INTRODUCTION

The packaging industry is very diverse and makes use of a large variety of materials for packaging and substances/materials/items to be packaged. The industry stores materials, mixtures, and products in small and in large quantities and units. There is also a range of processes involved as shaping, filling, painting, and finishing. Altogether, the industry handles, stores, and processes a host of combustible materials; there are numerous ignition sources around and even, albeit in smaller quantities, toxic materials. There is therefore a chance of mishap with disastrous consequences given a situation of sizable quantity of material/substance with hazardous properties.

Scale enlargement of operations leads to large quantities. Space is scarce, competition severe, time is costly, and hence safety is under pressure. Several accidents around the world with disastrous results show that such an event means a risk for the continuity of the company or puts the company at least under a severe financial threat. On the other hand, experience shows too that a good safety attitude instigated from the top pursuing thorough hazard identification, and investing in risk controls by preventive and protective measures, hence performing risk assessment, increases productivity and worker motivation, and lowers the frequencies and costs of mishaps. Workers are feeling more secure, safety culture is fostered, and insurance charges are being lowered.

EXAMPLES OF MISHAPS

Two examples of disastrous mishaps will be briefly considered. The first is of a company in the Netherlands burned down and going bankrupt, namely Chemie-Pack at Moerdijk in 2011. About the event an extensive report by the Dutch Accident Investigation Board (OVV) has been published [1].

Fig. 1. Fire at Chemie-Pack, Moerdijk, the Netherlands, January 2009 (Foto:Micha Okkerman/Twitter).
The company with a workforce of 50 had activities of repacking chemicals going on at the present location since 1982. On the rectangular premises were several sheds, storage buildings, and an office along the fence periphery, all connected with the entrance via a courtyard. The facility was licensed according to the Seveso Directive. At the day of the fire with an outside temperature of, at maximum, 3 to 4 °C, several orders were being worked on. Due to the high activity, level stores were overfilled and although violating their license, the courtyard contained a variety of stored flammables such as xylene and other raw materials for plastics, packed in a few hundred 1m³ IBC’s (intermediate bulk containers) and 200 litre steel drums. One activity was pumping resin components and mixing them. The mixing was under a roof, but the pump was outside and was cleaned before the operation with xylene of which some was spilled. As due to the low temperature the pump ceased working, it was heated with a handheld propane burner. The xylene underneath accidentally ignited; a powder fire extinguisher brought in appeared not to function. Meanwhile the resin pump kept on running while the heated exit line broke and resin spilled. The crew then tried to extinguish the fire with a water jet worsening the situation drastically. One of the IBCs caught fire (see [2] for behaviour of an IBC in fire) upon which the event escalated quickly. The local fire brigade rushed in but was overwhelmed by the conflagration and called in regional forces. An enormous, many kilometres long black cloud started passing over large cities causing much anxiety in the population. Preparedness for such an event appeared to be low, leadership and coordination failed, and crisis teams on local and regional policy levels were informed too late. The firewater polluted agricultural grounds causing tens of millions of damage. Inspection of the plant had occurred over the years after pre-announcement. This way, work not allowed by the license, was not noted. Personnel were badly trained. Over the years management obtained advice on fire safety measures, but follow-up was inadequate. The whole is a typical example of a lack of safety management and bad safety culture. The event aroused much parliamentary and government response.

The second example is an American one reported by the Chemical Safety and Hazard Investigation Board [3]. This concerns a vapour cloud explosion inside a small facility caused by an overnight release from a solvent tank for preparing ink for ink products. The explosion in the middle of night caused 10 people injured, 24 houses, and 6 businesses destroyed, Fig. 2. The facility was operated

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**Fig. 2.** Left. Disastrous result of vapour cloud explosion inside an ink products plant near Boston, USA [3]. Right. Mixing tank with flammable solvent steam heated to 32 °C [3].
by two companies, CAI Inc. (20 employees) and Arnel Inc. (9 employees) which before 1985 formed one entity. The plant stored thousands of litres of solvents and 25 tons of industrial nitrocellulose pellets (most of which in a trailer adjacent to the building). The 7500 litres solvent tank filled with volatile flammable liquid was steam heated to 32 °C to dissolve resin. At the end of a normal workday in November 2006, the production manager left leaving the stirrer on and believed to have closed the steam supply. Half an hour later the last employee switched off ventilation fans (exhaust and fresh air supply) and locked the building. At 2:46 in the morning alarm went off at the local fire brigade 1.5 km away; few seconds later the firemen experienced the blast. Several organizations contributed to the emergency response. The fire brigade was not made aware of the hazardous materials present. A complication arose when pipework of a LPG tank of a neighbouring bakery started leaking (domino effect). In the middle of the night, 300 people had to be evacuated, and the fire burned for 17 hours. Management had not conducted a process hazard analysis; volatile flammables were stored inside the building with no detectors and alarm provisions or adequate ventilation. Written procedures or checklists did not exist. Again, this is an example of a lack of safety management, training, emergency response, and a poor safety culture.

HAZARDS, DANGER, SAFETY, SECURITY AND RISKS

English is a language that makes a distinction between hazard and danger and between safety and security. Many other languages do not. Hazard is an inherent capability (energy, material/substance property, activity) for harm or damage by an effect to something exposed that is valued; danger is a hazardous situation prone to result in harm or damage. Safety is a state of being protected against harm and other consequences of failure, while security is concerned with being protected, for instance, against terrorist or other criminal acts. Safety can be inherent in the absence of hazards; it can be engineered by applying measures, and it can be procedural by developing and implementing rules. Much the same can be said of security. In Figure 3 the elements are illustrated: a trigger unleashes the hazard potential in case the preventive barrier ceases due to a chain of causes.

Fig. 3. Illustration of elements of a hazard scenario for an exposed receptor; LOP is layer of protection [4].

A distinction should be made between process safety and personal safety, although the two are linked. Personal safety concerns the slips, trips, falls, and the like. By Occupational Safety and Health regulation, the EU Machine Directive, training and personal protection equipment (PPE) over the years much improvement has been seen. Process safety is concerned with high impact, low probability events. It is more treacherous as it usually seems to occur without warning and for those involved unknown. For many years a process can run without a problem and yet suddenly disaster strikes. Process safety deserves enhanced attention.

Risk is defined in ISO 31000, Risk management principles and guidelines, as the effect of uncertainty on objectives. In other words, absolute safety as objective means absence of risks, but as there are always risks around, safety is never perfect. Safety
cannot be quantified, but risk can. Risk components are possible consequence/effect severity and likelihood/probability, which both can be quantified but remain subject to uncertainty, consequence less than likelihood. Uncertainty will reduce when our knowledge level increases.

RISK ANALYSIS AND ASSESSMENT

General
Risk analysis consists of a systematic search for what can go wrong, what likelihood this will have, and how severe consequences will be. In assessment one asks whether the established risks are acceptable, or at least tolerable, and if not what can be done to reduce them to a tolerable level. Hence, it is trying to answer the question “how safe is safe enough?” in a predictive sense.

A risk assessment, whether it is on safety, on success of a project or of an investment must always start with establishing context, of goal, stakeholders, and key elements. Then, follows identification of the risks via scenarios as shown in Figure 3: hazards, triggers, possible effects, exposed target vulnerability. Next is determination of consequences followed by that of likelihoods. The latter are the most difficult to determine. In fact, probability and thus uncertainty comes in at all key elements, as neither consequences nor the chance of occurrence can be determined accurately due to many possible influencing conditions, and lack of insight and knowledge. Nevertheless it pays to make estimates, determine a relative order by risk magnitude and distribute available resources for preventive and protective risk reducing measures such that an optimum risk level will be obtained.

Qualitative methods
A first approach to obtain an overview of risks threatening your operations would be to derive a qualitative risk matrix as shown in Figure 4. It is a matter of making a hazard inventory of quantities of hazardous substances present. Estimate effects in case an unintentional release will take place by a sudden rupture of a container, a large leak occurring during a limited time, say 10 minutes, or a small leak over an indefinitely long time. Given a leak the property of the spilled material is important: volatility, flammability, toxicity, oxidizing property, or corrosiveness. Further, risks shall be considered due to unintentional release of a large amount of potential energy such as large mass falling, bursting of container with compressed gas, et cetera.

Fig. 4. Qualitative risk matrix with example risk dots and indicated urgency of risk reduction action

Although for identification a host of methods is available, two are really important: Hazard and Operability study (HAZOP) and Failure Mode and Effect Analysis (FMEA). Both HAZOP and FMEA should be carried out by a team led by an experienced chairman. In HAZOP a team performs a systematic analysis of the effect of deviations from design intent (+, − or not); HAZOPs are conducted worldwide. FMEA partly overlaps HAZOP but contributes. Because of the required effort, research is going on to increase productivity by a system approach and use of computing power. Human, management, and organizational failure are the most difficult causes to predict.

Semi-quantitative and quantitative risk assessments (QRA)

In a semi-quantitative approach severity of an
event and probability of its occurrence are estimated in orders of magnitude and may be plotted in a risk matrix as in Figure 4 but then with logarithmic scales and units of factors of 10. Consequence severity may be expressed in monetary units. For predicting severity one has to apply physical models of heating, collapse, rupture, fracturing, outflow, evaporation, dispersion, ignition, explosion, fire, and toxic concentration. Probability is considered over a certain period usually a year and is called frequency. In a risk matrix frequency ranges usually from an event once in ten to once in ten million years ($10^{-1}$ to $10^{-7}$/yr).

Fully quantitative methods must generate detailed scenarios with cascading and escalating effects. It will include so-called domino effects of one unit to another, and incompatibility between stored substances in case of fire. Such analyses are effort intensive and always lack data. The main value, however, is the brainstorming in a team and the thinking about cost effective risk reduction.

**Limitations**

Uncertainty and unknowns limit the confidence one can have in risk assessments. One or two factors of ten uncertainty range is not unusual. Accidents not having been predicted by an assessment are plenty. Yet, a systematic approach is key to attain control on risks.

**PREVENTIVE AND PROTECTIVE MEASURES**

**Leadership, management, organizational measures**

As in many things in life but certainly in safety the attitude of leadership in a company is crucial. There may be many safety paraphernalia such as signs “Safety first”, but when a CEO does not care or is perceived not to care about safety, accidents are bound to happen. Analysis of many accidents has over and over again shown that behind the direct and intermediate causes there are root causes that for a very high proportion are management failures.

Very helpful and accepted in many companies is a safety management system (SMS). EU Seveso Directive 3 requires it for ‘establishments’ that fall within its scope of controlling major hazards, but it may be as well useful for companies exhibiting smaller risks. An SMS has many similarities with a quality management system and implementing it can also mean higher quality and effectiveness, hence higher productivity. A SMS contains requirements with respect to roles and responsibilities of employees, identification and evaluation of hazards, training/retraining, operational control and procedures, management of change, emergency planning, performance monitoring with indicators, auditing and reviewing, and corrective organizational mechanisms.

Today, also the safety culture and measuring it via safety climate surveys is given much weight.

**Bowtie thinking**

The bowtie developed from the late 1970s onwards but the concept really spread in 2000 and later. The name derives from the gentleman’s tie as two triangles pointing to each other. Left triangle is a fault tree showing cause-consequence chains with OR and AND gates and the right triangle an event tree of possible events developing and branching out after a critical or initiating event following occurring failure causes, see Figure 5. The bowtie appeared to be an excellent concept to obtain an overview where preventing (left) and protecting (right) barriers are useful or already present. Each branch from left to the far right forms a scenario.

Although the bowtie originally was thought of being composed of two technical quantitative risk analysis tools: a fault tree with its top event being the
initiating event of an event tree, it can well be used qualitatively to discuss risks and prevention and protection measures. In that case, the hazard is often symbolized by a rectangular box above the critical event (CE) with an arrow down to it to show how activating the CE unleashes the hazard potential, as shown in Figure 3.

Properties of materials, physical measures: explosion and fire protection

Material data sheets contain many properties. Test methods are available. Measures are possible to reduce risk of explosion and fire, the most common threats in the packaging industry, although fire causes toxics. Sources of knowledge are plentiful. Practical sources that can be consulted for free are FM Global Data sheets: https://www.fmglobal.com/fmgloba1registration/. Lower flammable limits of most hydrocarbons are around 2 vol. % in air. Ignition can occur by a myriad of source types. An important principle is compartmentalization to avert explosion and block fire progress.

Regulatory: protection of workers, population, environment

Company operators as they are called in EU Directives have a responsibility for occupational safety and health of workers and for the safety of residents with regard to major hazards resulting from operations on their premises. Two of these regulations concerned with preventing and protecting for gas and dust explosion effects shall be mentioned here as important for the branch: ATEX 95 and 137 directives (Atmosphères Explosibles). The first is with respect to equipment not forming an ignition source in various degrees of protection depending on its location as prescribed by ATEX 137. The latter is requiring a risk assessment, e.g., resulting in an area classification in three hazard zones 0, 1, and 2 for gases and 20, 21, and 22 for combustible dusts, meaning for 0 and 20 permanently, for longer duration or frequently explosive (US: flammable).
atmosphere present, for 1 and 21 likely to be present occasionally and for 2 and 22 not likely and of short duration. With these safety regulations Europe is in the preventative forefront witnessing disasters elsewhere.

Another European achievement pertains to the risk acceptance criteria. The most known one that captures most of the following elsewhere is the UK HSE’s ALARP: As Low As Reasonably Practicable. It has a certain development history. First is the distinction of three risk levels: Unacceptable, Tolerable and Acceptable. As a minimum, risk must be lowered to become tolerable, but then further reduction must be realized till costs become unreasonably higher than the benefits. This required more detailed ruling, which took time to develop.

Emergency planning

Various parties are involved: company responders, community fire brigade, medical personnel, and police (for investigation of cause and providing quick access to the site). A risk assessment is a good basis for planning but is not enough. From the many scenarios a selection must be made and in a team a scenario analysis conducted to think through details and familiarize all parties with the situation. Periodically training, alarming, testing of equipment and teamwork is a must, in particular to train company and community emergency responders in effective cooperation together.

CONCLUSIONS

Risk assessment and management pays. Their methods may have many weaknesses, but they compel us to think about and characterize hazards and analyse risks. By reducing likelihood and effects, and therefore costs of mishaps, they can prevent much misery. Methodical improvements are underway as discussed and exemplified in [4]. Their application assumes good knowledge of hazardous properties of substances together with imagination and data for scenario building.

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REFERENCES


