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Joint applicability test of software for laboratory assessment and risk analysis

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ABSTRACT: Most of the available risk management methods are not directly applicable to academic research laboratories. One solution to systematically perform risk analyses in this environment is the Laboratory Assessment and Risk Analysis (LARA) method. This method was developed to allow untrained personnel to identify of possible risks and rank them according to their importance. The purpose of this study was to find out, if this method can be used as a holistic risk management technique in different environments, and which are the differences when comparing the results to other, well established risk analysis techniques. The risk analyses were performed at two European universities and for various procedures. The results show, that the LARA procedure is more easily performable than the other methods and gives comparably adequate results. Being applicable by non-experts, this holistic risk analysis method for research laboratories can help to reduce the accident rate in the academic environment.

1 INTRODUCTION

In most sectors of industry, the rate of occupational accidents decreased during the past decades. This fact is due to intensified efforts in occupational safety as well as more strict regulations and laws. Risk management techniques helped to guide those efforts in the desired direction, since they help to allocate the measures according to the relative importance of risks. Most of those methods originate from a specific field of application and are suited for the demands of this field (e.g. Hazard and Operability studies (HAZOP) for the chemical industry (Bluvband et al. 2004)). For academic research laboratories, such a specific technique was never developed; existing methods are often only working for a definite application and cannot be used to perform a risk analysis in different fields (Pluess et al. 2013). Since improving occupational safety gained more importance at universities after various accidents (Marendaz et al. 2013), there is a need for specific risk management technique for research laboratories (American Chemical Society, 2013).

Various solutions were presented in the literature (Kremer et al. 2009, Langerman 2009 Leggett 2012). However, those methods are still too specialized to serve as a universal risk analysis method for academic research and teaching laboratories (Pluess et al. 2013). A new approach to fulfill the demands of academic research is the Laboratory Assessment and Risk Analysis (LARA) method (Ouedraogo et al. 2011). This method was developed at the Ecole Polytechnique Fed´erale´ de Lausanne (EPFL) in Switzerland to analyze and manage risks even for non-experts and facilitate the risk management process at universities. One of the main features of LARA is taking into account the special setting of this environment (e.g. high personnel turnover, emerging technologies, etc.) and including synergies between different hazards (Pluess et al. 2013).

Since the method was developed based on safety regulations of EPFL and originates from its safety culture, the feasibility of LARA to other environments was not demonstrated yet. For the further development and the improvement, the adaption to other universities is a crucial element. The use of LARA at other universities can help to find improvement potential and is able to show if untrained personnel with different occupational safety background can fully benefit of this risk management method. For this reason, joint tests were performed at the Institute of Energetic Materials (IEM) at the University of Pardubice (Czech Republic) and the Institute of Chemical Sciences and Engineering (ISIC) of EPFL.

The purpose of this study is to answer two following questions: 1) Can the LARA method be used as a holistic risk management technique in different academic environments? and 2) What are the main differences when comparing to the results obtained by industrial risk analysis techniques? In order to answer these questions, analyses of different experimental procedures were performed using LARA, Failure Mode, Effects, and Criticality Analysis (FMECA), HAZOP, and PreHA. The experiments analyzed belong to the operations performed or at University of Pardubice or at EPFL. The main differences of the results using the different methods are pointed out and compared.

Since the answer to question 1 is positive, and the answer to question 2 provides the authors with material for comparisons, an additional relevant practical questions is discussed in the end of this paper: 3) What should be expected from the application of LARA in different environments?

2 METHODS

In order to compare the results of LARA with well established risk management methods, three examples of experimental procedures were selected: two from the University of Pardubice and one from EPFL. To have a variety of laboratory tasks, both chemical experiments and routine tasks were considered in the comparison. The first example was analyzed using the LARA method and a HAZOP procedure, the second one was analyzed using the LARA method and the FMECA procedure, the last one compares LARA and PreHA. All of these analysis procedures are widely accepted tools to identify and manage risks (Bluvband et al. 2004).

The joint tests described in this article are performed under conditions that simulate the environment for which the LARA method is intended. The risk evaluations were performed and guided by a group of researchers, being familiar with the experimental procedures and having experience in performing FMECA and HAZOP procedures. For the LARA method, those researchers had a short introduction, but no detailed information about the principles of the method. This was intended, since non-experts are the designated users of the LARA method. The researchers involved in the tests provided the analyses with all information necessary, including details about the laboratory environment.

2.1 HAZOP

HAZOP was derived from so called Critical Examination in early sixties. The original technique was focused on uncovering possible modifications, which could improve the assesed process. Later it was altered to identify deviations from the process intentions (Kletz 1997).

The HAZOP technique is a systematic approach to investigate the processes by determining possible deviations from the process intentions and consecutive effects on whole facility. Its strength is in dividing assessed process in the small sections called nodes and thus ensuring examination of each part of the system. The nodes are analyzed by a small multi-disciplinary team, whose members should be able to answer the most questions about given issue on spot. The members have the authority to recommend any needed changes in design (Dunjoa et al. 2010).

This scenario-based method relies on using a defined list of guidewords (e.g. as, no, more, less) in combination with process parameters (such as temperature, pressure, flow). The aim of this combination is to reveal deviations from the process intention (e.g. no flow, more temperature, less pressure). The procedure divides a process or a system into specific nodes according to their intentions. Guidewords are applied to each examined node. Once deviations are determined, their possible causes and consequences are discussed by the team of experts. For both cause and consequence corrective measures that could prevent, detect or mitigate the hazardous situation must be identified. If there are not any feasible safeguards, a change in intended design must be considered (Center for Chemical Process Safety, 2011).

2.2 FMECA

The FMEA systematically analyzes a system for potential failures and their consequences on the system. The procedure divides a process or a system into specific components according to their function. Then, the possible failure modes are determined on every component. Failure mode describes how equipment could fail, what will happen if operated improperly and how the failure could cause an accident or contribute to accidents occurrence. Once the failure modes are determined, the systems response to the failure leads to a certain effect. The effects provide a feedback for determining where system changes or improvements should be made (Center for Chemical Process Safety, 2011). Each individual failure mode is considered independently without a relation to other failures in the system, except for the subsequent effects it can produce. Results of this procedure are qualitative unless FMEA is extended to FMECA by including the criticality of the failure mode; the priority ranking is based on the failures severity and their probability (R. I. Wagoner 1988). FMECA uses quantitative or semiquantitative scales to describe the likelihood and impact of a potential incident. After assigning likelihood of occurrence and impact values to each incident, a matrix is used to prioritize incidents importance (W.E. Jordan 1982).

2.3 PreHA

A Preliminary Hazard Analysis (PreHA) is a hazard evaluation technique based on the U.S. Military Standard System Safety Program Requirements. The technique is usually used in early stage of designing a process plant. However PreHA is sometimes used even for existing systems where lack of experience makes risks identification difficult. It is also helpful for hazard prioritization and for analyses of large existing facilities.

PreHA is generally focused on hazards arising from materials and physical conditions present in a system. The technique offers control lists of common hazards and provides ranking of hazardous situations used for risk prioritization. As PreHA is not as exhaustive and systematic as e.g. HAZOP, it does not require only all available information about a system, but it has to be performed by experienced analysts, because significant amount of judgement is necessary for the relevant results. (American Chemical Society, 2013)

Komentář [MF1]: Doplnit odkaz.

The analysis itself consists of dividing the evaluated process in steps for which present hazards, undesired situations and their causes are identified and prioritized. An analyst must take in consideration hazardous equipment and materials including interactions between them, environmental factors potentially influencing the system, system maintenance and safety related equipment. Analysis results conventionally have the form of table. (American Chemical Society, 2013)

Komentář [MF2]: Doplnit odkaz.

2.4 LARA

During the past several years, various severe accidents (injury and death of scientists, financial losses, and interruptions of the scientific research as consequences) happened at different universities worldwide (Marendaz et al. 2013), emphasizing the need to improve the occupational safety and health in this environment. Differences between research and industrial environment (e.g. equipment and processes at development stage, high turnover of collaborators, scarce statistical data on reliability and accidents) made attempts difficult to implement existing risk analysis methods and are not leading to useful results (Ouedraogo et al. 2011). Solutions for this problem were already presented in the literature, e.g. for biology (Kremer et al. 2009) and chemistry (Langerman 2009, Leggett 2012). However, they focus on a narrow field of scientific research, such as biology, or only on selected steps of risk analysis. In order to tackle this problem, EPFL's Group for Chemical and Physical Safety (GSCP) is currently developing a holistic risk analysis technique for the academic research setting, called LARA. The goal of this development is to design a risk management method with following properties (Pluess et al. 2013):

- Easily performable by non-experts.
- Less resource demanding compared to other available methods.
- Semi-quantitative and improved risk estimation. Consider the special conditions encountered in academic research laboratories.

First results of risk analyses for different sectors of the academic research environment were already presented by (Ouedraogo et al. 2011). Based on the development, a web application software was developed. The workflow of the LARA method is presented as following:

1) **Risk identification:** every element (equipment, chemicals and activities) involved in a process is determined. Based on these elements, each hazard present in this process is selected out of a database. This database contains a large number of different hazard categories, based on regulations, past accident data, measurements and expertise. Additionally, the users of the software are able to suggest hazards and expand the database.
2) **Risk description:** the semi-quantitative risk estimation is a crucial element to reach the goals of the method. In such an estimation method, verbal statements are used to describe the risk factors. According to these verbal statements, a value on a numerical scale is assigned for each hazard. For all the variables a scale of integer numbers between one and five was used. LARA uses four different main factors to describe and estimate the risk related to a hazard: severity, probability, detectability and worsening factors. To improve the risk estimation and to take into account the special conditions in academic research laboratories, GSCP introduced the concept of worsening factors (Ouedraogo et al. 2011, Pluess et al. 2013) in addition to the commonly used elements in different risk analysis techniques (severity, probability and detectability). This new concept integrates specificities of research laboratories, which can aggravate the outcome or the probability of an accident. GSCP classified this worsening factors into three groups: general worsening factors are those types of influences which are not directly related to a certain kind of hazard, but which can influence the probability, the severity or the detectability. Hazard-specific worsening factors are directly influencing a certain risk. Synergetic worsening factors are describing synergies between two risks, in particular situations where a risk can be worsened or enabled by the presence of another risk (Pluess et al. 2013).

3) **Risk calculation:** GSCP developed a new method using Bayesian networks to calculate a risk index called Laboratory Criticality Index (LCI) for each hazard. This improved method is based on Bayesian networks, being used in various applications of risk management (Marhavilas et al. 2011). Bayesian networks are using probability tables (Fenton and Neil 2012) with different states for each node of the network. For LARA, these states represent the different verbal statements for a risk factor. The probability tables used for the factors were created using a ranked node concept described by Fenton et al. (2007). This concept helps to generate the probability tables using truncated Gaussian probability distributions. For better comparison of the different risks, the LCI is finally calculated as single crisp number (this calculation is based on a method presented by Yang et al. (2008)). This calculation approach based on Bayesian network is capable of overcoming various disadvantages of other risk estimation methods used in semi-quantitative risk analysis by giving reliable results with a constant variance through the whole spectrum of the results (Pluess et al. 2013).
4) **Risk mitigation:** Once the LCI value for each hazard is determined, the risk mitigation takes place. The board of the institution sets the limits, which LCI values are not acceptable and which are acceptable. For risks with an acceptable LCI value, no measure is necessary to proceed with the experiment. The unacceptable risks are treated regardless of the costs and the effort necessary and are reevaluated. The risks, which are neither acceptable nor unacceptable, should be reduced as low as reasonably practicable (ALARP). Since the academic environment has different demands than the industrial sector, the choice of corrective measures is realized using an allocation matrix. With this matrix, other aspects, such as acceptance and feasibility of the corrective measures are taken into account as well.

3 RESULTS

3.1 Example 1: Synthesis of methyl nitrate

Description of process: There is an intention to produce methyl nitrate for testing reasons at the Institute of Energetic Materials of the University of Pardubice. This uncommon, sensitive liquid explosive should be produced occassionally. The synthesis and the product properties are well described in literature (Black 1943). Although the process itself does exhibit difficulties, it requires a certain level of experience. The laboratory intended for the preparation of this explosive does not differ much from standard laboratories equipped for organic synthesis. A couple of tests have been already performed in smaller amounts.

The synthesis is carried out in a beaker. A mixture of nitric and sulfuric acid is poured into a beaker. Methanol is then added dropwise while the reaction mixture is stirred well and cooled in an ice bath. The temperature of the reaction mixture must be kept between 15-20^{o} C. When the whole amount of methanol is added, the reaction mixture is left for five minutes at room temperature. Methyl nitrate is separated from the acid residue, washed with cold water and sodium carbonate solution.

An accident occurred during one of the test synthesis; a sudden decomposition of the product occurred. Later it was discovered that this was caused by the presence of ricin oil in methanol, which was used as a key precursor for methyl nitrate. It is highly probable that if the decomposition would have occurred in larger amounts, it would have caused an explosion.

Safety aspects of the synthesis were discussed with the leader of the project. According to his statement the most important risk is connected with sensitivity of methyl nitrate. Even a small friction in a part of the equipment used for the synthesis could lead to an explosion. The accident mentioned above emphasizes that only pure chemicals (p.a.) should be used for this synthesis. The acids and toxic materials present during this synthesis may lead to increased risks as well, but can be reduced to minimum by appropriate safety measures.

HAZOP results: The HAZOP analysis was performed according to (British Standards Institution 2001) by the team consisting of organic chemist, explosives and safety engineering experts. The synthesis was divided into six nodes: methanol nitration, stirring, cooling, pouring into separation funnel, separation and washing. Overall eightyeight deviations were considered. Table 1 shows the six most serious hazards of the methyl nitrate synthesis. Since HAZOP does not provide the quantitative risks evaluation and prioritization, the relative importance of risks were chosen according to the experts opinions. The analysis is well performable on a laboratory scale, although is designed mainly for industrial environment. HAZOP gives appropriate results and reflects the experience and predictions of experts. Despite the applicability and realistic results, the procedure is relatively complicated, time and resources consuming and not suited to be performed by non-expert.

Table 1: Most important contributions to risk according to HAZOP.

No.	Guideword	Element	Deviation	Possible causes	Consequences
1	More	Methanol	Faster dropping	Funnel valve leaky	Exothermic reaction, explosion
2	As well as	Methanol	Impure methanol	Error at supplier	Exothermic reaction, explosion
3	As well as	Separation funnel	Valve grease washout	Inappropriate grease	Exothermic reaction, explosion
4	No	Stirring	No stirring	Stirrer failure	Local overheating, explosion
5	Other than	Pouring	Reaction mixture poured out	Personnel failure	Irritation and intoxication
6	No	Separation funnel	Valve grease not applied	Personnel failure	Explosion caused by friction

LARA results: LARA analysis performed by the same researchers identified 15 hazards. Risks of all of them arise from hazardous properties of the involved substances. The relevance of the analysis results is given by risk prioritization, which corresponds to the particular laboratory practice. The procedure determined that methyl nitrate explosives properties have the highest risk priority. Among the risks with highest importance belongs methyl nitrate toxicity, corrosive effects of nitric acid and methanol flammability. All these risks are mentioned in laboratory rules and personnel is periodically familiarized with them during safety training. The most important risks according to this analysis are presented in Table 2.

Comparison: Table 1 and Table 2 reveal the most important hazards of this activity based on the results of both analyses. Almost all deviations identified by HAZOP lead to exothermic reaction and/or explosion of methyl nitrate. According to LARA, explosive properties of methyl nitrate have the highest priority. However these results do not incorporate the experience of the experts who performed HAZOP analysis, thus it is not so clear in which particular situation methyl nitrate explosive properties could exert. Remaining risks determined by LARA procedure are connected with the effect of involved substances on the personnel. This is in agreement with the deviation pointing out leakage of the reaction mixture identified by HAZOP.

Table 2: Most important contributions to risk according to LARA.

No.	Risk
1	Explosion caused by methyl nitrate
2	Intoxication (inhalation) caused by methyl nitrate
3	Intoxication (skin) caused by methyl nitrate
4	Irritation (skin) caused by methyl nitrate
5	Intoxication (oral) caused by methyl nitrate

3.2 Example 2: Medium scale purification of solvents

Description of process: the second example, which was chosen to test the LARA method, is the purification of larger quantities of solvents. This process is realized at the laboratory of asymmetric catalysis and synthesis (LCSA) at EPFL. Large amounts of solvents, mainly ethyl acetate and pentane, are used in this laboratory for chromatographic purposes. Since the commonly available solvents are not sufficiently pure enough, a further purification is performed directly in the lab. The task is realized according to a plan, which obligates each member of the group to perform this process periodically. Even thought the task is planned and recurring, there is no standard operation procedure (SOP) available.

For the purification, a Heidolph LABOROTA 20 medium scale rotary evaporator was used. The purification is realized several times per week with a quantity between 5L and 10L of solvent each time. For the ethyl acetate, the device is heated to 50^o C and the pressure was set to 25 kPa. For the purification of pentane, the device was heated to 50^o C and the pressure was set to 95 kPa. Until now, no accidents have occurred. According to the responsible reseracher, the main risk in this process is related to the flammability of the solvents. Other hazards related to the chemical properties of the solvents, such as the hazards for the environment or toxicity, are estimated to be negligible.

FMECA results: a team of researchers performed a systematical analysis of the most important components using the FMECA method. In total, 29 potential failures were identified and their relative priorities for applying measures were determined. Seven of these failure modes are only influencing the operability itself and are not relevant from a safety point of view. Among the remaining 22 failure modes, 6 are related to mechanical operations and the remaining 16 are indirectly related to the hazardous properties of the solvents. Since those properties are not directly evaluated by the procedure, the relative importance and magnitude of the effects remain unclear after the FMECA analysis.

LARA results: the same team of researchers used the LARA method to perform a risk analysis on this activity. This analysis revealed nine different hazards originating from different sources (chemicals and devices). All of those hazards are relevant from an occupational safety point of view. Four of the hazards are directly related to the hazardous properties of the solvents. The other five hazards present according to the LARA analysis are related to mechanical or physical risk.

Comparison: Table 3 shows the most important hazards of this activity based on the results of both analyses. The most important hazard determined by the LARA method is the toxic property (aspiration toxicity) of both solvents. In the FMECA analysis, the toxicity is indirectly related to the failure modes with the relative priority 2, 3 and 4 (all those failure modes are leading to leakage of solvent). Based on the FMECA method, the blast shield of the apparatus is the most hazardous element of this process, which is ranked second in the LARA method. The mechanical hazards do have the same importance according to the LARA method, since both do have similar occurrences and exposures. The FMECA analysis however ranked the similar hazards in a different order, even though the hazards are comparable. The FMECA analysis fails to differentiate between the different hazards originating from the chemical properties of the solvent.

Table 3: Comparison of the risk priorities in example 2 using LARA and FMECA method.

Hazard	Risk	Priority in LARA	Priority in FMECA
Blast shield	Injuries due to unintended closing	2	1
Lowering mechanism	Injuries due to pinching	2	5
Toxic substance (solvent)	Intoxication by inhalation	1	2/3/4
Irritating substance (solvent)	Eye irritation	3	2/3/4
Flammable substance (solvent)	Fire	5	2/3/4

3.3 Example 3: Preparation of diazomethane

Description of the process: The last example represents one of the possible ways how to prepare diazomethane, which is important reagent for organic synthesis. Despite hazardous properties of diazomethane (extreme toxicity, flammability and unstability) the procedure is carried out regularly at the Institute of Organic Chemistry and Technology in University of Pardubice without any standard operation procedure (SOP), but always under supervision of an experienced researcher. According to the statement of these researchers no accident connected with this synthesis occurred yet since strict safety measures must are always followed: all ground joints must be lubricated perfectly with silicone because diazomethane explosion can be initiated by contact with a sharp edge, preparation must be done in an enclosed hood and diazomethane solution must not be stored.

The preparation is realized by decomposition of N-Nitroso-N-methylurea in saturated solution of potassium hydroxide. Potassium hydroxide is dissolved in water, cooled and poured in a ground joint flask which is placed in ice bath. N-nitroso-N-methylurea is added into hydroxide solution. Diazomethane from the mixture is absorbed in series of three gas washing flasks filled with diethyl ether placed in an ice bath.

PreHA results: The analysis that was performed by a researcher with a process safety background and certain experience with organic chemistry, identified 10 hazards with 24 undesired situations leading to harmful effects. All of them arise from the used hazardous materials and have potential to harm the personnel. The prioritization of the hazard severity was based on qualified estimation according to (American Institute of Chemical Engineers 2001). It gives rough insight in real hazard importance without considering factors like exposure and detectability.

LARA results: LARA was performed by the same analyst who performed PreHA. The analysis identified 10 hazards, all of them connected with hazardous properties of materials. The priority of hazards is in fair agreement with the real laboratory practice; method is applicable by an unexperienced person, although the method itself would not yield correct results if performed by an analyst who does not have any insight in an analysed procedure.

Komentář [MF3]: Tohle je rozpor s požadavkem, že LARA má být prováděna nezkušenými lidmi.

Comparison: Table 4 compares results of LARA and PreHA. Although PreHA hardly distinguishes the importance of identified hazards, five most important hazards are common for the both methods. According to LARA, first two most important hazards arise from toxic and explosive properties of diazomethane, which is in agreement with PreHA results. Remaining results differ slightly, LARA puts corrosive properties of sodium hydroxide on the third place, while in PreHA they represent the lowest hazard. Dermal toxicity of diazomethane is among three most important hazards, whereas LARA consideres it to be second lowest hazard. Carcinogenity of N-methyl-N-nitroso urea was identified as the lowest hazard by LARA and second lowest by PreHA. Despite good correlation of both methods results, PreHA lacks fine distinguishing of hazards – for example there is no difference between inhalation and dermal toxicity in this method and identified hazards have just four degrees of importance

Table 4: Comparison of the most important contributions to risk according to LARA and PreHA.

Hazard	Risk	LARA	PreHA
Diazomethane inhalation toxicity	Ventilation failure	1/2	1/2/3
Explosive properties of diazomethane	Sharp edges in the aparature	1/2	1/2/3
Corrosive properties of sodium hydroxide	Spillage of hydroxide solution	3	5
Diazomethane dermal toxicity	Vessel failure	4	1/2/3
N-methyl-N-nitroso urea carcinogenity	Repeated contact with N-methyl-N-nitroso urea	5	4

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4 DISCUSSION

The test results highlight the different aspects of this new method to assess laboratory risks. The results do not only focus on the successfully evaluated risks, but also on the other factors of the evaluation, such as prerequisites and effort to perform the analysis. The tests provide us with answers for questions whether the LARA method is performed easily, how fast it can be completed, and if it is capable to uncover all hazards connected with an experiment. In this article we focus on identification of hazards and evaluation of the risks; we omit the aspect of applying corrective measures, which is not as relevant for this comparison.

1) Can the LARA method be used as a holistic risk management technique in different academic environments?

The results of this study suggest that the LARA can be used as a holistic risk analysis method in university laboratories. Even though only three examples were examined, the joint test at two universities showed the advantages compared to established risk analysis techniques. The method is easy to use and provides the user with reasonable identification and prioritization of hazards.

2) What are the main differences when comparing to the results obtained by industrial risk analysis techniques?

One of the most important features of a risk management method is the capability to identify hazards and evaluate risks. Since no method is able to identify all the possible risks, an appropriate method should be capable of discovering the most important contributions to risks of a process. On the contrary, the more risks a method can identify, the higher is the probability to identify scenarios, which are either highly improbable or of no importance for occupational safety.

In the first example, the HAZOP procedure identifies several scenarios, which are influencing the performance of the process, but are not important to the safety of the involved scientists. Such irrelevant scenarios (in terms of safety) can detract from the safety-related relevant scenarios; additionally, they are extending the analysis itself in terms of complexity. The LARA method is capable of identifying the same relevant scenarios as the HAZOP method. Additionally, the method is able of identifying relations, which the HAZOP procedure is not capable of, because in contrast with another methods takes into account worsening factors influencing the process and synergic effects among possible hazards and risks. HAZOP in the first examples deals mainly with the nitration process itself, whereas LARA emphasizes risks connected with hazardous properties of involved substances threatening the personnel and takes into account more risks than explosion during nitration.

Results of FMECA are more similar to LARAs results: both techniques identified the same hazards and risks, but FMECA fails to differentiate them. On the other hand, FMECA method, similarly as HAZOP, identifies more specifically the points on which the protective measures against identified hazards should be focused.

From the three examples mentioned in this article, LARA method is the most similar to PreHA. Both techniques are or can be used in early life of an evaluated process; both of them are easy and quick to perform. LARA, although it is not its main purpose, could serve as a precursor for another hazard evaluation, which is also one of PreHA characteristics. On the other hand, PreHA is more focused on dividing process into steps and identifying undesired situations without a deep insight in hazard priorities. LARA offers much more hazard generics and possibility of the precise hazard prioritization which covers most factors influencing hazard importance.

The effort needed to perform a risk analysis is another important aspect, which influences the feasibility of a method. An ideal risk analysis method for academic research laboratories should not require too demanding resources, since both qualified personnel in safety and time is a rare commodity in this environment. The systematic approach of the HAZOP procedure is not complex itself; however, in order to perform the analysis, an experienced user (the HAZOP moderator) needs to participate to find most of the scenarios. In contrast, the examined example showed that the LARA method is more intuitive when performing the risk analysis. Both methods anyhow need expertise about the process, but LARA needs less experience about the risk management method itself.

If we compare performing LARA and FMECA, we see that there is not so big difference like in the previous comparison because FMECA lets the analyst to think more independently on the technique, but still offering good lead for the process analysis. This means that FMECA is not as difficult and complex as HAZOP, but still requires more experience with both process and risk identification than LARA. This is even more obvious when we use PreHA, because this method is as easy to perform and as intuitive as LARA, but will hardly ever lead to correct results if performed by an inexperienced analyst.

Another possible way of application of LARA was discovered when comparing it with PreHA. PreHA is often use as a precursor for next analyses and so could be LARA, because it gives quick information about hazards, risks and their priority. Thus it is providing the analyst with information which could serve as a starting point for further analyses even in different environment than academic.

3) What should be expected from the application of LARA in different environments?

User can expect the method that is potentially universal. Its field of application is potentially unlimited; it depends only on a range of generic hazards which are covered by a database.

Also a method that is easy to use can be expected. Application of the method is supported by a software tool which guides the user intuitively. It is a characteristic property of LARA that the method is designed to be used by persons who are not familiar with risk analyses. In practice it means that even the students could perform LARA before every laboratory exercise in order to realize risks connected with their laboratory work. Such a way the method could help the improvement of safety, because to be aware of the risks and learn how to identify them is something what still is not considered being automatic in plenty of laboratories.

Finally, this is a method that results in a reasonable number of prioritized hazards. If more detailed results are necessary e.g. in order to support identification of protective measures, the LARA application can be followed by some of more laborious hazard evaluation methods.

However, the comparison has shown some limitations of the LARA method as well. The method relies on a database, and is therefore as accurate as the database is. This drawback can be overcome by systematic use of the software at universities in order to fill the databases with possible hazards and risks.

5 CONCLUSIONS

Since there is no dedicated technique, performing risk analysis in academic research and teaching environment is a challenging task. Nevertheless, being aware of the possible risk is crucial in an environment dealing with emerging technologies and equipment in experimental states. Even though the impact might be less significant compared to accidents in the industry, the accident rate is still unacceptably high. To lower this rate, a specific and holistic risk management method serves as an important tool. The LARA method is such an approach; it was developed specifically for the use at universities and research laboratories. Different experiments and procedures, performed at two European universities were analyzed using the LARA method and compared to well established risk management techniques. This comparison shows the capability of LARA to be used as a holistic approach, used in various fields of research and for various kinds of tasks. The findings in this article emphasizes that an academic environment could benefit from the introduction of this technique. In order to integrate this method to an environment, it should be embedded into an existing safety framework. Further studies will be comparing more examples and the ease of implementing this technique into such an existing safety framework.

REFERENCES

Komentář [MF4]: Je potřeba zjistit si v JLPPI, jak mají vypadat reference, a podle toho sjednotit. Hlavně vidím problém v umísťování iniciál křestních jmen autorů.

American Chemical Society (2013). *Identifying and Evaluating Hazards Hazards in Research Laboratories.* ACS.

American Institute of Chemical Engineers (2001). *Layer of Protection Analysis: Simplified Process Risk Assessment.* WILEY-AIChE

Black, A. P., Barbers, F. H. (1943). Methyl nitrate, in E.H. Blatt (ed.), *Volume 2 of Organic Synthesis*. Wiley and Sons.

Bluvband, Z., Grabov, P., & Nakar, O. (2004). Expanded FMEA (EFMEA). In *Reliability and Maintainability, 2004 Annual Symposium - RAMS*, pp. 31–36.

British Standards Institution (2001). *BS IEC 61882:2001*. BSI.

Center for Chemical Process Safety (2011). *Guidelines for Hazard Evaluation Procedures* (3rd ed.). Wiley.

Dunjoa, J., Fthenakis, V., Vilchez, J. A., & Arnaldos, J. (2010). Hazard and operability (HAZOP) analysis. A literature review. *Journal of Hazardous Materials* 173(13), 19–32.

Fenton, N. & Neil, M. (2012). *Risk Assessment and Decision Analysis With Bayesian Networks*. CRC PressINC.

Fenton, N. & Neil, M. & Caballero, J. G. (2007). Using ranked nodes to model qualitative judgments in bayesian networks. *IEEE Transactions on Knowledge and Data Engineering* 19(10), 1420–1432.

Jordan, W. E. (1982). *Failure modes, effects and criticality analysis,. Proceedings of the Annual Reliability and Maintainability Symposium*, San Francisco.

Kletz, A. T. (1997). HAZOP – past and future. *Reliability Engineering and System Safety* 55, 263-266.

Kremer, G. G., Switzer, S., & Ryan T. J. (2009). *A Risk Assessment Method and Safety Plan for a University Research Lab*, pp. 263–268. New York: Amer Soc Mechanical Engineers.

Langerman, N. (2009). Labscale process safety management. *Journal of Chemical Health and Safety* 16(4), 22–28.

Leggett, D. J. (2012), Identifying hazards in the chemical research laboratory. *Process Safety Progress*, 31, 393–397.

Marendaz, J.L., Suard, J.C., & Meyer, T. (2013). A systematic tool for Assessment and Classification of Hazards in Laboratories (ACHiL). *Safety Science* 53(0), 168–176.

Marhavilas, P. K., Koulouriotis, D., & Gemeni, V. (2011). Risk analysis and assessment methodologies in the work sites: On a review, classification and comparative study of the scientific literature of the period 2000-2009. *Journal of Loss Prevention in the Process Industries* 24(5), 477–523.

Ouedraogo, A., Groso, A,, & Meyer, T. (2011). Risk analysis in research environment part i: Modeling lab criticity index using improved risk priority number. *Safety Science* 49(6), 778–784.

Pluess, D. N., Groso, A., & Meyer, T. (2013). Expert judgements in risk analysis: A strategy to overcome uncertainties. *Chemical Engineering Transactions* 31, 307–312.

Wagoner, R. I. (1988). *Hazards Analysis of Petroleum Systems (HAPS): An Adaptation of the Failure Modes and Effect Analysis (FMEA) Technique*. AREYE Corporation, Friendswood, TX.

Yang, Z., et al. (2008). A new risk quantification approach in port facility security assessment. Transportation Research Part A: Policy and Practice 59(0), 72–90.