazards	Hazards from heat	Hazards generated by noise	Hazards generated by vibration	Hazards generated by radiation	Hazards generated by handled substances	Hazards caused by inobservance of ergonomic principles	Hazards caused by faults in the power supply, breakage and malfunctions	Hazards caused by the absence or improper placement of Safety measures or equipment
Mechanical hazards	1	5	7	7	7	7	4	7	3	3
Electrical hazards	1/5	1	3	3	3	3	1/3	3	1/5	1/5
Hazards from heat	1/7	1/3	1	1	1	1	1/5	1	1/7	1/7
Hazards generated by noise	1/7	1/3	1	1	1	1	1/5	1	1/7	1/7
Hazards generated by vibration	1/7	1/3	1	1	1	1	1/5	1	1/7	1/7
Hazards generated by radiation	1/7	1/3	1	1	1	1	1/5	1	1/7	1/7
Hazards generated by handled substances	¼	3	5	5	5	5	1	7	1/2	1/2
Hazards caused by inobservance of ergonomic principles	1/7	1/3	1	1	1	1	1/7	1	1/7	1/7
Hazards caused by faults in the power supply, breakage and malfunctions	1/3	5	7	7	7	7	2	7	1	1
Hazards caused by the absence or improper placement of Safety measures or equipment	1/3	5	7	7	7	7	2	7	1	1

AHP: an example

- Thanks to the eigenvalue method and the built from pairwise comparison between the types of hazards, we can obtain the following vector representing the weights of the second level of the hierarchy:

Tipologie di pericolo	Pesi
Mechanical hazards	0.320
Electrical hazards	0.066
Hazards from heat	0.028
Hazards generated by noise	0.028
Hazards generated by vibration	0.028
Hazards generated by radiation	0.028
Hazards generated by handled substances	0.134
Hazards caused by inobservance of ergonomic principles	0.027
Hazards caused by faults in the power supply, breakage and malfunctions	0.203
Hazards caused by the absence or improper placement of Safety measures or equipment	0.133

AHP: an example

- The hazard function, relating to the use of the machine considered, can be obtained by multiplying the functions of risk calculated in two different ways, depending on the presence or absence of sublevels, for the weights:

	Mechanical hazards (0.320)	Electrical hazards (0.066)	Hazards from heat (0.028)	Hazards generated by noise (0.028)	Hazards generated by vibration (0.028)	Hazards generated by radiation (0.028)	Hazards generated by handled substances (0.134)	Hazards caused by inobservance of ergonomic principles (0.028)	Hazards caused by faults in the power supply, breakage and malfunctions (0.203)	Hazards caused by the absence or improper placement of Safety measures or equipment (0.133)	**OVERALL RISK FUNCTION**
A	0.031	0.033	0.002	0.002	0.002	0.002	0.010	0.002	0.014	0.009	**0.107**
MA	0.033	0.017	0.005	0.005	0.005	0.005	0.025	0.005	0.018	0.011	**0.129**
MB	0.137	0.009	0.012	0.012	0.012	0.012	0.060	0.012	0.100	0.076	**0.442**
B	0.114	0.004	0.008	0.008	0.008	0.008	0.037	0.008	0.067	0.035	**0.297**

0,031*0,320+0,033*0,066+… = 0,107

AHP: an example

- The determined risk functions do not allow a direct comparison between different hazards necessary in order to establish a priority of intervention.
- For this reason, we have to define a **Risk Index.**
- We have to perform a pairwise comparison between the levels of risk (A, MA, MB, B) to determine a scale of weights through which assign a weight of importance to the individual levels of risk:

Risk scale	A	MA	MB	B	weigh ts
A	1	1.2	2	6	0.402
MA	1/1.2	1	2	5	0.350
MB	1/2	1/2	1	2	0.174
B	1/6	1/5	1/2	1	0.074

AHP: an example

- Multiplying the functions of risk for the weights thus obtained and adding the resulting elements, we can get a **Risk Index** that can be determined at each level of the hierarchy: it allows to establish **a priority for action**.

Oggetto	Indice di rischio
Risk linked to the machine use	0.187
Mechanical hazards	**0.056**
Crushing : fall of weights / ballasts	0.122
Lateral accessibility to rotation of the drum	0.040
Risk of falling while accessing	0.211
Electrical hazards	**0.021**
Hazards from heat	**0.005**
Hazards generated by noise	**0.005**
Hazards generated by vibration	**0.005**
Hazards generated by radiation	**0.005**
Hazards generated by materials and substances handled or discharged by the machine	**0.026**
Chemical / Thermal: projection of fluids	0.197
Hazards caused by inobservance of ergonomic principles	**0.005**
Hazards caused by faults in the power supply, breakage and malfunctions	**0.034**
Alarm Devices: control devices and tests of light indicators have not been provided	0.053
Crushing: unexpected movement of the test tire support in absence of line voltage	0.117
Hazards caused by the absence (temporary) and / or from the incorrect placement of the measures or equipment conditioning safety	**0.023**
Accessibility to the rotation of the tire from below and from the inner side of the protection.	0.089
Accessibility to the rotation of the drum and the test tire : fix not interlocked and dimensionally insufficient	0.089

0,014*0,402+0,018*0,350+0,100*0,174+0,067*0,074=0,034