Incorporating Safety into Engineering Teams and the Design Process

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Section 1: Introduction to safety in engineering design and teams

1.1 Engineering design and safety

Improper design can lead to unexpected consequences in engineering.

Sometimes such consequences involve safety risks, some of which result in safety incidents. Consequences can be as severe as death.

Removing safety risks to ensure worker and public safety is:

- a key component of engineering design
- a responsibility of engineers and engineering teams

These statements embody the focus of this module, which is on understanding and mitigating the health and safety risks in engineering design and engineering teams.

1.2 Examples of consequences of inadequate consideration of safety in engineering design

1. Fires and explosions
    - E.g. power plant fires, pipe explosions

Figure 1.1 Pipe explosion

2. Equipment collapse and other equipment hazards
   - E.g., bridge collapse, sparks from a circuit

Figure 1.2 Bridge collapse

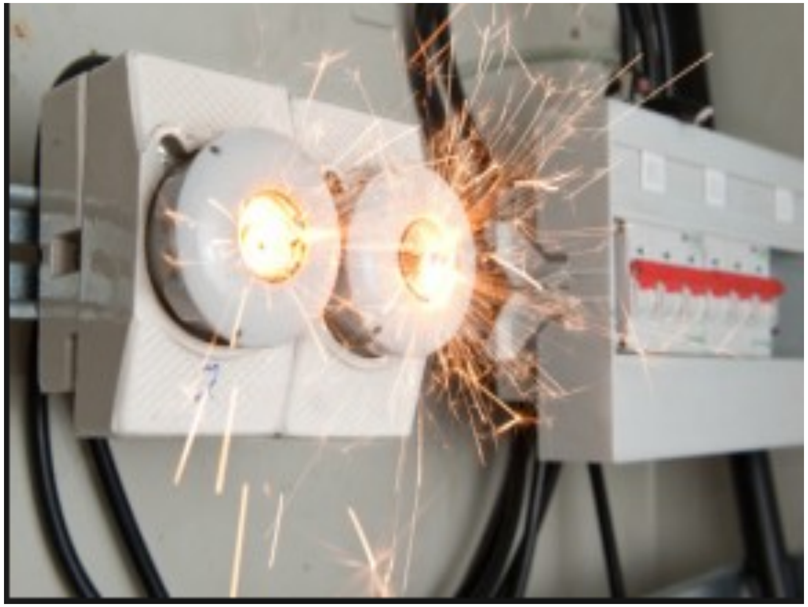

Figure 1.3 Sparks from a circuit

3. Design flaw in nuclear power plants

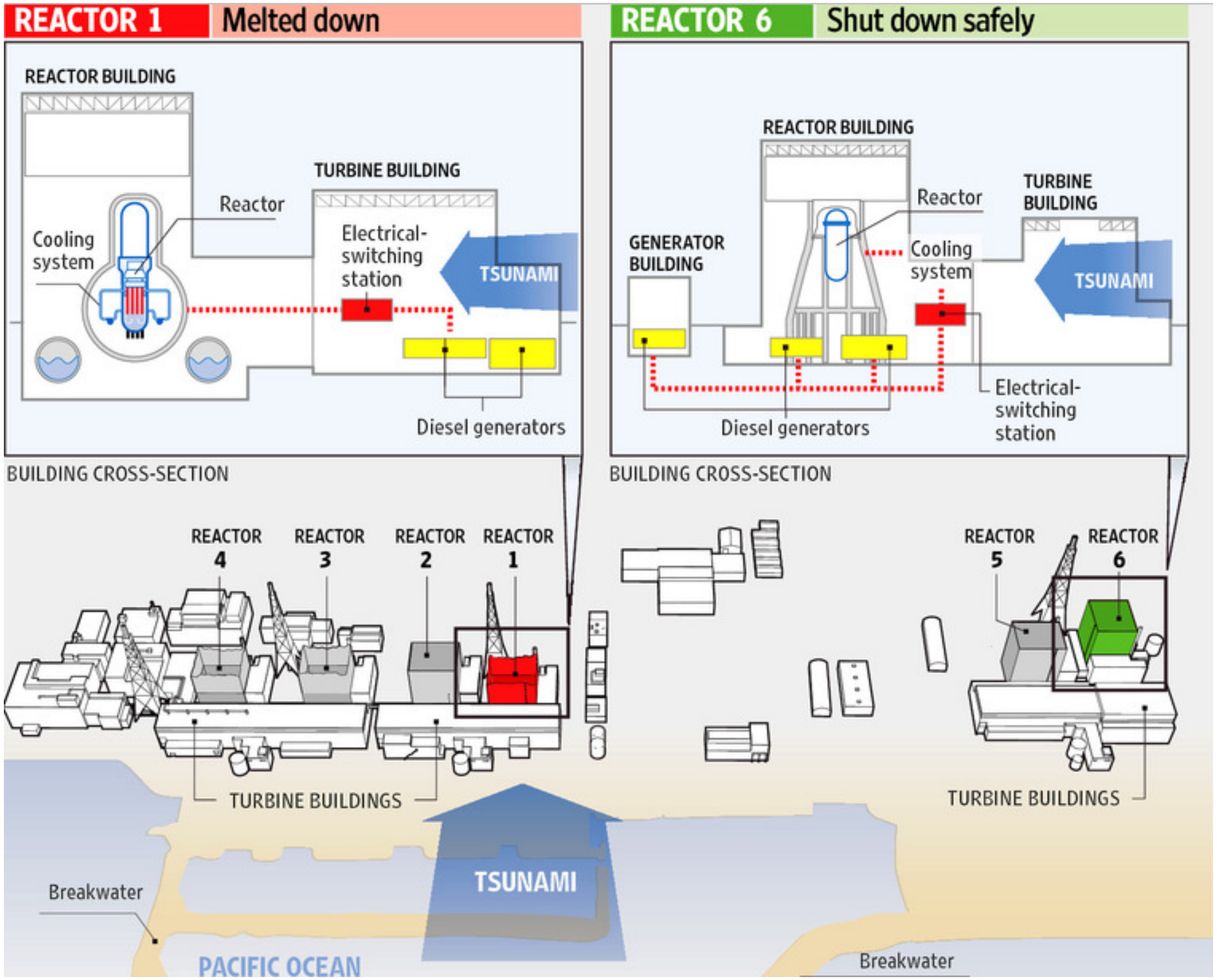

Figure 1.4 Nuclear reactors at Fukushima Daiichi

4. Space shuttle Challenger disaster

Figure 1.5 Explosion during take-off of the space shuttle Challenger

5. Spills and releases of hazardous or toxic wastes

- E.g., oil spills, pipeline ruptures, radioactive discharges

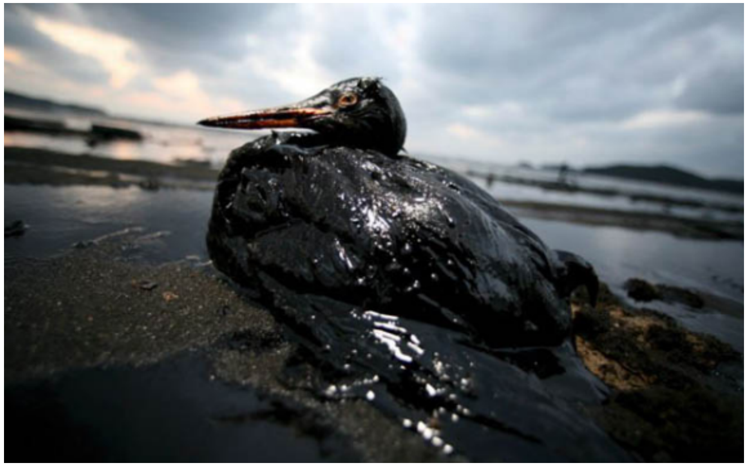

Figure 1.6 Oil spill

Key lesson of these examples:

Incorporating safety into engineering teams and the engineering design process is vital for:

- protecting workers, the community and the people who live and work within it, emergency responders, etc.
- avoiding significant financial costs from safety incidents for businesses and communities, and attaining financial benefits in organizations associated with good health and safety practices and the associated good practices this promotes in general
- protecting the conditions of the environment, in both the short and long terms, including the protection of ecosystems and the people, animals and other living entities within them

1.3 Engineering teams and design

- When designing a complex device or system, e.g., automobiles, aircraft, computers and manufacturing plants, many engineering experts from different areas come together in the design process.
- These experts need to cooperate, to consider each other's requirements and, often, to compromise regarding facets of engineering designs.
- Teams have meetings regularly throughout the design process to discuss different engineers' requirements and preferences, so that the whole team achieves the best design solution.

Figure 1.7 Engineering teams working on a transportation device

Example

- For the design of a space robot by NASA, various kinds of engineers comprise the team tasked with designing a complete robotic system.
- Each engineering group may have its specific subtasks.
- Robotic structural engineers, for instance, consider the requirements specified by robot control engineers so that the robot achieves optimum control performance.

Figure 1.8 Engineering teams testing capabilities of a vehicle

1.4 Engineering design process and safety

- The engineering design process involves many steps, from problem statement and concept development to the final product or process.
- Safety must be considered throughout the engineering design cycle to ensure all areas of risk are addressed at every stage of the process.

One way to illustrate the engineering design process is the engineering circle [1].

Each of the steps in the engineering circle are now described.

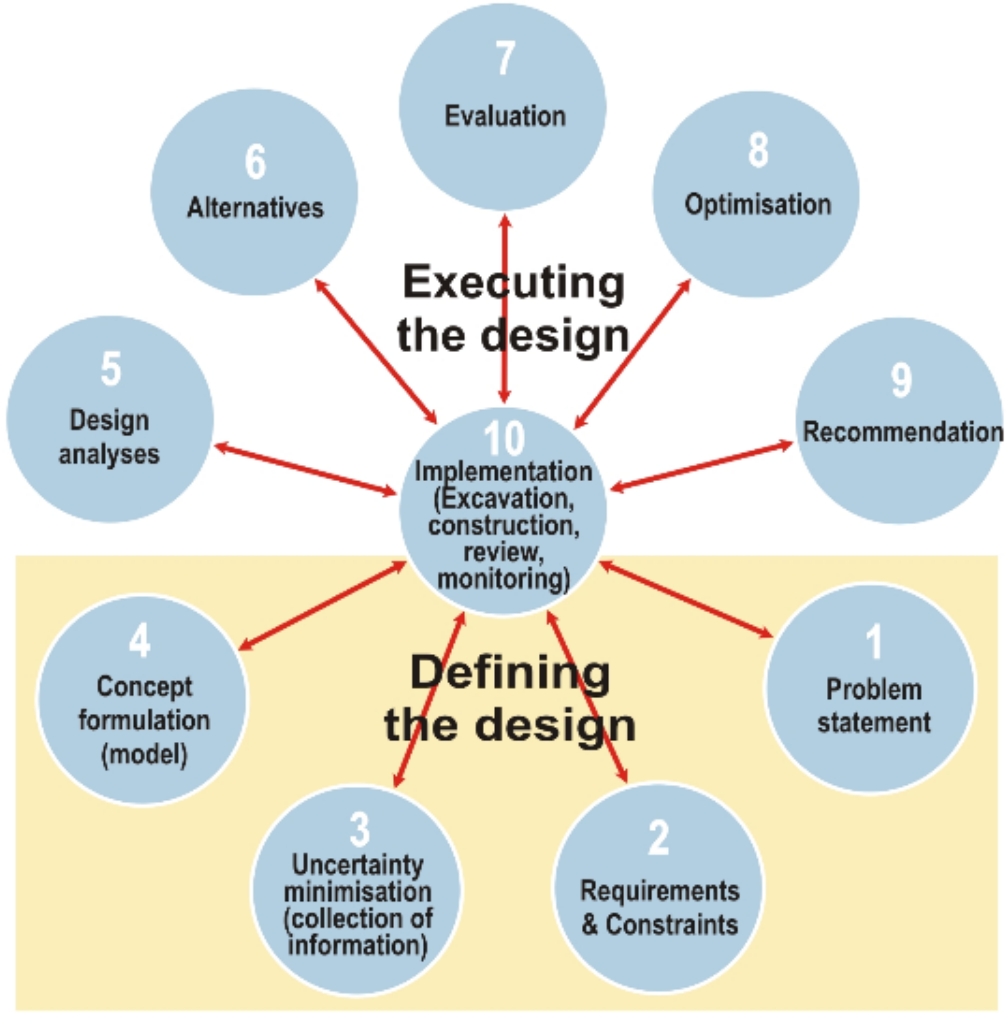

Figure 1.9 Engineering circle

Step 1: Problem statement. For example, existing safety issues with a current design or technology need to be identified.

- Here, one needs to determine the potential safety issues that exist within the system by resorting to current engineering methods.

Step 2: Requirements and constraints. The current design constraints and the requirements to fulfill the objective need to be understood.

- After one determines potential safety issues, the next step is to ascertain the requirements or final goals one is expected to achieve and relevant constraints that limit options.

Step 3: Uncertainty minimization. All available information is collected to reduce uncertainties in the design to a minimum.

- This step aims to minimize uncertainties that exist within the system or process.
- Although ideally uncertainties should be considered, they are sometimes ignored for the ease of analysis.

Step 4: Concept formulation. Mathematics and other methods are used to model the current design process.

- Concept formulation in engineering sometimes can be thought of as problem modelling.
- One needs to formulate the general and sometimes vague problem into a mathematical model to provide understanding and facilitate subsequent analysis.

Step 5: Design analysis. Engineering tools, like finite element analysis (FEA), are utilized to conduct analyses of potential hazards.

- After modelling, commercial engineering tools can be used to help identify hazards within the model.
- This step is usually called design analysis.

Step 6: Alternatives. Further investigations are carried out to seek any other alternatives to the current design.

- This step is optional.
- One can use mathematical analysis instead of engineering tools to analyze hazards within the model.

Step 7: Evaluation. Computer software is used to evaluate the current system or process.

- In engineering, Matlab software is often employed to help evaluate a system or process.

Step 8: Optimization. Computer software is used to optimize the current system or process and to improve it.

- In engineering, Matlab is often employed in system or process optimization.

Step 9: Recommendation. The optimization results from the prior step are used to develop recommendations for actions.

- The optimal solution can be recommended as an option for engineers or managers, or alternatives can be presented and recommended.

Step 10: Implementation. The recommended actions, which may be to implement the optimized results, are implemented to improve the current design to make the operation and field work consistent with safe operating practices.

- In most instances, the design is executed following the recommendations.

Section 1 - Quiz

1. Which of the following is correct?
   a. Improper design rarely leads to unexpected consequences in engineering
   b. ✔ Improper design often leads to unexpected consequences in engineering

2. Which of the following is the first step in the engineering circle?
   a. Evaluation
   b. Design analysis
   c. ✔ Problem statement
   d. Concept formulation

Section 2: Safety documentation, rules and culture in design and teams

Standards are publications that establish accepted practises, technical requirements and terminologies.

By using standards, organizations can ensure products and services are consistent, safe and effective.

Figure 2.1 Safety and teamwork to protect people

2.1 Safety standards and codes

There are four types of standards that cover a wide range of requirements for products, processes and services [2]:

- **Performance** - ensure that a product meets a prescribed test (e.g. strength requirements)
- **Prescriptive** - identify product characteristics (e.g. dimensions of material)
- **Design** - sets out the specific design or technical characteristics of a product
- **Management** - set out requirements for the processes and procedures (e.g. environmental management systems)

To be considered valid and meaningful, standards must have certain attributes:

- Their development must be overseen by a recognized organization or authority
- The development process must be open to input from all interested parties
- The resulting standards must be properly documented and publicly available
- A method must be available for monitoring and verifying that organizations are complying with the standards

Codes can include codes of conduct, codes of practice, voluntary initiatives, guidelines and non-regulatory agreements.

Codes can cover a wide a range of activities:

- Environmental protection
- Health and safety
- Labour standards
- Human rights
- Advertising
- Public standards of decency

Some workplace examples of codes used in engineering practice follow:

- Building Codes
- Fire Codes
- Electrical Codes

2.2 Description of safety rules

Different engineering fields have their own safety rules. Some elements are general, while others are discipline specific. Working with electrical equipment is considered as an example [3]:

- **Rule 1**: Avoid contact with energized electrical circuits.
- **Rule 2**: Treat all electrical devices as if they are live or energized.
- **Rule 3**: Disconnect the power source before servicing or repairing electrical equipment.
- **Rule 4**: Use only tools and equipment with non-conducting handles when working on electrical devices.
- **Rule 5**: Never use metallic pencils or rulers, or wear rings or metal watchbands, when working with electrical equipment.

- **Rule 6**: When it is necessary to handle equipment that is plugged in, be sure hands are dry and, when possible, wear nonconductive gloves, protective clothes and shoes with insulated soles.

- **Rule 7**: If it is safe to do so, work with only one hand, keeping the other hand at your side or in your pocket, away from all conductive material. This precaution reduces the likelihood of accidents that result in current passing through the chest cavity.

- **Rule 8**: Minimize the use of electrical equipment in cold rooms or other areas where condensation is likely. If equipment must be used in such areas, mount the equipment on a wall or vertical panel.

- **Rule 9**: If water or a chemical is spilled onto equipment, shut off power at the main switch and unplug the equipment.

- **Rule 10**: If an individual comes in contact with a live electrical conductor, do not touch the equipment, cord or person. Disconnect the power source from the circuit breaker or pull out the plug using a leather belt.

- **Rule 11**: Equipment producing a "tingle" should be disconnected and reported promptly for repair.
- **Rule 12**: Do not rely on grounding to mask a defective circuit nor attempt to correct a fault by insertion of another fuse or breaker, particularly one of larger capacity.
- **Rule 13**: Drain capacitors before working near them and keep the short circuit on the terminals during the work to prevent electrical shock.
- **Rule 14**: Never touch another person's equipment or electrical control devices unless instructed to do so.
- **Rule 15**: Enclose all electric contacts and conductors so that no one can accidentally come into contact with them.

- **Rule 16**: Never handle electrical equipment when hands, feet or other body parts are wet or perspiring, or when standing on a wet floor.

- **Rule 17**: When it is necessary to touch electrical equipment (e.g. when checking for overheated motors), use the back of the hand. Thus, if accidental shock were to cause muscular contraction, you would not "freeze" to the conductor.

- **Rule 18**: Do not store highly flammable liquids near electrical equipment.

- **Rule 19**: Be aware that interlocks on equipment disconnect the high voltage source when a cabinet door is open but power for control circuits may remain on.

- **Rule 20**: Do not wear loose clothing or ties near electrical equipment.

2.3 Safety culture and its impact on teams

A safety culture [4]:

- relates to the ways in which safety is managed in the workplace, and
- reflects the attitudes, beliefs, perceptions and values that employees share in relation to safety

A safety culture affects health and safety, as well as many other aspects of performance.

Here, the London 2012 Olympic project is used as an example. Instilling a good safety culture made this project and its design a success.

Safety culture example – London 2012 Olympic project

Figure 2.2 London 2010 Olympic site

The elements that contributed to the development of an effective safety culture on the Olympic site [5] included the following:

- The strategic role of the Olympic Delivery Authority (ODA) across the site, with safety being set as a priority and integrated into the companies involved from the outset through standards and requirements
- Clarity throughout the supply chain of the organizational standards and requirements, including the desire for cultural alignment (i.e. consistent commitment to the same health, safety and environment standards)
- A focus by the ODA on engaging contractors, enabling them to develop their own good practices and to drive their own performance; this allowed contractors to develop and apply their own processes
- Recognition of the prestige of working on the Olympic Park and consequently striving for excellence in activities, including health & safety
- The scale of the project and the length of the construction phase, which meant that initiatives had time to 'bed in', and could be tailored to ensure their efficacy and success
- Belief by workers in the genuine commitment within organizations, as the message was consistent and reiterated across the Olympic Park over time

The following points are derived from the London 2012 Olympic project, where they contributed to achieving a positive safety culture:

Organizational commitment

- Management should:
  - appreciate value of leading by example and demonstrating positive behaviors
  - be visible and approachable
  - provide support where conflicting pressures may arise

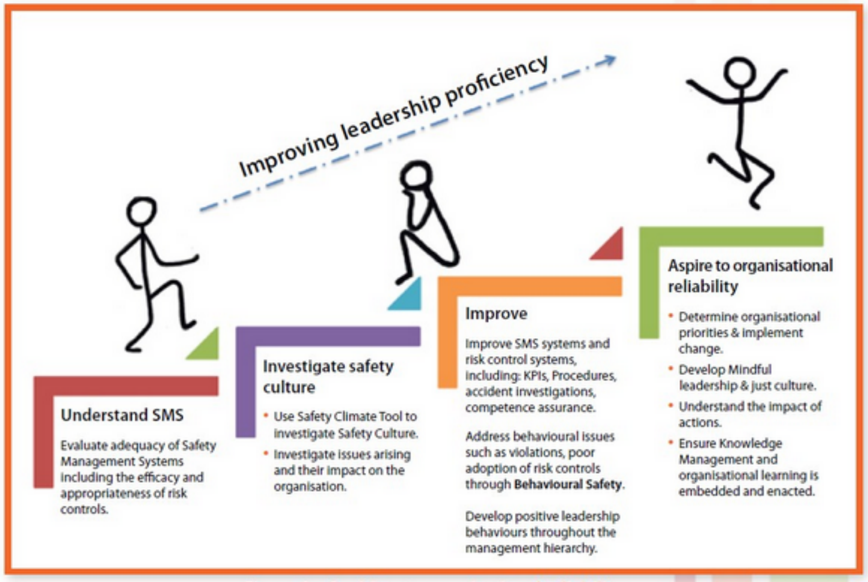

Figure 2.3 Improving leadership proficiency

Health and safety oriented behaviors

- Tailor workshops and campaigns to make them relevant and appropriate to workers (i.e. based on trends in recent incidents/injuries on site), and incorporate interesting activities to engage the workforce.
- Use credible champions and guest speakers to help deliver campaigns and training messages.
- Use incentives to encourage positive behaviors on site (e.g. donating money to charity for observations submitted).
- Involve workers as well as management in observing behaviors on site, and recording observations.

Health and safety trust

- Use a variety of reward and recognition schemes within the workplace to encourage positive behaviors.
- Carefully consider the impact of management decisions and recognize the possibility of human error.
- Create regular opportunities for workers to discuss health, welfare, safety and environmental issues with managers and ensure agreed actions are followed up on.

Figure 2.4 "Safety promotion" mug

Usability of procedures

- Develop risk assessments following a structured process, with involvement from appropriately experienced workers who are familiar with the work tasks being assessed.
- Ensure workers have a clear understanding of risk assessment and method statements documents.
- Encourage workers to review risk assessment documentation at the point of work.
- Involve workers in discussions around risk assessments, method statements and other documentation, and use this as a basis for daily briefings to maintain high situational awareness.

Engagement in health and safety

- Develop a variety of reporting methods, communicate these to workers and consider ways of refreshing the methods adopted to keep their importance at the forefront of workers' minds.

- Make all workers confident and empowered to discuss health and safety issues with anyone on site.

- Set clear health and safety expectations from the outset through the training and induction of new employees.

- Consider the development of a behavioral-based safety initiative to identify and embed good health and safety behaviors.

Peer group attitude

- Devote time and resources to enable workers to develop strong, positive working relationships, and to take responsibility for their own and others' health and safety.
- Ensure workers and managers recognize the importance of fostering a safe and supportive working environment and put measures in place to achieve it.
- Make the working environment and job a positive experience for workers, encouraging them to continue their employment, and reducing absenteeism and turnover where possible.

Resources for health and safety

- Begin planning of work early to ensure resources (human and equipment) are agreed upon and allocated prior to the project start and to ensure enough time is allocated to complete the work safely.

- Consider the training needs of workers (e.g. role, tasks and equipment) and provide relevant training to affect lasting attitude and behavioral change and to help ensure the competence of staff.

- Deliver training during working hours.

Health and Safety Awareness Training for Workers

Human Resources Advisory Services

Figure 2.5 Safety workshop

Accident and near miss reporting

- Ensure workers understand the purpose and value in reporting observations and near misses using training, briefings and campaigns.
- Develop targeted training to enhance workers' understanding of what a near miss is.
- Provide clear, timely feedback to workers to demonstrate the value of their observations and any resulting actions, and make changes where appropriate.
- Take prompt, appropriate actions, i.e. raising standards through improvements to procedures and practices, to prevent accidents, reduce bullying and improve the working environment.

Section 2 - Quiz

1. There are 4 types of standards that cover a wide range of requirements for products, processes and services. Which of the following is not one of them?

A. Performance - ensure that a product meets a prescribed test

B. Prescriptive - identify product characteristics

✓ C. Promotion - advertise product

D. Management - sets out requirements for the processes and procedures

2. Which one of the following statements in incorrect?

A. A safety culture reflects the attitudes, beliefs, perceptions and values that employees share in relation to safety

✓ B. A safety culture does not affect health.

C. A safety culture relates to the ways in which safety is managed in the workplace

Section 3: Safety control and management schemes

3.1 Safety control:

Main ways to control a hazard [6]:

- Elimination
- Substitution
- Engineering controls
- Administrative controls
- Personal Protective equipment

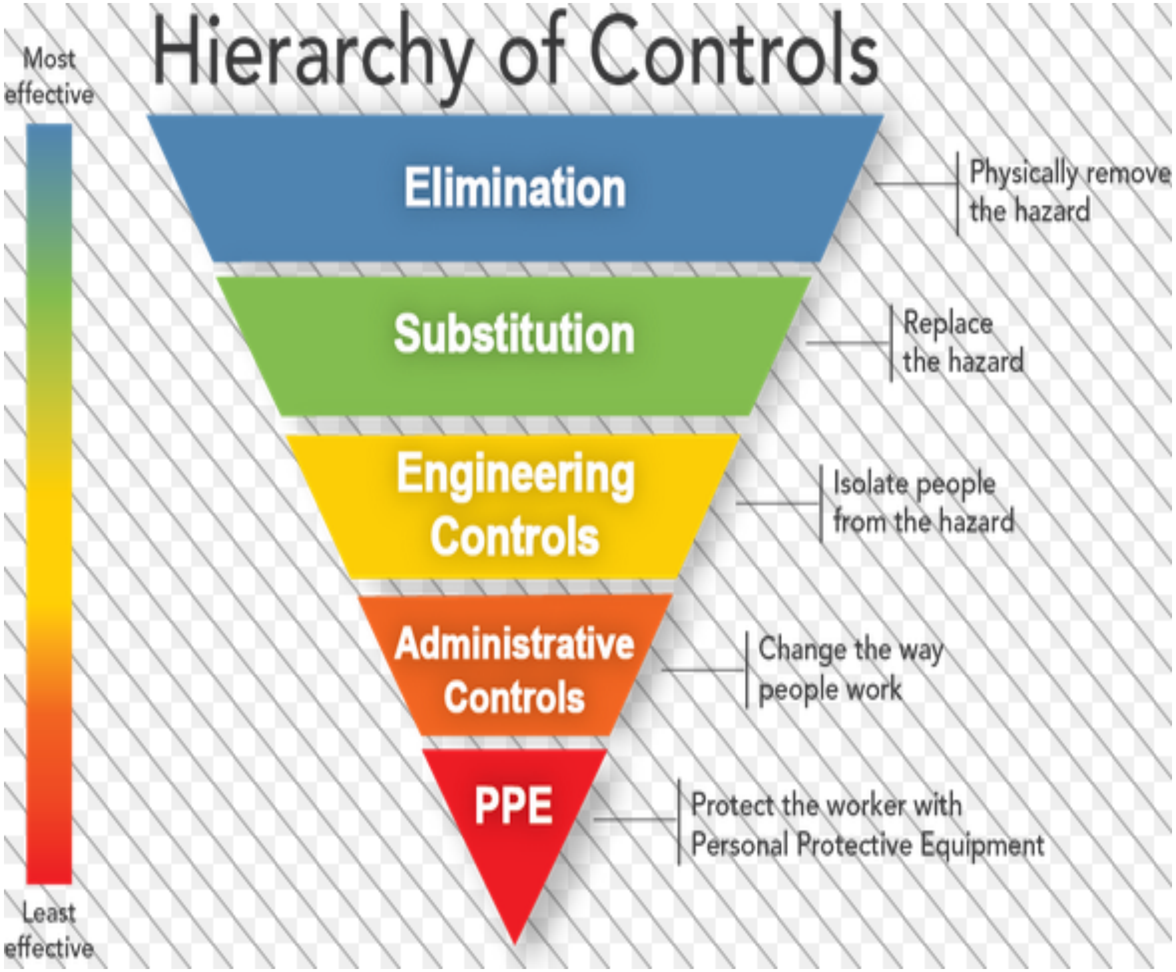

Figure 3.1 Hierarchy of controls

Safety control: Elimination

- Involves removing the hazard from the workplace.
- Often, the most effective way to control a risk.
- Example: If employees must work high above the ground, the hazard can be eliminated by moving the piece they are working on to ground level to eliminate the need to work at heights.

Figure 3.2 Fall hazard

Safety control: Substitution

- Involves replacing something that produces a hazard with something that does not produce a hazard
- Examples:
  - Replacing lead based paint with acrylic paint
  - Replacing an organic solvent-based glue with a water-based one

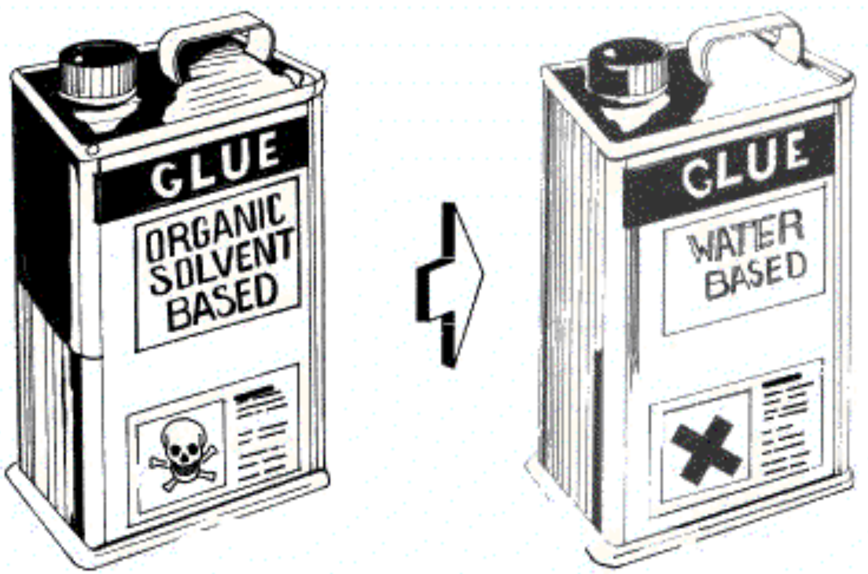

Figure 3.3 Glue substitution

Safety control: Engineering controls

- Involves designing the work environment and the job itself to avoid or reduce, to the extent feasible, exposure to hazards.
- Usually focus on the source of the hazard, unlike other types of controls that generally focus on the employee exposed to the hazard.
- Does not necessarily mean an engineer is required to design the control, even though the approach is called engineering control [7].
- Examples:
  - A crew might build a work platform rather than purchase and maintain fall arrest equipment
  - A fan can be added to remove hazardous gases from a workspace

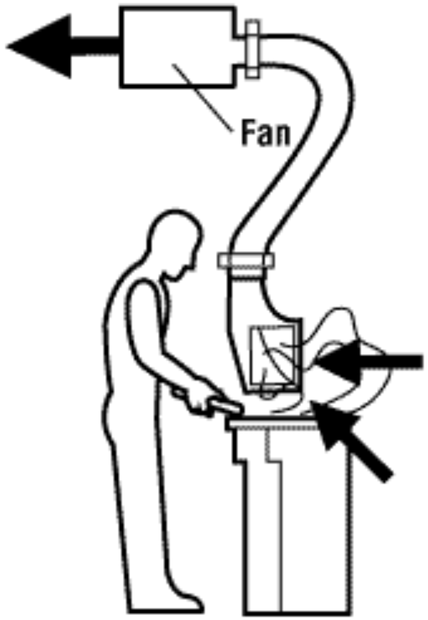

Figure 3.4 Removing the contaminant at the source

Safety control: Administrative controls

- Describes measures aimed at reducing employee exposure to hazards, generally by manipulating the work schedule and how people work
- Work schedule measures include:
  - Lengthened rest breaks
  - Additional relief workers
  - Exercise breaks to vary body motion
  - Rotation of workers through different jobs
- Measures to change how people work include:
  - Procedure changes
  - Employee training
  - Installation signs and warning labels
- Also involves implementation of safe work practices (see next slide)

Figure 3.5 Administrative control

Safe work practices

Safe work practices include:

1. Developing and implementing standard operating procedures.
2. Training and educating employees about operating procedures as well as providing other necessary workplace training
3. Establishing and maintaining good housekeeping programs
4. Keeping equipment well maintained
5. Preparing and training for emergency responses for incidents such as spills, fires or injuries

Safe work practices are a form of administrative controls.

Safety control: Personal protective equipment (PPE)

When exposure to hazards cannot be engineered completely out of normal operations or maintenance work, a supplementary method of control is the use of protective clothing or equipment, collectively called personal protective equipment (PPE).

PPE includes gloves, respirators, hard hats, safety glasses, high-visibility clothing, and safety footwear.

PPE should not be the only method used to reduce exposure except under very specific circumstances because it leaves a worker close to a hazard and PPE may fail.

Figure 3.6 A PPE ensemble worn during high pressure cleaning work

3.2 Safety Management

- Safety management provides a systematic way to identify hazards and control risks while maintaining assurance that these risk controls are effective.

- As with all management systems, a safety management system provides for goal setting, planning and measuring performance [8].

- A good safety management system (SMS) is woven into the fabric of an organisation, and becomes part of the culture [9, 10], i.e., the way people do their jobs.

Hazard identification methods

Methods for identifying safety hazards can usually be divided into two main groups:

- *Reactive hazard identification methods*: Hazards are recognized through trend monitoring and investigations of safety incidents
  - Incidents and accidents are clear indicators of deficiencies in systems and should be investigated to determine the hazards

- *Proactive hazard identification methods*: Hazards are identified by analyzing system performance and functions for intrinsic threats and potential failures

Basic safety-management components

- Policy
- Organization
- Planning
- Implementation
- Evaluation
- Action for improvement

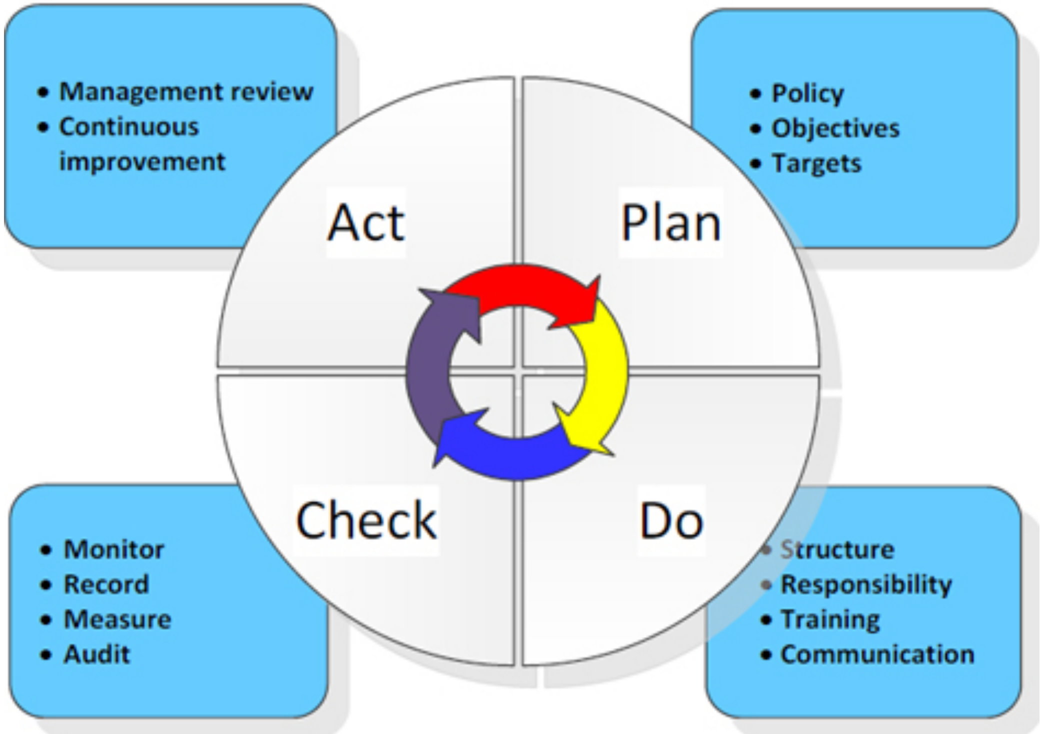

Figure 3.7 Safety management components

3.3 Process Safety Management (PSM)

A process safety management program is divided into 14 elements [11].

The U.S. Occupational Safety and Health Administration (OSHA) 1910.119 defines the 14 elements of a process safety management plan (see next slide).

Figure 3.8 Process safety management

PSM elements:

- Process Safety Information
- Process Hazard Analysis
- Operating Procedures
- Training
- Contractors
- Mechanical Integrity
- Hot Work
- Management of Change
- Incident Investigation
- Compliance Audits
- Trade Secrets
- Employee Participation
- Pre-startup Safety Review
- Emergency Planning and Response

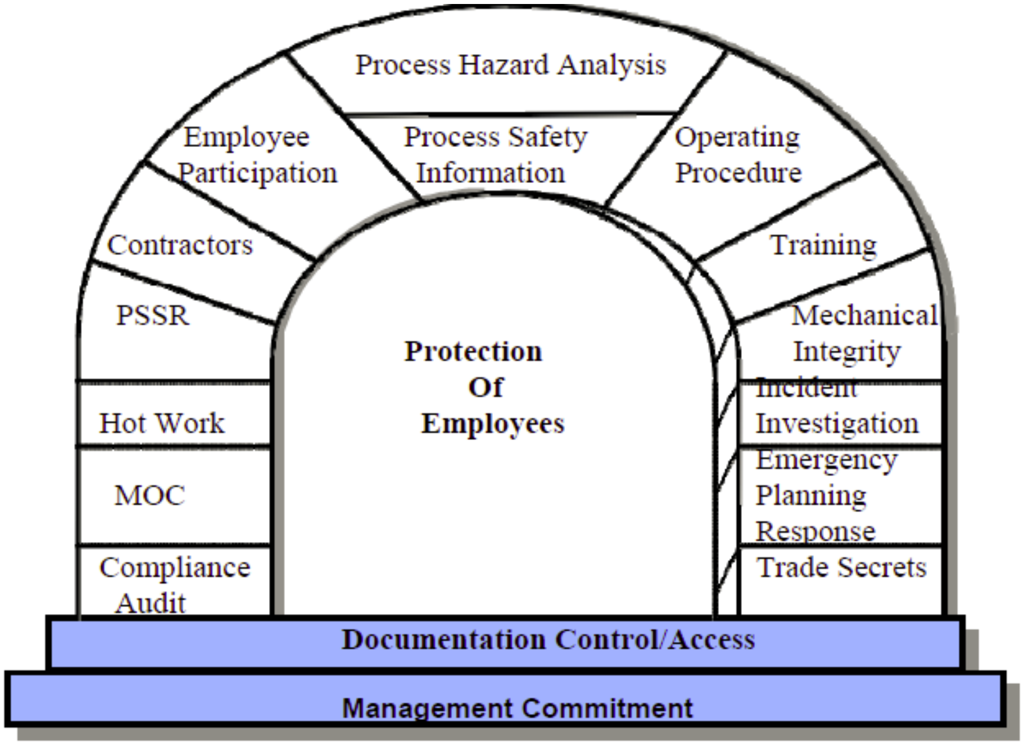

Figure 3.9 Process safety management elements

3.4 Management of Change (MOC)

A best practice used to ensure that safety, health and environmental risks are controlled when a team in a company makes changes in their:

- Facilities
- Documentation
- Operations
- Personnel

Figure 3.10 Management of change

When is Management of Change used?

- Generally, a business need or opportunity becomes a project or business solution and requires changes in the workplace that can affect processes, systems, people, or organizational structure. The need can be as simple as replacing a failed part on a machine or changing the team structure if necessary.

- MOC is particularly important because, when decisions and changes are made rapidly, safety and health risks can increase resulting in safety incidents and potentially disasters.

- For related MOC documentation, refer to "Environment, Social, Health and Safety Management System (ESHS MS), MOC Procedure, Document Number: 02/GP/PJ/PR/009/A01" [12].

What are the benefits of MOC?

- Increases productivity and efficiency of planning, coordinating, and implementing of changes in a team.
- Reduces unplanned adverse impacts on system integrity, security, stability and reliability for business process being altered or added.
- Provides a stable production environment inside a design team.
- Ensures the proper level of technical completeness, accuracy of modifications, and testing of systems before implementation.
- Provides an appropriate level of management approval and involvement in a team.
- Improves safety for each individual inside a design team during the design process.

MOC best practices

- Compile safety information on products, equipment, materials or processes that are changing and write policies and procedures to incorporate the new information.
- Incorporate employee comments and suggestions into draft policy and procedures.
- Write instructions for all employees on every process in which changes are involved inside a team.
- Train employees on the changes.
- Establish written procedures for what will be done when subsequent changes are made in safety management.

Section 3 - Quiz

1. Which of the following is not a main way to control a hazard:
   a. Eliminate hazards
   b. Apply engineering controls
   c. Expand plant size ✓
   d. Use personal protective equipment

2. Which of the following is correct?
   a. Engineering controls means that an engineer is required to design the control
   b. Engineering controls does not necessarily mean that an engineer is required to design the control ✓

Section 4: Illustrative examples

Example I

Incorporating safety in design at the Alice Springs to Darwin Rail Link [13]

Situation:

- A Build, Own, Operate and Transfer (BOOT) project was performed to construct a railway from Alice Springs to Darwin and take over an existing railway from Tarcoola to Alice Springs
- The project involved a design and construct contract
- A design working group was developed by the client, and included:
  - representatives of the client
  - representatives of the state and territory governments
  - other external stakeholders

Example I (cont.)

How safety was incorporated in the design:

- Weekly meetings were held during the design stage to ensure that the design was both practical and safe to build and operate
- An independent reviewer was engaged by the client to audit and certify all work performed by the design working group
- Monthly design reports were required, documenting (among other things) the safety aspects of the design
- Members of the design working group were located on-site during the construction work and were able to be directly involved
- All subcontractors were required to submit a safety plan describing how they would manage safety in the project, and these plans were reviewed by the client, with input from the design and construct team

Example II

Design changes to reduce risks associated with construction and maintenance [13]

Situation:

- In a design and construct project in Melbourne, Australia, a number of risks relating to the ongoing maintenance of a building under construction were identified
- As a consequence, design changes were made
- The building consisted of a glazed sawtooth roof with suspended lighting, and a fully glazed atrium covering all nine floors inside

Example II (cont.)

The problem:

- In the initial design, there had been some consideration given to the maintenance of all the glazing components and access to services installed on the roof
- In the original design, protection from falling during maintenance work consisted of a railing with rope access
- The design team deemed this unsuitable
- Designers therefore investigated ways in which maintenance work could be performed more safely

Example II (cont.)

The result:

- The final design:
  - A purpose-designed gantry was installed across the atrium, with a safe working platform on the gantry
  - The platform was installed on hydraulic lifts enabling safe access to the services located high in the ceiling space
  - When the platform was not in use it was retracted and positioned on top of the gantry
  - Another moveable working platform was suspended under the gantry, allowing access to the glazed atrium below
- Not only did this arrangement provide a safe environment for routine maintenance, but the gantry, which was erected early in the construction process, was also used for access during the construction of the atrium and roofing
- The gantry design also reduced costs and improved constructability of the atrium and roof, thus reducing construction time

Example III

Pre-assembly of stair frames [13]

The situation and original design:

- An analysis of an early design of the steel framing for a multi-level stairway in a high rise car park revealed that the original design
  - would not allow the framework to be pre-assembled
  - would require the framework to be assembled in small pieces while working at height
- The original design called for a beam running the full width of the stairway at each landing
- This prevented the structure from being pre-assembled

Example III (cont.)

The modified design for enhanced safety:

- The designer reviewed the original design in consultation with the steelwork fabricator and determined that, by splitting the original tie-beam and replacing it with smaller beams tied via fin plates, the stair flights could be
  - pre-assembled at ground level and
  - lifted into place as a whole including decks, stair treads and handrails
- This small modification
  - greatly reduced the amount of time spent by the framework erector at height and
  - provided a greater level of safety for workers as the framework installation proceeded

Section 5: Emerging trends in engineering design, teams and safety

5.1 Integrated design

- Integrated design is a collaborative method for designing which emphasizes the development of a holistic design.
- The goal is to look at all the systems together to make sure they work in harmony rather than against each other.
- The system is considered as a whole regarding health and safety issues and how they are addressed.

Integrated design requires multidisciplinary collaboration, including key stakeholders and design professionals, from conception to completion.

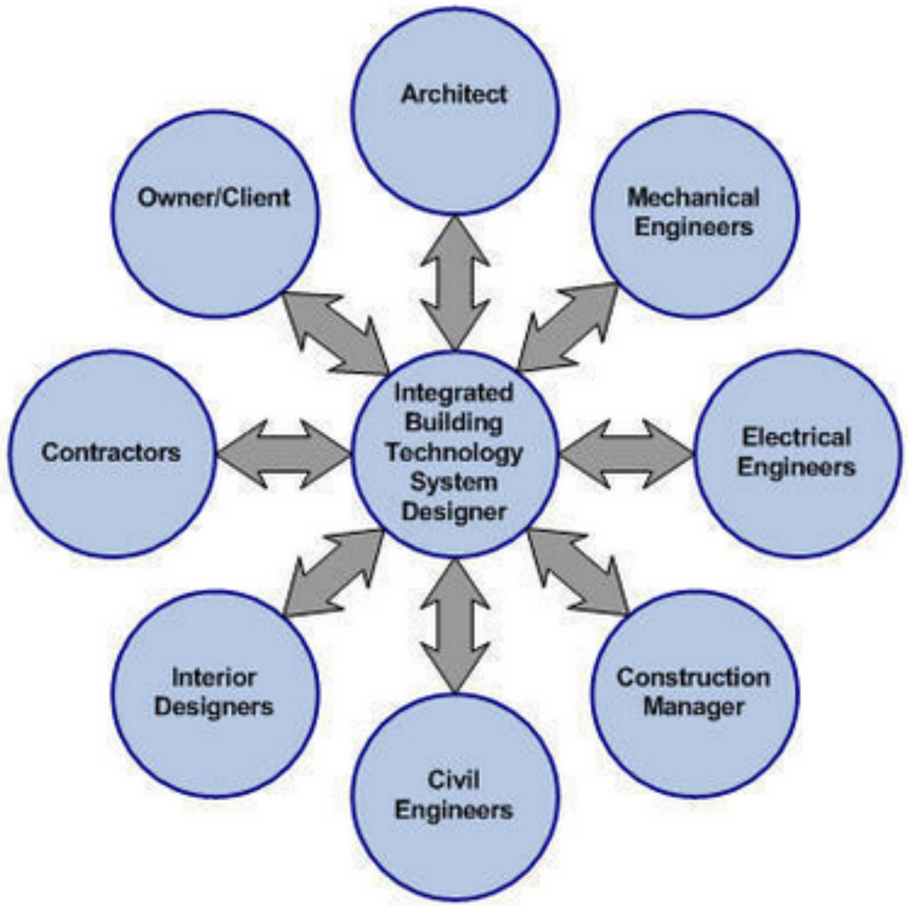

Figure 5.1 Integrated building technology systems

5.2 Modular design

- Modular design is a design approach that subdivides a system into smaller parts called modules.
- Each module can be independently created and then used in different systems.
- Each module or component is considered independently regarding health and safety issues.

5.2.1 Modular design in robotics

Modular design can be seen in robotics.

Figure 5.2 Modular robotics design

5.2.2 Modular design in cars

Aspects of modular design can be seen in cars to the extent of there being certain parts of the car that can be added or removed without altering the rest of the car.

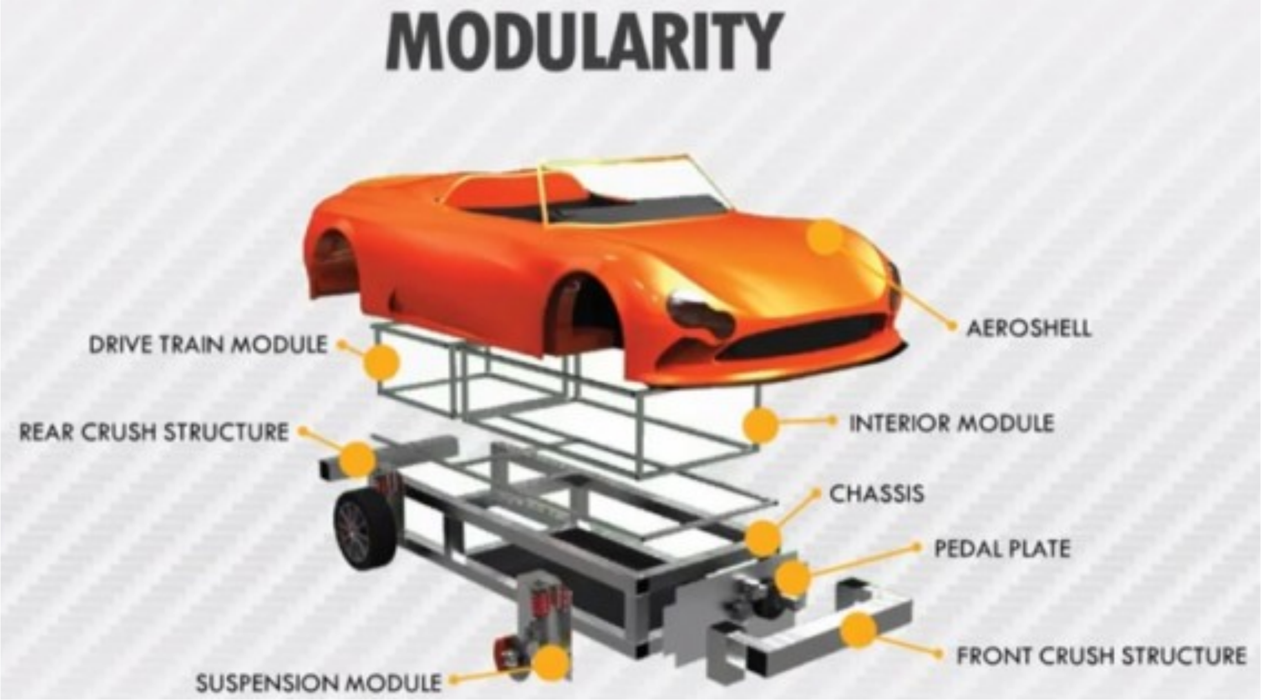

Figure 5.3 Modular design in cars

5.2.3 Modular design in buildings

Modular design can be seen in some buildings.

Example:

- If an office needs to be expanded or divided to accommodate employees, modular components can be added or relocated to make the necessary changes without altering the whole building.
- Later, this same office can be broken down and rearranged to form a retail space, conference hall or other building type using the same modular components.

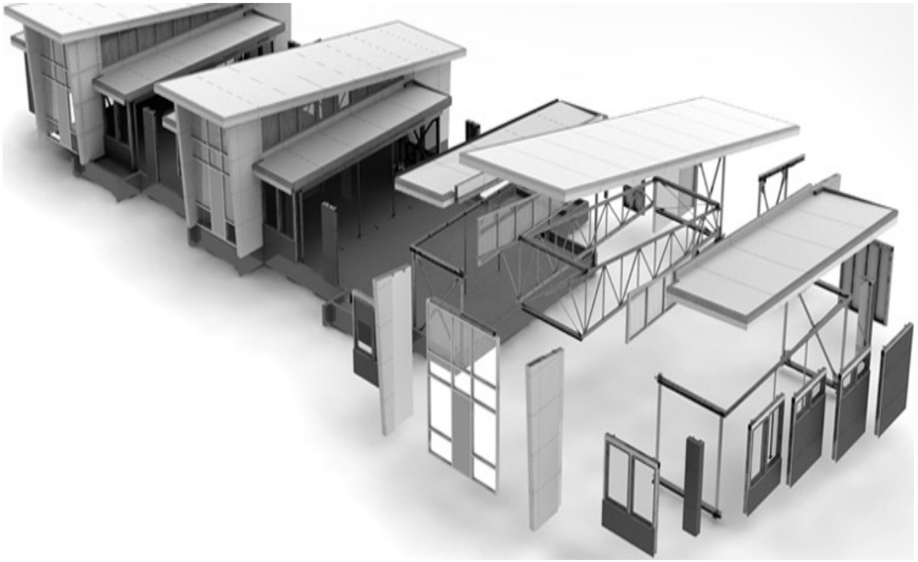

Figure 5.4 Modular design in buildings

5.2.4 Modular design in computer hardware

The idea is to build computers with easily replaceable parts that use standardized interfaces.

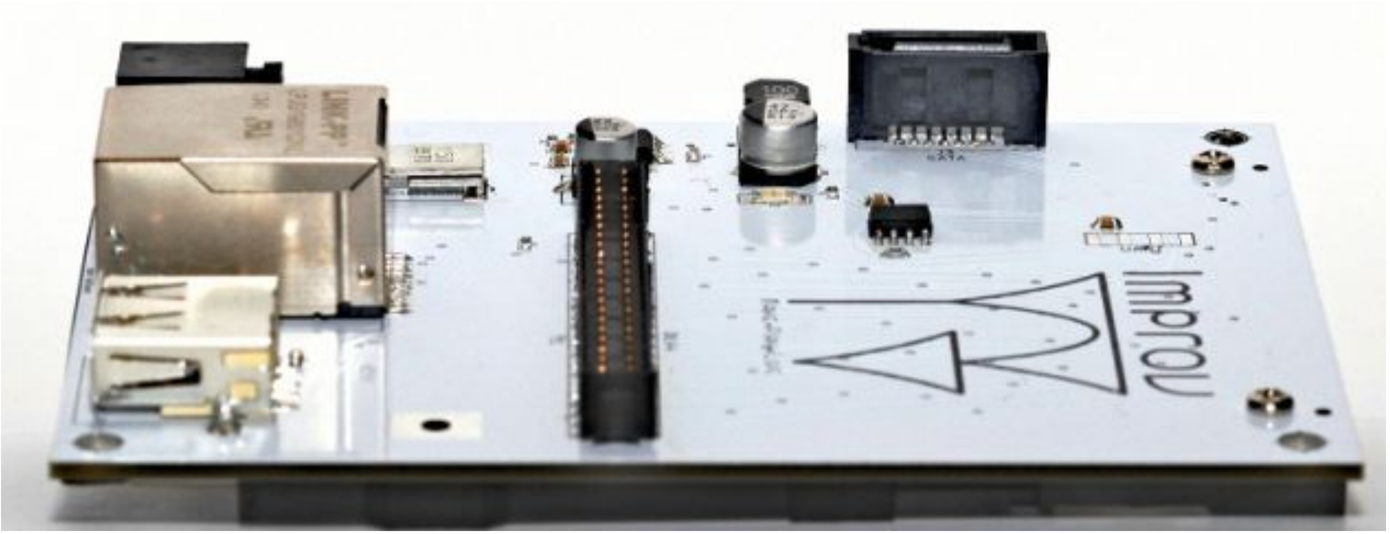

Figure 5.5 Modular design in computer hardware

5.3 Changeability of Manufacturing

Refers to rapid changeability of manufacturing to meet customer needs and respond to external factors and impediments.

Safety has to be considered in ensuring changes are compatible when manufacturing components are upgraded, modified or substituted.

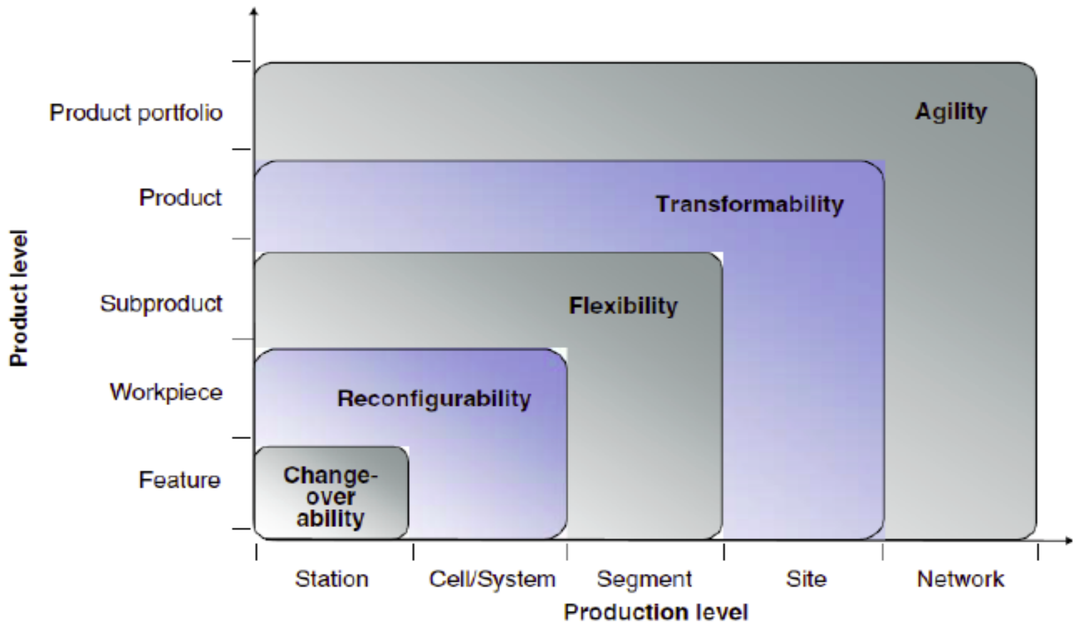

Figure 5.6 Changeability at various product and factory production levels

5.4 Emerging trends in safety and health

The status of occupational safety and health is affected by many factors:

- Changes in demographics, including a changing age profile of the workforce
- New technologies that provide new ways to support health and safety and also create new categories of employment
- Existence of dangerous substances, such as harmful chemicals
- Exposure to ultraviolet radiation and noise
- Concerns over occupational diseases and work-related stress

Emerging trends in health and safety will affect engineering teams and need to be addressed to ensure safety in teams.

Some of these are discussed in more detail in the following slides.

Age

Changes in the age distribution of the workforce of many countries will have consequences for the safety and health of workers.

- Example: In Europe, between 2000 and 2005 the number of people in the workforce decreased by 0.7 million among those aged 15 to 24 years, and increased by 4.2 million among those aged 55 to 64 years [14].

Teams will likely be comprised of members having different ages and experience levels, posing potential concerns regarding health and safety.

Correspondingly, efforts are being made to maintain good health and safety among members of the workforce:

- Measures that reduce occupational accident for older workers
- Measures that reduce occupational diseases rates
- Effective rehabilitation programmes

Nanotechnologies

- Nanotechnologies are potentially beneficial in many areas, but concerns have been expressed about their potential health and environmental risks, which can affect the teams and individuals within them.
- Nanotechnologies are currently one of the priorities for occupational safety and health research in many developed countries.
- Workers in nanotechnology may be exposed to the novel properties of materials and products causing health effects that have not yet been fully explored.
- Because of their small size, nanoparticles can enter the body in three ways, via the digestive system (ingestion), the respiratory tract (inhalation), and the skin (direct exposure).
- The limited evidence available suggests that employers should take a precautionary approach when potential exposures to nanoparticles may occur.

Chemical risks in small- and medium-sized enterprises (SMEs)

The rate of incidents at work relating to dangerous substances is generally higher in SMEs than in large ones:

- SMEs account for around 80% of all occupational diseases caused by chemical agents
- Workers in SMEs exposed to chemical agents often suffer diverse health effects

Figure 5.7 Workers in a chemical enterprise

Chemical risks in SMEs (cont.)

Some of the main preventive measures that companies can implement for dealing with chemical risks are as follows:

- Elimination of hazardous substances and processes, or substitution with less hazardous alternatives
- Application of collective protection measures, e.g., engineering controls, adequate ventilation, appropriate organisational measures
- Provision of suitable equipment for work with chemical agents
- Reduction or minimization of number of workers likely to be exposed
- Reduction or minimization of the duration and intensity of exposure
- Application of appropriate hygiene measures
- Reduction in the quantity of chemical agents to the minimum required for the type of work
- Use of suitable work procedures, including safe methods for handling, storing and transporting hazardous chemical agents and wastes

Exposure to ultraviolet radiation

Ultraviolet (UV) radiation (i.e., electromagnetic, non-ionizing radiation of wavelength range 100–400 nm) can be a significant risk in the workplace.

Overexposure to UV radiation can cause:

- damage to the eyes, the skin and the immune system, and
- cancer

Workers who are particularly at risk from artificial UV radiation include those involved in:

- dye and paint drying techniques
- disinfecting applications
- welding processes
- phototherapy

Exposure to noise and hearing impairment

Exposure to excessive noise can cause hearing impairment.

Noise-induced hearing impairment can be caused by:

- a one-time exposure to a noise impulse (more than 140 decibels (dB(C))
- exposure to high intensity (more than 85 decibels (dB(A)) sounds several hours each day over an extended period

The highest levels of work-related hearing impairment are in:

- mining and manufacturing
- construction
- transport and communication

Occupational diseases

Musculoskeletal disorders (MSDs) are the most common work-related disorders.

The mining sector has the highest incidence rate of occupational diseases.

In 2005, the industry sectors with higher-than-average incidence rates of occupational diseases, apart from mining, were manufacturing, agriculture, hunting, forestry and fishing, and other community, social, personal services activities.

In the manufacturing sector, rates and types of occupational diseases tend to be roughly the same for men and women.

Work-related stress

Work-related stress (WRS):

- is experienced when workplace demands exceed the employee's ability to cope with (or control) them
- can cause mental and physical ill health if intense and long lasting

WRS can be caused by:

- Psychosocial hazards, such as work design, organisation and management, high job demands, low job control, and workplace harassment or violence
- Physical hazards, such as noise and temperature

Risk factors for WRS include:

- Work with a very high pace and to tight deadlines
- Work pace dictated by external demand or machine-dictated work pace
- Mismatch between skills and work demands

Section 5 - Quiz

1. Which of the following is true?
   a. ✔ Recent changes in the age breakdown of the workforces of many countries are likely to affect worker safety and health
   b. Recent changes in the age breakdown of the workforces of many countries are not likely to affect worker safety and health

2. Which of the following is correct?
   a. The rate of accidents at work relating to dangerous substances is generally lower in SMEs than in large enterprises
   b. ✔ The rate of accidents at work relating to dangerous substances is generally higher in SMEs than in large enterprises
   c. The rate of accidents at work relating to dangerous substances is roughly the same in SMEs as in large enterprises

Section 6: Case studies

Case study I

Situation: In a hypothetical Canadian manufacturing plant, a large number of engineering activities (design, production of parts, assembly, testing, and quality assurance, etc.) are carried out in a wide range of areas.

Some manufacturing processes are performed using automated equipment and others by people, depending on such factors as cost, time, quality and worker health and safety.

The plant produces and assembles heavy machine parts (e.g., pumps, fans, exterior parts, electronics). The plant normally operates three shifts per day and has production lines including machining equipment, conveyers and overhead cranes, punch presses, and paint-spray booths. The plant utilizes electricity and natural gas extensively.

Case Study I (cont.)

The problems:

Some plant workers have over the last six months been subject to several different health problems

The plant's head engineer receives the following information:

a. In an assembly area that was installed recently, workers have to bend to the ground throughout the day to attach several small parts onto a large and heavy machine component. Some workers have begun to develop lower back pain, likely due to the repetitive bending. The problem has become so severe for one of the workers that he has been told by his doctor to stay off work for two weeks so his back can recover. The manufacturing engineers who designed the assembly operation had wanted to use an automated system, but that option was deemed not to be economic. So they used a manual operation, but did not take into account industrial ergonomics, as they had no expertise in that discipline.

Case Study I (cont.)

b. An increased incidence of respiratory illnesses has been reported over the last month by workers near paint-spray booths. Many of the substances used in the booths (paints, solvents, etc.) are known to be causes of the observed respiratory illnesses. But the workers are not supposed to come into contact with any of the substances because the paint-spray booths are designed to ensure all materials exit the plant through a high-capacity ventilation system and no materials leak back into the plant. No tests had been carried out on the ventilation system, or on the air quality around the paint spray booths, so it is uncertain whether there have been any leaks into the plant from the paint-spray booths.

c. In an area where metal cutting occurs and workers use protective eyewear, workers have reported minor eye injuries. The area is one where it is common knowledge that the workers do not routinely use the protective eyewear. It is often observed to be hanging on nearby hooks or to be loosely hanging around the necks of workers. Workers complain that they find the protective eyewear uncomfortable and do not think it is needed or important. The plant manager knows of this behavior but overlooks it, since enforcing the use of the protective eyewear seems may make the workers unhappy and, consequently, less productive. That, he feels, could render the plant non-competitive.

Case Study I (cont.)

Discussion questions:

Consider the case study in the context of the engineering circle in Figure 1.9, and address the questions that follow.

Be sure to use the engineering circle to help enhance understand the entire spectrum of issues involved in team design.

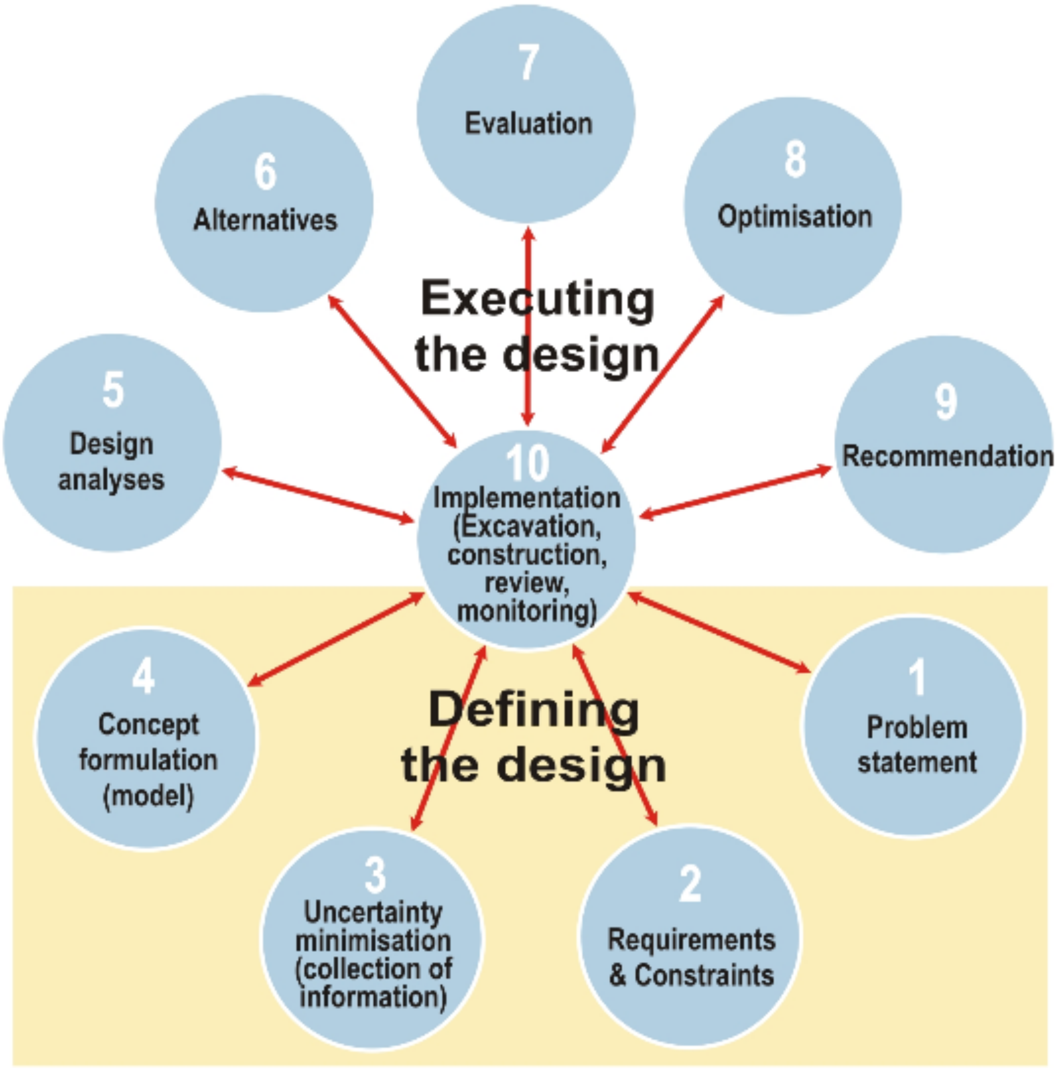

Figure 1.9 Engineering circle (repeated)

Case Study I (cont.)

Discussion questions:

a. How would you identify the causes of the health problems?

b. From a requirements and constraints perspectives, what requirements do you think the plant as a team should put forward to achieve safety in the areas mentioned, and what are the current constraints that exist inside the plant?

c. Try to convert the above problem into an explicit mathematical model, i.e., setup the objective function (to represent the health issue), the design variables (to represent the factors that cause the illnesses) and your own constraints.

d. Which of the unsafe conditions and acts identified in part b are (1) of a technical nature, or (2) related to human behavior or management?

Case Study I (cont.)

Discussion questions:

e. What are some steps that can be taken to rectify the health problems observed?

f. Should the head engineer endeavour to rectify the health problems on her own, or should she report the problems to the plant manager beforehand? The head engineer is not sure if she will receive the support of the plant manager in rectifying the problems; what should she do if support is not provided?

g. Do you feel that some of the health problems that have occurred are due to worker health and safety being unduly compromised to allow the plant to be more productive or profitable?

Case Study II

Consider again the hypothetical plant described in Case Study I.

The head engineer at the plant wants to ensure that the plant provides a safe and healthy environment, so she decides to ask an engineering health and safety consulting company to do a health and safety audit of the plant.

The report provided by the consulting company lists the following safety problems:

Case Study II (cont.)

a. An expert on fires and explosions notes that the extensive use of natural gas in the plant could lead to an explosion in the plant in some circumstances. The force of such an explosion could lead to severe injuries or deaths of workers and, possibly, cause the building to be damaged or to collapse. The potential for an explosion could develop if a sufficient natural gas leak occurs or the plant ventilation system fails to perform properly or certain controls or sensors fail. But, the expert further notes, there is insufficient information available on the concentration of natural gas in the plant air, as only one natural gas sensor is in place at the plant, but it is not located in the main area where an accumulation of natural gas is likely to occur. Thus, the potential for an explosion could exist, yet not be detected or acted upon. In addition, the expert is concerned because the natural gas sensor is connected neither to an automated shut-off system for the natural gas supply nor to an alarm, thus increasing the likelihood of an incident and its potential severity.

Case Study II (cont.)

b. Although maintenance is supposed to be done quarterly on the natural gas lines and equipment, no evidence is found that maintenance has ever been performed since they were first installed four years ago. Such maintenance typically involves checking for and fixing gas leaks. Also, no training has been provided to workers on either understanding the potential for explosion, or the steps to take to avoid an explosion. In fact, most workers did not even realize the potential for an explosion existed. Furthermore, no written procedures relating explosions exist within the plant.

c. The plant contains toxic materials that can harm people and animals. The way this material is stored in the plant, it could, in the event of a plant explosion, be released and impact an area within one kilometer of the plant. Such an incident could lead to illnesses or deaths among members of the public and could harm animals in the environment.

Case Study II (cont.)

Discussion questions:

Again, address the questions considering the engineering circle in Figure 1.9, to help enhance understanding of the issues involved in team design.

a. What are the unsafe conditions and acts in the plant?
b. What requirements/constraints does the plant need to propose and implement inside the plant in order to achieve a safe working condition?
c. What uncertainty factors inside the plant do you think that can cause the natural gas leak?
d. Similarly with the case study I, try to convert the above problem into an explicit mathematical model (i.e. setup the objective function (to represent the plant safety issue), the design variables (to represent the potential factors that cause safety problems) and your own constraints.

Case Study II (cont.)

e. From point c) in the consulting company report, it is clear that the problem affects not just worker safety, but also the safety of the public and the environment. Should the difference in who or what is affected cause head engineer to modify her actions in addressing the problem? If so, how?

f. Can the head engineer choose to ignore or not act fully upon the safety concerns raised by the consulting company? If yes, in what instances and under what conditions?

g. If the head engineer at the plant decides that measures must be taken to protect health and safety, but the plant manager refuses to approve the measures, what are the obligations of the head engineer?

h. Do any of the problems cited demonstrate that it is best to address health and safety comprehensively in the early stages of an engineering activity, preferably within the design process and not as an afterthought? For instance, can you indicate some measures that will likely be more expensive to implement or fix the problem compared to the cost that would have been incurred during the design process to resolve the problem then?

Section 7: Student assignment

Students are to carry out a group project to design a mobile robot that runs in a maze. The robot needs to locate a water bottle (placed anywhere inside the maze), pick it up, and carry it back to the starting point.

In this project, students work as a team. When designing a complex device or system, many engineers (in this case engineering students) from different areas come together in the design process.

The students need to cooperate, consider each others' requirements and, where necessary, compromise.

Safety is to be considered when designing and constructing the robot since it contains electronics and mechanical parts, which can introduce hazards.

The students should refer to the teaching module slides when carrying out the project as a team.

Requirements and constraints:

- The water bottle cannot touch the ground (except after the robot carries it back to the starting point) once it has been picked up.
- The robot cannot cross the boundary of the maze.
- Students cannot touch or intervene with the robot once the robot starts operating.
- When the robot carries the bottle back to the starting point and puts it on the ground, the bottle cannot fall down. It also has to be smoothly and steadily placed on the ground.

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Thank you!

Questions?