LECTURE NOTES IN SAFETY SCIENCE

Introduction to Risk Identification

Qualitative Approach to Safety

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Improvements

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Rationale

❖ HAZARDS

As a quick reminder, the concept of risk is based on (1) objectives that are specified and (2) actions that are planned and then (3) executed. Any deviation from the execution of the action plan is defined as an **effect**. The **qualitative approach** considers that all effects have a **cause** and that the **cause-effect relationship** is deterministic. For this reason, it is also called the **deterministic approach**. Figure 1 symbolizes these terms and their relationships.

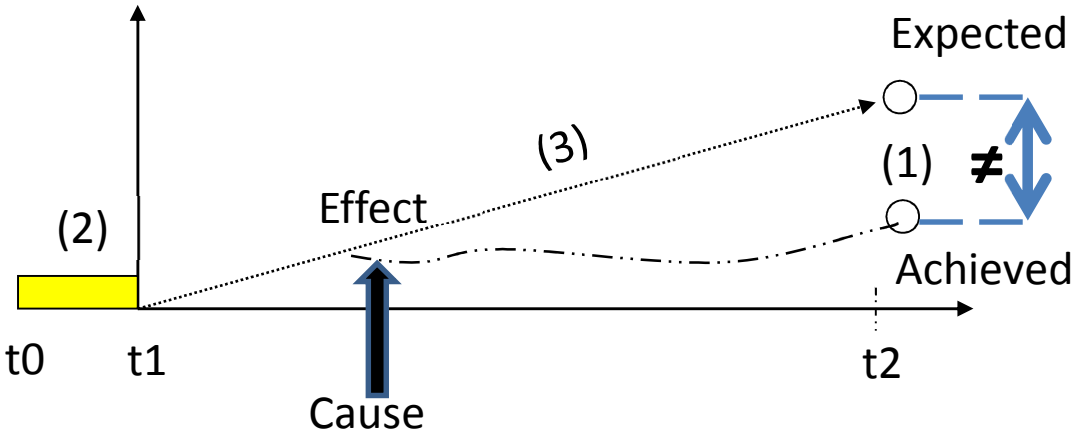

Figure 1. Qualitative approach on risk

As far as safety is concerned, that is, when the objective is the preservation of health, people appraise causes hindering the achievement of this objective as negative; the generic term **hazardous circumstances** is used to refer to these causes. Effects are called **accidents** and consequences on health, **injuries** (including death as fatal injury). Consequences on the environment are called **harms**. Figure 2 summarizes the terminology of risk applied to the safety domain.

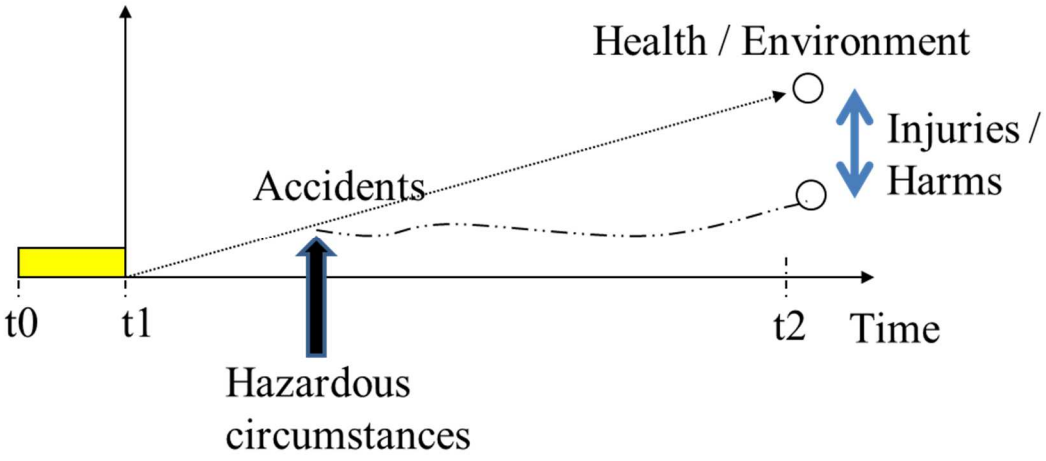

Figure 2. Hazards, accidents, injuries and harms

Many types of hazardous circumstances exist. Initially, hazards were associated with energies: a storm materializes kinetic energy; a fall is due to potential energy; an earthquake reveals mechanical energy; a fire releases thermal energy. Thereafter, other phenomena were considered, including the toxicity of chemical products and the failure of operating systems. The features characterizing hazardous circumstances will be introduced later on.

❖ RISK IDENTIFICATION

To be treated, that is, avoided or controlled to prevent accidents, existing hazardous circumstances and their consequences have to be known. The **risk identification** step aims at being familiar with the potential risks. The ISO 31000 defines Identification as:

> **Identification is the process of finding, recognizing and describing risks.**

To successfully complete this step, two tools are necessary:

- A **model** to describe the identified risks, and
- A **method** for finding and recognizing the existing risks.

Even with the qualitative approach, multiple models and various methods exist for identifying risks. This lesson introduces a first model. Over the next two lessons, several methods (and their respective models) will be introduced.

❖ A FUNDAMENTAL AND DIFFICULT STEP

Before introducing the first model, let me insist on the importance of the identification step and highlight some challenges.

First of all, **only identified risks will be handled**. To quote Leonardo Da Vinci: “Not to anticipate is already to moan”. That is, the unidentified risks will lead to accidents. In my opinion, risk identification is the most important step of the risk management process. So engineers and managers must take the time to provide a full list of potential risks.

Second, the **choice of the identification model is fundamental**. Indeed, the identification model provides the perspective on risk. Consequently, only the risks which can be expressed by the model will be identified. For instance, if your model considers that an accident is represented by the combination of events occurring at a given time, the accidents due to a sequence of events will not be identified.

Finally, the **choice of the identification method is fundamental**. Again, the list of identified risks may depend on the method used. For example, consider that, for a given situation, the existing risks are established using a list a predefined hazards. For instance, this list specifies that the presence of electrical power may lead to electrocution. When new technology is used, its risks are not integrated into this list; therefore, they will not be recognized.

The first identification model

Before introducing the first identification model, a word of warning: this model has many features. This is owing to the complexity of the concept of risk or, at least, to the complexity of the considered approach on what risk means. Simpler models exist. Some of them will be introduced later on. However, they will not be able to reflect the complexity of certain risks. Equally, it is not because this model is more complex that it can describe all risks. As other (complex or simple) models, the model introduced in this chapter considers a particular look at the concept or risk.

When reading this chapter, don't be put off by the complexity of the model; we will be using examples several times to help you understand it. You may well have to re-read this chapter several times to understand the relatively complex relationships between the numerous features of the model.

Finally, once you have mastered this first model, bear in mind that it will not necessarily be applicable to any given situation. The particular situation you are analysing may require a different model. Therefore, a critical approach will present the limits of the model. The limits of any given model are not drawbacks but simply define its scope of applicability.

❖ OBJECTIVE

As previously mentioned and represented in Figure 1, the qualitative perspective defines a risk as a cause and effect relationship. The effects affect the achievement of specified objectives. The first proposed model consists of two parts: the representation of the effects and the representation of the causes called **origins of the risk**.

To introduce the model, let us consider the following sentence: "When using my car to reach my office, I take a risk". Risk is defined in terms of the objective to be achieved.

Generally, multiple **objectives** are associated with one action plan ("When using my car"). Some of them are explicit, e.g. "to reach my office". Others are implicit such as

- to reach the office before 9am,
- to preserve my health,
- to be informed of the latest news.

The specification of the considered objectives is fundamental because each objective will lead to the identification of various risks.

❖ EFFECT

"When using my car to reach my office, I run the risk of being injured in an accident". Expanding the initial sentence, we introduce two additional pieces of information:

- "being injured" means that the considered objective is the preservation of my health; it also points out the type of **consequence** hindering the objective: an injury;
- "in an accident" specifies that an **event** must occur leading to the consequences.

Figure 3 symbolizes these 2 terms and their links with the objectives and the action plan.

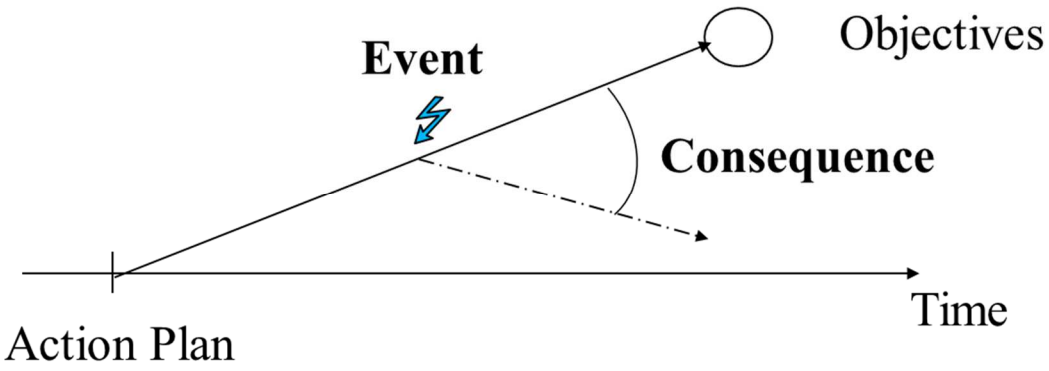

Figure 3. Event and consequence

The following table provides three examples of events and associated consequences on the achievement of three expected objectives.

Event	Consequence	Objective
Accident	Injuries	Health preservation
Traffic jam	Delay	Before 9am
Radio Failure	Not informed	Being informed

The terminology we used was neutral: we talked about events and their consequences. However, particularly in the field of safety, we want to highlight the negative impact of these features on objectives. This is done using qualifying adjectives as **harmful events** and negative terms such as **harms** to refer to the consequences.

Positive events may also occur. They make the achievement of objectives easier. These events are qualified as **beneficial events** and their consequences as **benefits**.

❖ ACTOR AND TARGET

If someone climbs the Himalayas, we consider the activity as risky. This person could get killed. However, we accept such activity. On the other hand, we don't accept the building of a nursery school close to a chemical plant. The difference between these two value judgements comes from a distinction in where the responsibility lies: the **actor**, also called **risk owner**, bearing the responsibility of the risk and the **target** suffers the consequences. In the first situation, the actor and the target are one and the same person: the climber is also affected by the possible consequences. In the second case, the actor is the plant whereas the targets are the children. They are different entities. This second situation also highlights that actors and targets are not necessarily people. They can be technological systems (i.e. a plant) or organizations, etc.

In the previous example of using a car, the three risks considered were caused by the driver, other road users or the radio. They affect the driver (injuries, delays, uninformed). If our objective is to preserve the health of other citizens, the actor is the driver and the targets are other road users (other drivers, bikers, pedestrians…).

❖ ORIGIN

The origin of risk defines the causes leading to effects (i.e. events and consequences).

In the field of safety, origins are called **hazards**. This general term must also be specified, defining several features.

To introduce a model of the origins of risk and hazards, let us consider a new example: during the weekend, family members are walking along a cliff. "Persons walking" is not a hazardous circumstance; a cliff is not dangerous as long as nobody gets close to the edge. On the other hand, the coupling of these two statements, that is, family members are walking *along* the cliff, may lead to accidents. Therefore, we will

distinguish the **source of the risk**, e.g. associated with the cliff, and the **cause of the risk**, i.e. the family members walking. The joint occurrence of a source and a cause may lead to effects. And constitute the origin of the risk.

Origin of risk = Source + Cause.

The source concerns the actor where as the cause concerns the target.

❖ SOURCE

The ISO 31000 provides the following definition of the source:

The source of risk is an element which alone or in combination has the intrinsic potential to give rise to risk.

The cliff actually has the intrinsic potential to give rise to risk that is to lead to accidents.

A Source is not only an Actor ("an element" in the ISO definition). It also has an "intrinsic potential" to give rise to risk.

For instance, a chemical product such as chlorine is an actor having the intrinsic potential to affect people's health. A flight is also an actor which has the intrinsic potential to kill passengers. When sources negatively affect the achievement of objectives, they are called **hazards**. For instance ISO/IEC Guide 51 (2014) defines:

A hazard is the potential source of harms.

However, some actors also have the intrinsic potential to contribute to the achievement of objectives. This qualifies as **opportunities**.

An opportunity is the potential source of benefits.

Frequently an actor has the intrinsic potential for both. For instance, a vaccine may injure or kill some people; thus it can be considered as a hazard; it also preserves the health of many others; so it is an opportunity. However, safety managers often only take the negative approach into consideration.

The following table summarizes the vocabulary.

Perspective		Vocabulary		
	Neutral	Source	Event	Consequence
	Negative	Hazard	Harmful event	Harm
	Positive	Opportunity	Beneficial event	Benefit

❖ HAZARDOUS PHENOMENON AND PROPERTY

Recalling the definition of a source of risk: it is an element which alone or in combination has the intrinsic potential to give rise to risk.

The "element" is defined as the actor. The definition also specifies that a source has "intrinsic potential to give rise to risk", that is, possess an inherent characteristic ("intrinsic") which may lead to consequences ("potential to give rise to risk"). To identify the risks, these characteristics must be expressed using features of the identification model. So we have to characterize the sources of risk.

To introduce these features, consider the following circumstances: to save space in my garage, I make the decision to suspend boxes from the ceiling. The actor is the box because the actor was defined as an element supporting the source of risk. Why are these circumstances risky? If the box is put on the floor, we do not consider that risk exists. The risk comes from the **hazardous property** of the box, defined as follows:

A hazardous property is the property of an actor to whom one or several hazardous phenomena are assigned.

The box has a hazardous property because it "is suspended". This property assigns potential energy to the box. Potential energy is a **hazardous phenomenon**. More generally, we define it thus:

A hazardous phenomenon is a phenomenon which affects targets [provoking harms].

The following table provides several examples of actors, hazardous properties and hazardous phenomena.

Actor	Hazardous property	Hazardous phenomenon
Box	Is suspended	Potential energy
Snow	Is on the top of the mountain	Potential energy
Aircraft	Is flying	Potential + kinetic energy
Robot	Is moving	Kinetic energy
Cash dispenser	Is out of order	Failure
User	Is scatter-brained	Human error

From this table, several comments can be made:

- One actor's hazardous property may give rise to several phenomena. For instance, when an aircraft is flying (hazardous property), it possesses potential energy which may lead to a crash and kinetic energy which may lead to a collision.
- Hazardous phenomena include, but are not limited to, energies. For instance, any system may fail. So failure is a phenomenon affecting any operating system. By the same token, any human may make a mistake. So "human error" is a generic phenomenon that can affect any single person.

The reader may think about the distinction between hazardous property and hazardous phenomenon. Hazardous properties define the specific properties of actors, whereas hazardous phenomena are generic. So generic studies can be conducted on hazardous phenomena; then they can be applied to specific hazardous properties of given actors. For instance, knowledge can be obtained studying the impact of kinetic energy on the human body. That knowledge can then be re-used for any actors possessing this hazardous phenomenon, such as a car driver, a military pilot, an astronaut, etc.

Numerous hazardous phenomena exist including:

- Mechanical energy, that is, kinetic and potential energies,
- Chemical energy,
- Thermal energy,
- Electrical energy,
- Toxicity of products,
- System failure,
- Human error.

Generally, in the field of safety, people qualify properties and phenomena as hazardous. However, in reality, situations are more complex as they have negative but

also positive effects. People often take risks because they are hoping for benefits. Most people cry foul when this assertion is mentioned. For instance, how dare one compare effects on safety with effects on profits? This perspective is too simplistic. Taking risks could also improve safety. Let's consider the following example: when using a bicycle, we expect to save time compared to walking. The higher speed reduces the length of the journey. Of course, kinetic energy is a hazardous phenomenon: a cyclist may be severely injured or killed if an accident occurs. On the other hand, if the speed of the bicycle is too low, it is hard to control. The cyclist falls down and is injured. So, the speed of the bicycle confers kinetic energy which improves safety. Specifically, when the bicycle speed increases, the rotation speed of the wheels increases. This improves the bike's stability, thereby reducing the risk of falling and increasing the cyclist's safety.

❖ CAUSE

In the previous paragraphs, a model of the sources of risk was proposed based on three features: actor, hazardous property, and hazardous phenomenon. However, the source is passive. For instance, nobody was injured by the box suspended in my garage. Something must happen to cause harm, such as the wire breaking. This event is called a **hazardous event**.

A hazardous event is an event which triggers an actor's hazardous property.

It is also called **initial event** or **dreaded event**.

In the case of a flying aircraft, losing control is an example of a hazardous event as it could lead to a crash.

The occurrence of the hazardous event does not necessarily have consequences. Going back to the example of the box suspended in the garage, the wire breaking has no consequences if nobody is in the garage. On the other hand, if a person spends time in the garage, he/she may be injured. So the target must meet with the source, that is, a **hazardous situation** must exist to trigger effects.

A hazardous situation is a situation in which a target is exposed to one or several phenomena.

This definition states that a target is exposed to a phenomenon, not to a property. In the previous example, the person in the garage is not exposed to the box itself but to its mass. This mass is an attribute of the potential energy. Whatever the mass,

Potential Energy = Mass x Height.

Consider a robot moving in a workshop. The robot is the actor; "is moving" is its hazardous property; the kinetic energy is the hazardous phenomenon. If an operator enters the robot's work space, a hazardous situation is created. The loss of control by the robot is a hazardous event.

We can also consider that the actor is the operator; if he/she is untrained, this is a hazardous property; the hazardous phenomenon is human error; access to the robot's work place is a hazardous situation and may lead to an accident. This example shows that multiple sources of risks may lead to the same consequence.

❖ OVERALL MODEL

Figure 4 summarizes the various features of the first identification model introduced in this chapter.

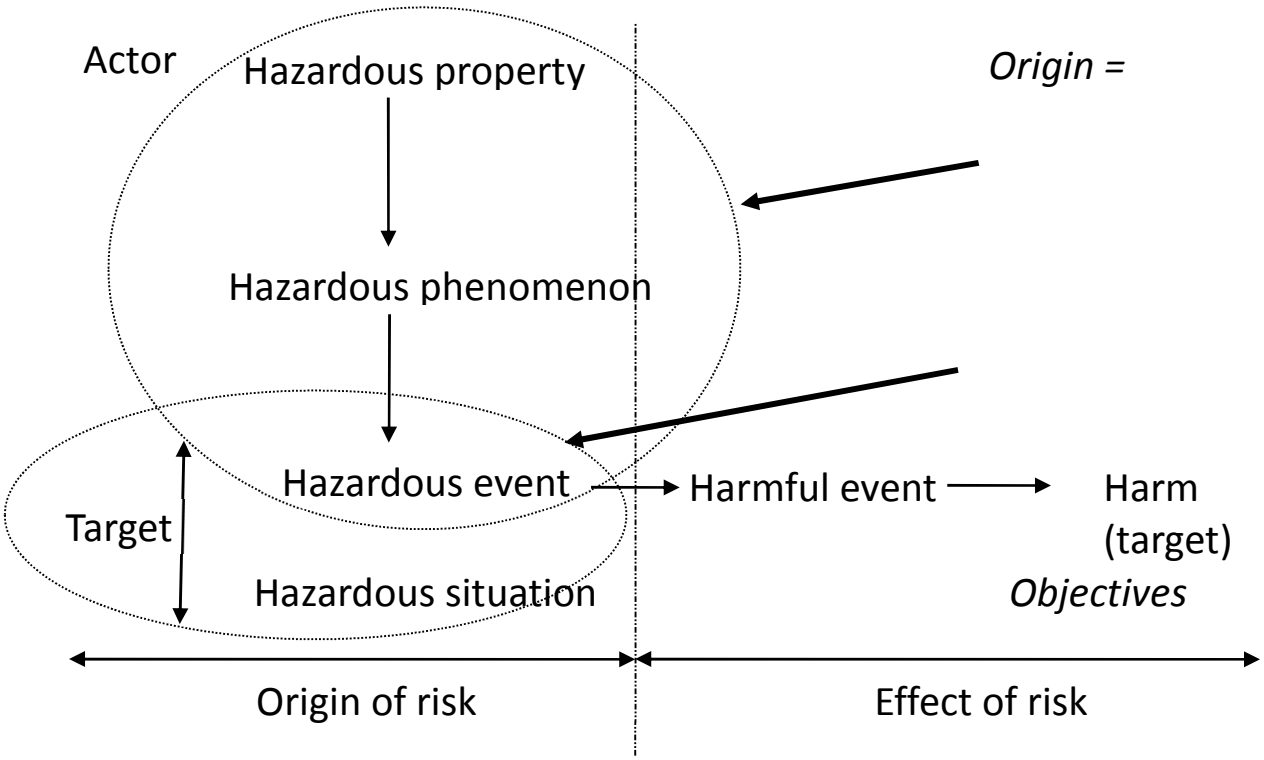

Figure 4. The first identification model

The risk identification step leads to a description of many risks using the same identification model. Identifying a risk consists in defining the values of the features of the said model. For instance, when using the above model, we have to specify the hazardous properties, the associated hazardous phenomena, the hazardous events, the hazardous situations, the harmful events and the harms.

It is important to stress that the definition of the objective and the specification of the targets are fundamental prerequisites to the identification process. The example developed in the following chapter will illustrate just how important. Frequently, people disagree on what constitutes a risk because they have different objectives and therefore identify different risks.

The following table gives an example of the form to be filled in.

Risk #	
Objective	
Target	
Actor	
Hazardous property	
Hazardous phenomenon	
Hazardous event	
Hazardous situation	
Harmful event	
Harm	

Example

❖ CONTEXT

A house was built in a residential neighbourhood that also had a small number of SME's. The landlord chose LPG (Liquefied Petroleum Gas) as a means for heating and cooking. A gas tank was installed in the garden by a gas company which rented the tank and also supplied the gas. The landlord rented the house out to a family.

Our goal is to identify all the risks involved. Considering this simple example, most people would say that one risk exists: the tenants could get burned if the gas tank explodes. In reality, we shall see that the risk identification process will lead to a relatively extensive list.

❖ OBJECTIVES AND TARGETS

The main reason for obtaining too short a list of risks is the lack of thought given to the objectives and targets. This deals a fatal blow to efficient risk management. We therefore suggest defining the objectives and the affected targets first, then revisiting these results.

What are the objectives for putting in a gas tank or for living with a gas tank as a source of supply?

Tenants' objectives

Let us consider the tenants as stakeholders.

Their first objective is to survive then to preserve their health. Survival is the first objective of most organizations (individuals, companies, employees, etc.). Unfortunately, the tenants could potentially get hurt or killed by an explosion. To avoid this, an obvious choice would be electricity. However, they chose this house because

LPG is cheaper. So another objective emerges: saving money. However LPG prices may rise unexpectedly.

We must not lose sight of the fact that the fundamental objectives are heating and cooking, and be aware of events that may disrupt achieving these objectives.

It becomes apparent that the tenants have multiple objectives, each with their respective risks.

Landlord's objectives

The house landlord's primary objective is to preserve his/her asset, i.e. the integrity of the house. However, if the gas tank were to explode the house could be partially or completely destroyed.

Furthermore, the landlord rents out his/her house to gain income. This is another objective. If the house is damaged, no more income will be gained. This could have severe consequences on repaying a loan, for example. In such a case, an additional objective for the landlord is to pay off his/her loan.

Neighbourhood objectives

An explosion may also affect the residents and landlords in the vicinity (their health and their assets). We also mentioned some SME's. An accident could potentially halt their activity and thus their income. They could lose clients or their clients could ask for compensation. Here again, multiple objectives emerge.

Supplier objectives

Let's consider another stakeholder: the gas company. An accident would have a hugely negative impact on the company's image and their business. Indeed, preserving their brand image is an important objective for the companies.

Objectives constitute the first feature

The first step of risk identification consists in listing the objectives and targets. Our simple example has shown the complexity involved in situations with diverse objectives and targets. This brief analysis has provided an initial and certainly incomplete set of values for these first two features.

❖ EXAMPLES OF RISK IDENTIFICATION

Let's consider the following objective: the tenants' health. The three following tables describe some associated risks.

Risk #	1
Objective	Preservation of tenants' health
Target	Tenants
Actor	LPG
Hazardous property	LPG is a toxic gas
Hazardous phenomenon	Toxicity
Hazardous event	Gas diffusion
Hazardous situation	Tenants' proximity to the tank
Harmful event	Inhalation
Harm	Intoxication

Scope. The aim of risk identification is not to explain the causes (such as the reasons of the gas diffusion) but simply to lay out the overall circumstances of the risk. Causes will be dealt with the Risk Analysis step. For instance, identification will reveal the presence of a risk, in this case, gas diffusion; Analysis will reveal its causes (a leak, a valve failure, etc.).

Subjectivity. Identification is a completely subjective process depending on the person's point of view. For instance, one could consider that intoxication is due to the gas toxicity. Whereas others could consider that intoxication is due to tank failure.

Relativity. Identification depends on the model. As a result, the list of identified risks may differ from one model to another. Examples will be provided in Chapter 7.

Risk #	2
Objective	Tenants' health
Target	Tenants
Actor	LPG
Hazardous property	LPG is inflammable
Hazardous phenomenon	Thermal energy
Hazardous event	Fire
Hazardous situation	Tenants' proximity to the tank
Harmful event	Burns (thermal shock)
Harm	Injuries

Risk #	3
Objective	Tenants' health
Target	Tenants
Actor	LPG
Hazardous property	LPG is under pressure
Hazardous phenomenon	Mechanical energy
Hazardous event	Explosion
Hazardous situation	Tenants' proximity to the tank
Harmful event	Shock wave
Harm	Injuries

Risks 4 to 6 consider other targets and objectives.

Risk #	4
Objective	Landlord asset preservation
Target	Landlord
Actor	LPG in the tank
Hazardous property	LPG is under pressure
Hazardous phenomenon	Mechanical energy
Hazardous event	Explosion
Hazardous situation	House close to the gas tank
Harmful event	Destruction of the house
Harm	Loss of money

Risk #	5
Objective	Cooking & heating
Target	Tenants
Actor	Gas tank
Hazardous property	Mechanical device affected by ageing
Hazardous phenomenon	Failure
Hazardous event	Leak
Hazardous situation	Using gas for cooking and heating
Harmful event	No more gas
Harm	No cooking and no heating

Risk #	6
Objective	Maintain activity
Target	Neighbouring SME
Actor	LPG
Hazardous property	LPG is inflammable
Hazardous phenomenon	Mechanical energy
Hazardous event	Explosion
Hazardous situation	SME building close to the gas tank
Harmful event	Building unusable
Harm	No more activity

Of course, this is not a full list of the risks. I have just provided some examples to show their diversity. All the stakeholders, all the origins, and all the effects have not been identified. So, even though our example is very simple, it presents more than 50 different risks.

An identification step must be preceded by the **definition of the context**. For instance, the previously identified risks do not take into consideration the various consequences of an accident on the gas company which rents the tank and supplies the gas. Do we include this company in our study? This must be specified when defining the scope of Risk Management.

Risk analysis

❖ GOAL

ISO 31000 defines **Risk analysis** as

> **Risk analysis is a process to comprehend the nature of risk and to determine the level of risk.**

Risk identification provides an initial overview of risks. Risk analysis provides more detail in particular by examining the causes of hazardous events; for instance, the reasons for gas diffusion or explosion.

The second objective of the risk analysis step is to determine the level of risk. However, the qualitative approach does not aim to assess the risks. We will just examine if the risk being considered is real, that is if it really affects objectives. In particular, we will detect the presence of risk controls which neutralise the potential effects.

❖ RISK ANALYSIS CONTRIBUTION TO THE QUALITATIVE APPROACH

In the context of a qualitative approach, the contribution of risk analysis is in fact quite limited. Risk identification partially incorporates both objectives of the risk analysis process: 1) comprehension of the nature of risk and 2) risk level determination.

Firstly, the comprehension of the nature of risk depends on the risk identification model used. The model introduced in Chapter 2 is relatively detailed and usually sufficient to fully grasp the nature of risk. During the following lessons, various identification models with differing levels of detail will be presented. Sometimes,

rough identification models have to be extended in order to obtain a clearer comprehension of risks.

Secondly, Risk identification implicitly incorporates an assessment of risks. Indeed, in practice, only the risks implicitly considered as "significant" are identified. It does not mean that no more risks exist but that they are considered as irrelevant (out of the scope of our study) or insignificant (that is their consequences are negligible and do not need to be considered). So risk analysis is often implicitly integrated within the risk identification activities.

However, Risk analysis also integrates a specific and fundamental activity for Safety Management: the mapping of existing **barriers** that prevent accidents. Where barriers exist, the identified risk will then be removed from the list of risks to address.

In the Risk Management domain these barriers are called **Risk controls** and are defined in the standard ISO 31000 as:

Risk control is a measure that is modifying risk.

Frequently in Safety Management, "modifying risk" is interpreted as reducing risk. Let's consider the simple example of the gas tank and the risk of explosion due to overpressure. If the tank is equipped with a pressure valve, this risk can be eliminated. In the same way, a house equipped with an ultra-sensitive circuit breaker can prevent electrocution.

Sometimes risk modification can be more complex leading to the notion of risk optimisation which will be covered later.

Risk evaluation

❖ GOAL

Risk identification aims to provide an exhaustive list of potential risks. Risk analysis leads to the selection of a subset of the actual risks (those whose significance is non negligible), taking existing risk controls into account.

Formally, ISO 31000 defines **Risk evaluation** as

> **Risk evaluation is a process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable.**

Risk analysis provides a subset of risks leading to consequences. These risks should be treated. However, when making the decision, some **risk criteria** may intervene that would exclude some risks from being treated. For instance, if the cost for treating a risk is exorbitant, this risk will not be treated. We will cover risk criteria, their principles and several examples, when we study the quantitative approach as most of these criteria take data into account.

So, at this stage, we will consider that all risks resulting from the risk analysis step will be treated. Thus, when the qualitative approach is considered, there's no need to dwell on it because the evaluation step has a limited impact.

6

Treatment and control

❖ GOAL

ISO 31000 defines **Risk treatment** as:

> **Risk treatment is a process to modify risk.**

❖ TYPES OF TREATMENT

The two definitions of safety considered by the qualitative approach, lead to two ways of treating risks.

First, "**Safety is the absence of hazards**". The risk treatment consists in eliminating the identified hazards which have consequences. These hazards are the outcomes of the risk analysis step. For instance, regulations can ban cars from city centres or certain chemical products from domestic use; hazardous properties are avoided. Pedestrians cannot access motorways; hazardous situations are prevented. Figure 5 shows these two risks treatments.

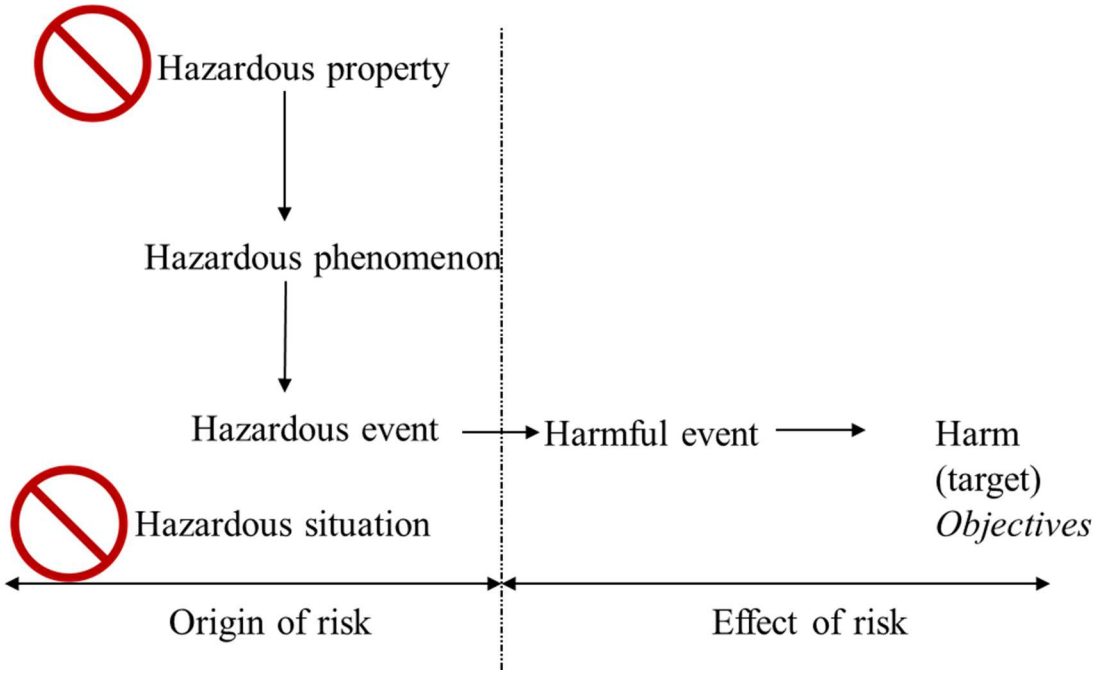

Figure 5. Hazardous properties or hazardous situations are avoided

Note that, strong hazard reduction is often assimilated with absence of hazard. For instance, pedestrians are not forbidden in pedestrian areas even if collisions may occur. Indeed, we consider that these collisions will not lead to consequences impacting people's health. They are excluded during the risk analysis step.

Second, "**Safety is the absence of accidents**". Here the treatment of risks aims to cut off the causal relationship from hazard to harms. Barriers are implemented as "risk controls" on various links of the causal chain:

1. **Preventing hazardous phenomena from leading to hazardous events**. For instance, when designing a building, safety margins are used to avoid rupturing the girders. Let's go back to our example of the box suspended by a wire from the garage ceiling: the use of a wire supporting 100Kg when the box weight is 10Kg illustrates just such a risk control.
2. **Preventing a hazardous situation from leading to a harmful event**. Let's consider the example of the factory robot again. If the power to the robot is cut and its motion stopped when an operator accesses to the room, then no accident will occur: the hazardous situation will not lead to a collision between the operator and the robot.
3. **Preventing a harmful event from leading to harm**. If the robot is equipped with contact sensors, its trajectory will be stopped by using a breaking system. In case of contact (that is a harmful event), no harm actually occurs.

Figure 6 symbolizes the three previous treatments.

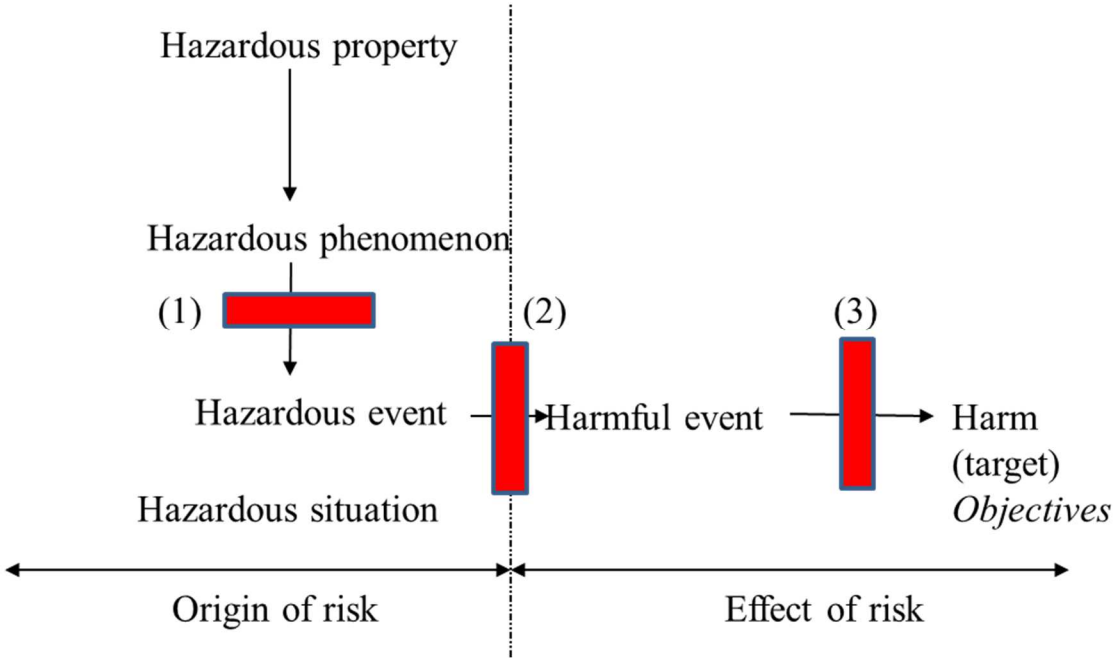

Figure 6. Cutting off the causal relationships

❖ VARIOUS TYPES OF CONTROL

Risk controls are measures that implement **risk treatments**. Understanding the distinction between these two concepts is essential. Risk treatment specifies a principle for handling risk; whereas risk control is the actual means for implementing this principle. For instance, "avoiding a hazardous situation" is a risk treatment; a "locked entrance" is a risk control. Therefore, several risk controls can be suggested for implementing one risk treatment.

Risk controls include but are not limited to

- Devices such as a safety valve, an emergency shut-down system, a panic bar, or
- Practices such as the distance between a hazardous device and people; for instance, the regulation may stipulate a minimum distance between a bike and a car when the car overtakes the bike.

❖ EXAMPLES

Here are some risk treatment suggestions and risk controls for the previously identified and analysed risks. Let's recall the first risk previously identified.

Risk #	1
Objective	Preservation of tenants' health
Target	Tenants
Actor	LPG
Hazardous property	LPG is a toxic gas
Hazardous phenomenon	Toxicity
Hazardous event	Gas diffusion
Hazardous situation	Tenants' proximity to the tank
Harmful event	Inhalation
Harm	Intoxication

With hazard elimination approach

The first possibility is to use electrical power instead of gas for heating and cooking. No hazard, no risk. Intoxication is prevented. So conditions seem safe. Unfortunately, the question can be more complex because the new action plan (use of electricity) introduces new risks such as electrocution.

A significant distance between the tank and the dwelling place will cause the gas to be dispersed, avoiding intoxication. This risk control avoids the hazardous situation. Avoiding a hazardous situation is one of the risk treatments previously mentioned.

With accident prevention approach

Other risk treatments and controls can be suggested to prevent accidents, thereby preserving LGP:

- A double-hulled tank and periodic maintenance may avoid the gas diffusion that is the occurrence of the hazardous event.
- A sensor triggering an alarm prevents the intoxication from occurring. Tenants will be alerted and move away.
- An offensive odour does not prevent inhalation but will avoid injury that is harm, as people will evacuate the house.

Now let us consider risk number 2:

Risk #	2
Objective	Tenants' health
Target	Tenants
Actor	LPG
Hazardous property	LPG is inflammable
Hazardous phenomenon	Thermal energy
Hazardous event	Fire
Hazardous situation	Tenants' proximity to the tank
Harmful event	Burns (thermal shock)
Harm	Injuries

A significant distance between the tank and the house will avoid the fire spreading from the tank to the house and the tenants. This risk control concerns the hazardous situation. The availability of a fire extinguisher, will limit propagation and consequences.

Taking the various types of treatment previously introduced, please suggest other risk controls.

Reconsider risk number 3:

Risk #	3
Objective	Tenants' health
Target	Tenants
Actor	LPG
Hazardous property	LPG is under pressure
Hazardous phenomenon	Mechanical energy
Hazardous event	Explosion
Hazardous situation	Tenants' proximity to the tank
Harmful event	Shock wave
Harm	Injuries

If the tank is put underground the explosion will have no effect.

Please suggest other risk controls and specify associated types of treatment.

Please suggest risk controls for other risks (from 4 to 6) and specify the associated types of treatment. Check that all types were considered.

Risk #	4
Objective	Landlord asset preservation
Target	Landlord
Actor	LPG in the tank
Hazardous property	LPG is under pressure
Hazardous phenomenon	Mechanical energy
Hazardous event	Explosion
Hazardous situation	House close to the gas tank
Harmful event	Destruction of the house
Harm	Loss of money

Risk #	5
Objective	Cooking & heating
Target	Tenants
Actor	Gas tank
Hazardous property	Mechanical device affected by ageing
Hazardous phenomenon	Failure
Hazardous event	Leak
Hazardous situation	Using gas for cooking and heating
Harmful event	No more gas
Harm	No cooking and no heating

Risk #	6
Objective	Maintain activity
Target	Neighbouring SME
Actor	LPG
Hazardous property	LPG is inflammable
Hazardous phenomenon	Mechanical energy
Hazardous event	Explosion
Hazardous situation	SME building close to the gas tank
Harmful event	Building unusable
Harm	No more activity

❖ EFFECTIVENESS REQUIREMENT

The qualitative approach to safety requires the absence of accidents if hazards are maintained. This means that risk control effectiveness must be continuously ensured. For instance, the valve preventing an explosion due to an overpressure in the tank must never be blocked.

To guarantee this characteristic, risk controls are frequently oversized using **safety margins**.

If risk controls fail, they cannot be considered for suitable treating risks.

❖ EFFICIENCY REQUIREMENT

Financial constraints often exist. They have a significant impact when risk controls are designed. Risk controls must be efficient, that is their costs must be **reasonable**. This notion is, of course, relative and subjective. It will be covered when we deal with the quantitative approach.

❖ RISKS OF RISK CONTROLS

Let us go back to the gas tank example. The first suggestion for avoiding risk was to exclude the hazard, replacing gas with electrical power. Of course, no explosion and no intoxication will occur. But tenants could be electrocuted. This illustrates the fact that risk controls avoid risks but may introduce new ones.

Consequently, risk identification, analysis, evaluation and treatment are four steps constituting a continuous flow (see figure 7). Therefore risk management is an iterative activity executing this loop several times.

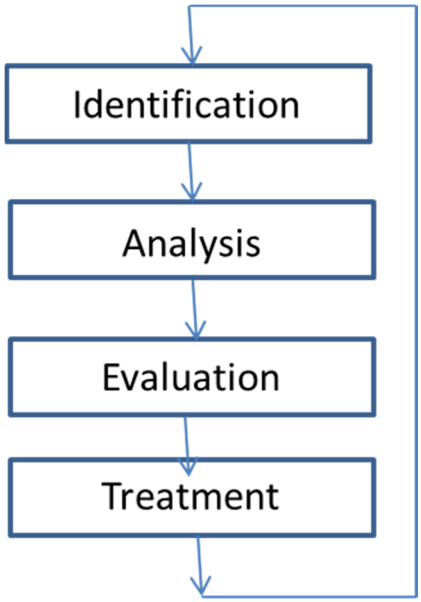

Figure 7. An iterative process

Models & Methods

❖ MULTIPLE MODELS

Whilst Chapter 2 introduced one model for identifying risks, it is imperative to bear in mind that this model is far from unique. **There are many different models** that respectively represent a given vision of what risk is. Even if we limit our investigation to a qualitative approach, multiple models exist due to the **numerous persepectives or perceptions of what risk is**.

Choosing which model is a critical step as it has a strong influence on which risks will actually be identified. In this document, a particular model was introduced; the following lessons will introduce others. The sets of risks identified by using these different models will not be the same. In particular, some real risks may not be identified when a model is used. For instance, let us consider a model that allows a combination of events leading to an accident to be described. Accidents due to a sequence of events will not be identified by this model. Conversely, a model identifying scenarios (a sequence of events) will not identify the risk of simultaneous events. This does not arise from a lack of thoroughness but is purely due to an inadequate model. It therefore implies that choosing a risk model is critical. This will be discussed during the following lessons. The chosen model must come from a common vision shared by all stakeholders. One can easily imagine the challenges involved in reaching an agreement on this vision.

Let us come back to the definition of risk treatments and to the development of risk controls. Both are based on the available modelling of studied risks. For instance, if the identification model introduced in this document is used, the risk treatments can only do the following:

- avoid the occurrence of hazardous events,
- avoid, the occurrence of hazardous situations,
- avoid the occurrence of harmful events,

- avoid the occurrence of harms.

This means that **the risk identification model will also have a strong impact on the way identified risks will be treated**. Here again, particular attention must be paid when selecting a risk identification model.

Finally, one must bear in mind that risks not being identified will not be treated and safety will not be guaranteed. So, specifically for a qualitative approach, risk identification is the first and fundamental step.

❖ MULTIPLE METHODS

Once a given identification model is selected, it then has to be used. If no instructions for use are provided to engineers, the effectiveness of the step will strongly depend on the skill of these engineers. Considering the identification step, the previous assertion leads to lists of identified risks whose completeness will be variable (as they depend on the person). This is unacceptable: stakeholders not only require the identification of all risks but also proof that **all** risks have been identified.

To fix this issue, a model must be accompanied by a **method**. A method explains how the results (for instance the list of identified risks) should be achieved. This then becomes the engineers' 'bible'.

Consider the model proposed in Chapter 2. A first method may consist in identifying the objectives, the actors, their hazardous properties and associated hazardous phenomena. Then, after listing the targets, the hazardous situations are deduced. Finally, the effects are described (harmful events and harms). This is an example of an **inductive approach** (from the causes to the effects).

The method can be completed by providing the following: lists of the hazardous properties of equipment, lists of the hazardous situations, lists of the hazardous events and lists of the harmful events. For instance, if a piece of equipment runs on electricity (hazardous property), it can lead to electrocution (harmful event) if one touches it (hazardous event).

A **deductive method** can also be used. It consists in specifying the objectives, the targets and the harms affecting these targets. Again, lists can be provided to help the safety manager in finding the values of these features. Then, events leading to these consequences are identified. Finally, actors and associated properties are listed.

A third method suggests the joint use of the two previous methods. This can increase our confidence in the completeness of the list of identified risks.

A method can also provide the manner for choosing people who will participate in the identification phase. Guidelines may also describe the identification process as a sequence of steps. In particular, these can involve the way the meetings are conducted.

Whatever the method, it has to be established and described in full before the implementation of the identification phase and its proceedings can take place.

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