THESIS ON CHEMISTRY AND CHEMICAL ENGINEERING G23

Workplace Assessment: Determination of Hazards Profile Using a Flexible Risk Assessment Method

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Declaration: Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

Karin Reinhold

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KEEMIA JA KEEMIATEHNIKA G23

Töökeskkonna hindamine: ohtude profiili määramine paindliku riskianalüüsi meetodi abil

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TTÜ KIRJASTUS

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INTRODUCTION

Successful health and safety management is a process of protecting people by continuously making successful decisions. In defining best practice for manufacturing performance, Basu and Wright (1997) consider health and safety management to be one of six key elements of a successful manufacturing organization alongside such issues as marketing and innovation.

Health and safety management relies on risk control, which is underpinned by the process of risk assessment (BSI, 2004). No matter how simple or complicated risk assessment is, it requires a systematic method and process to be effective. The requirements for risk assessment vary depending on the novelty of the work activities in the enterprise. In many countries, including Estonia, employers are legally obliged to carry out systematic, documented workplace risk assessment which sets a special requirement to the method used: it should be flexible enough to be applicable for a large variety of enterprises.

Even though the first schemes to assess workplace risks came to prominence in the 1970s (Harms-Ringdahl, 2001; Lees, 1980; Rouhiainen, 1990), the rapid kick-off in Europe appeared in 1989 when a new EU regulation (EEC, 1989) started to require national legislation of the member states to make firms of all sizes establish procedures for risk assessment.

Inadequacies of risk assessments have been one of the main violations in the field of occupational health and safety for years. For instance, in 2007, workplace risk assessment was still not carried out or did not meet the requirements in 63% of inspected enterprises in Estonia (Labour Inspectorate, 2008). Like in many other European countries, small and medium-sized enterprises are a problem area for Estonian occupational health and safety because their owners often lack knowledge on risk assessment and risk management. As there are about 60,000 small and medium-sized enterprises in Estonia, the National Labour Inspectorate has the capacity to inspect only those which deal with hazardous activities or where a serious accident has been reported (Reinhold et al., 2009). Therefore, an adequate overview of the level of existence and quality of risk assessment reports among small and medium-sized enterprises is still lacking.

The current research is an attempt to offer a flexible risk assessment method to assess hazards at workplaces. First, the macro statistics regarding Estonian occupational health and safety performance is outlined and the existing risk assessment methods are overviewed. Second, a flexible method of risk assessment developed for enterprises of different level of safety is presented. Third, the determination of risk levels for physical and chemical hazards and connections between risks and health hazards are offered. Fourth, a report on the original empirical surveys of Estonian enterprises in the clothing and wood processing industry is presented.

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Tallinn, March 2009

Karin Reinhold

LIST OF ORIGINAL PAPERS

This thesis is based on the following papers which will be referred to in the text by their Roman numerals:

I **Reinhold, K.,** Tint, P., Kiivet, G. 2006. Risk Assessment in Textile and Wood Processing Industry. International Journal of Reliability, Quality and Safety Engineering, 13(2), April 2006, 115-125.

II **Reinhold, K.,** Tint, P. 2009. Hazards profile in manufacturing: determination of risk levels towards enhancing the workplace safety. Journal of Environmental Engineering and Landscape Management, accepted.

III **Reinhold, K.,** Tint, P. 2007. Improvement of work environment in textile industry in Estonia. Foundations of Control and Management Sciences, 08/2007, 61-76.

IV **Reinhold, K.,** Tint, P. 2008. Chemical Risk Assessment in the Work Environment. Environmental Research, Engineering and Management, 4(46), 48-55.

V **Reinhold, K.,** Järvis, M., Tint, P. 2009. Risk Observatory—A Tool for Improving Safety and Health at the Workplace. International Journal of Occupational Safety and Ergonomics, 15(1), 101-112.

VI **Reinhold, K.,** Tint, P., Munter, R. 2009. Indoor air quality in industrial premises. Sci. Proc. Riga Technical University "Material Science and Applied Chemistry", accepted.

Other publications related to the topic:

1. **Reinhold, K.,** Tint, P., Tuulik, V., Saarik, S. 2008. Innovations at Workplace: Improvement of Ergonomics. Engineering Economics, 5(60), 85-94.
2. Tint, P., Kiivet, G., **Reinhold, K.** 2004. Improvement of the safety culture at Estonian enterprises. In: Hazards XVIII. Process Safety – sharing best practice. Institution of Chemical Engineering. Rugby, UK. 122-131.
3. **Reinhold, K.,** Tint, P. 2005. Implementation of a simple risk assessment method in the work environment of manufacturing. In: Environmental Engineering – Selected papers. The 6th International Conference. May 26-27, Vilnius, Lithuania. Volume 1, 234-238.
4. **Reinhold, K.** 2006. Chemical risk assessment in manufacturing. In: Safety and Reliability for Managing Risk. Ed: G.Soares & E.Zio. Taylor & Francis, London, 823 – 828.
5. Tint, P., Kask, Ü., Kõiv, T.-A., Vinnal, T., **Reinhold, K.** 2006. Improvement of environmental and health issues in educational institutions. In: Safety and Reliability for Managing Risk. Ed: G.Soares & E.Zio. Taylor & Francis, London, 835-840.

6. **Reinhold, K.,** Tint, P. 2007. Improvement of safety culture in Estonian garment industry with computer applications. In: Risk, Reliability and Social Safety. Volume 2: Thematic topics. Ed: T.Aven & J.E.Vinnem. Taylor&Francis, London, 1267-1274.
7. Tint, P., Järvis, M., **Reinhold, K.,** Tuulik, V. 2007. Prevention of physiological and psychological stress at workplace. In: Risk, reliability and Societal Safety. Volume 2: Thematic topics. Ed: T.Aven & J.E.Vinnem. Taylor & Francis, London, 1275-1282.
8. **Reinhold, K.,** Tint, P., Kiivet, G. 2005. Safety culture at Estonian enterprises. In: Adding years to life and life to years. Collection of Research Articles. TUT Press, Tallinn, 89-95.
9. Tint, P., **Reinhold, K.,** Tuulik, V. 2004. Risk assessment of chemicals influencing on central nervous system. In: Human Factors in Design. Shaker Publishing, Maastricht, 251-254.
10. Tint, P., Tuulik, V., **Reinhold, K.** 2003. Early diagnosing of occupational diseases caused by chemical hazards. In: Risk and Safety Management in Industry, Logistics, Transport and Military Service: New Solutions for the 21st Century, March 25-28, Tallinn, 86-92.
11. **Reinhold, K.,** Lell. K. 2003. Improving garment workers' ergonomics. In: Mind and Body in a Technological World. Proceedings of the 35th Annual Congress of the Nordic Ergonomics Society, August 10-13, Reykjavik, Iceland, 287-290.

Author's own contribution

I Author participated in working out and developing the new risk assessment method. The method was implemented in wood processing and clothing industry by the author and her colleague (second author).

II Author wrote the paper and developed the criteria for the model of physical occupational hazards. She and her colleague conducted the measurements in selected industries. The interpretation of all the results as well as calculation of predicted risk levels of noise measurements were performed by the author.

III Author wrote the paper and interpreted the results. The measurements were partly carried out with the co-author.

IV Author participated in writing the paper. She participated in conducting the measurements and compiled the practical part of the paper.

V Author participated in writing the paper. She prepared the figures, interpreted the practical results and wrote the paragraph about risk assessment.

VI Author wrote the paper. She carried out the measurements of indoor air and chemicals and worked out the criteria for the model with the co-author. The results were written by the author.

SYMBOLS AND ABBREVIATIONS

CCT	Chemical Control Toolkit
CNS	central nervous system
COSHH	Control of Substances Hazardous to Health
$\bar{E}_m$	mean illuminance, lx
EASE	Estimation and Assessment of Substance Exposure
ESAW	European Statistics on Accidents at Work
f	illuminance uniformity
GHS	Globally Harmonised System
IDLH	immediately dangerous to life or health concentration
$L_{Aeq,Ti}$	equivalent continuous A-weighted sound pressure level, dB
$L_{EX, 8h}$	noise exposure level, normalised to a nominal 8 h working day, dB
L_{peak}	C-weighted peak sound pressure level, dB
MSDS	Material Safety Data Sheets
NLI	National Labour Inspectorate
NNR	Noise Reduction Rate
OEL	occupational exposure limit
OHS	occupational health and safety
OSHA	Occupational Health and Safety Administration (USA)
PRHI	Process Route Healthiness Index
R_a	colour rendering index
REACH	Registration, Evaluation, and Authorisation of Chemicals
R-phrase	risk phrase
SME	small and medium-sized enterprises
TWA	time weighted average

1. LITERATURE REVIEW

1.1 Short overview of the current situation in the field of occupational health and safety in Estonia

Workplace risk assessment can be defined as a systematic procedure for analysing workplace components to identify and evaluate hazards and safety characteristics (Harms-Ringdahl, 2001). According to EU regulation (Council Directive 89/391/EEC) each member state of the European Union has to establish national legislation to demand risk assessment procedures in enterprises of all sizes (EEC, 1989). In Estonia, the Act on Occupational Health and Safety, which requires risk assessment at every workplace, was adopted in 1999. Workplace risk assessment has to be conducted by the employers using their own resources or by registered practitioners in occupational health (Occupational Health and Safety Act, 1999).

The basic aim of a risk assessment is to prevent accidents (Harms-Ringdahl, 2001). In Estonia, the rate of registered occupational accidents has increased compared to 1998 – a survey (Eurofound, 2007) shows that the standardized index of serious and fatal accidents at work in 2004 was 124. This value appeared 35.4% higher than the average EU value (Figure 1.1). The reasons for this outcome have not been studied in depth, therefore at this time understanding of their complex nature remains speculative. The National Labour Inspectorate (NLI) registered 3707 occupational accidents in 2007 (565.7 occupational accidents per 100,000 workers) which was approximately 7 times less than in the European Union on average (Eurostat, 2008a). The data of occupational accidents registered in Estonia in three months periods from 2004 to 2007 points to an increasing trend in minor and severe accidents while the number of fatal accidents was slightly decreasing (the rate of fatal accidents per 100,000 workers was 4.0, 4.2 and 3.2 in 2005, 2006 and 2007, respectively). Following ESAW methodology (Eurostat, 2001), the incidence rate of fatal accidents in Estonia in 2005 was over 15% higher than the average European Union figure (Eurostat, 2008b).

The experts in this field claim that Estonian statistics of occupational accidents presents a remarkable inconsistency (Kempinen, 2004; Tint et al., 2008; Vare, 2008). To find the answer for the increasing statistical trend (prognosis after visual smoothing (by using sliding mean) and removal of occasional component (by using seasonal index)) (Figure 1.2), it is essential to stress that only a minority of occupational accidents are registered in Estonia (Estonia does not have an insurance based system that would guarantee a high reporting level; but uses the reporting system based on the legal obligation of the employer to notify about the accident to the Sub-Bureau of the NLI). However, in recent years many campaigns and several projects on occupational health and safety (OHS) have been launched and carried out by the NLI, European Agency for Safety and Health at Work and the Ministry of Social Affairs. These have had a rather positive effect in increasing the employers' and employees' awareness of the importance of health and safety issues at enterprises as well as in the development of OHS in Estonia in general and probably have led to a higher number of reporting about accidents.

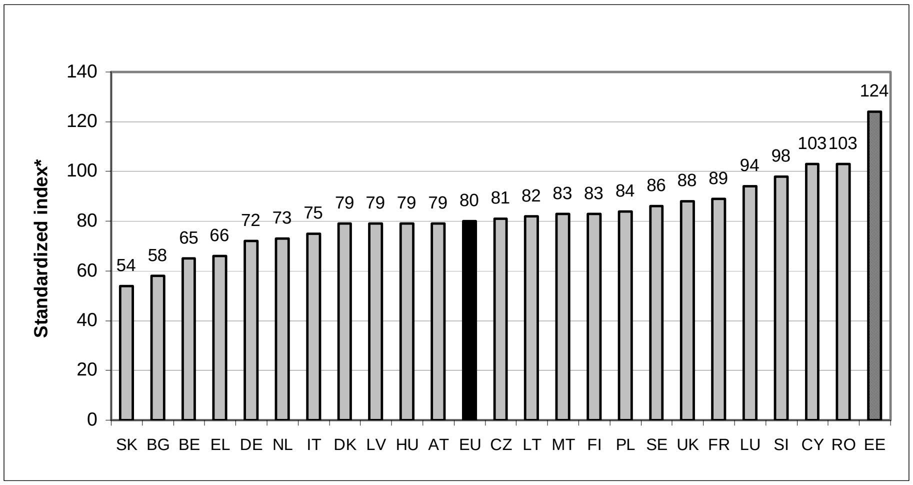

Figure 1.1 Serious and fatal accidents at work in the EU in 2004 (1998=100)*
*1998 is the reference year, and is indicated as the value of 100. Any data above 100 therefore represent an increase in the incidence of serious and fatal work accidents since 1998, while data below 100 represent a decline in the number of such accidents since that year. Data for IE, ES and PT are not available for 2004.

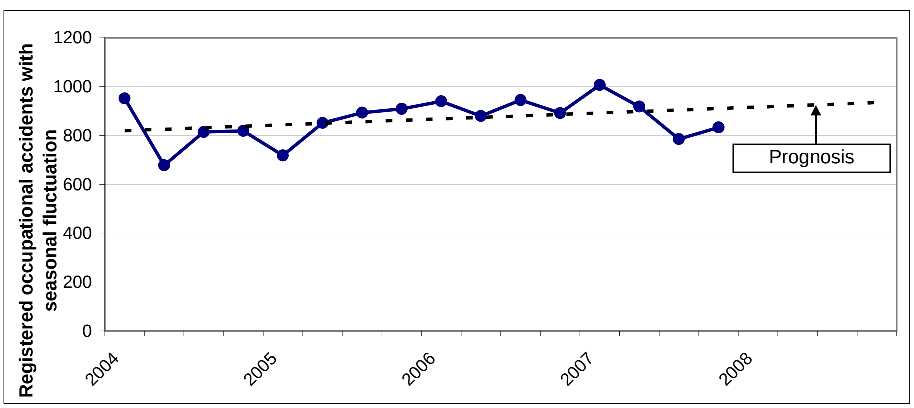

Figure 1.2 Registered occupational accidents with seasonal fluctuations and statistical prognosis (Reinhold et al., 2008a)

The incidence of occupational diseases is another specific indicator of existing hazards and risk factors in the work environment. In Estonia, a very small proportion of occupational diseases are diagnosed. The few that are registered by the doctors are already in their later stages when the patient is incapacitated. The rate of registered occupational diseases per 100,000 workers was only 16.0, 18.1 and 11.3 in 2005, 2006 and 2007, respectively (Labour Inspectorate, 2008). In Finland, the rate of registered or suspected occupational diseases is more than 15 times higher (e.g. in 2005, 280 cases per 100,000 workers (FIOH, 2006)). The most common diagnoses by Estonian occupational health doctors are noise induced hearing loss and repetitive strain injuries.

In most industrialized countries, there is a general obligation on the employer to provide occupational health services for personnel. Finland is one of the best examples, where the OHS system provides both preventive measures and, if necessary, medical treatment. According to Walters (1996), about 85% of the Finnish employees are covered by the OHS system, which is one of the highest proportions in Europe. In those European countries where the OHS personnel consists only of persons qualified in the medical professions, preventive activities are not so extensive. Diagnosis of occupational diseases in the early stages is facilitated when occupational health services are authorized by the government (Kahn et al., 2003). In these conditions, the possible disabling of workers in the middle age (40–45 years) can be prevented. According to Estonian legislation, the employer is obliged to organize medical examinations considering the results of risk assessment conducted in the work environment. However, the recent (2007) annual report of the NLI presents evidence to suggest both the absence and low quality of risk assessment reporting in many companies. This leads to a lower number of workers being covered by occupational health services in Estonia.

Considering the statistics of occupational accidents, the problems with diagnosing occupational diseases and higher number of people who receive compensation for damages related to occupational accidents and diseases, one can conclude that the efforts made to improve work environment conditions over the last years have not yielded the expected results. There is still a long way to go before companies succeed in controlling risks at their sources. The results of the overview indicate that despite the undeniable progress accomplished over the years, there are good reasons to re-examine the methods in the field and find a new approach to controlling risks.

1.2 Overview of the concept of workplace risk assessment

Risk assessment is the foundation of pro-active OHS management (BSI, 2004). The overall purpose of risk assessment is to understand the hazards that might arise in the course of the organization’s activities and ensure that any risks to people arising from the hazards are acceptable or tolerable.

According to statistical data of NLI, several shortages exist in implementing the regulations in OHS field (Figure 1.3).

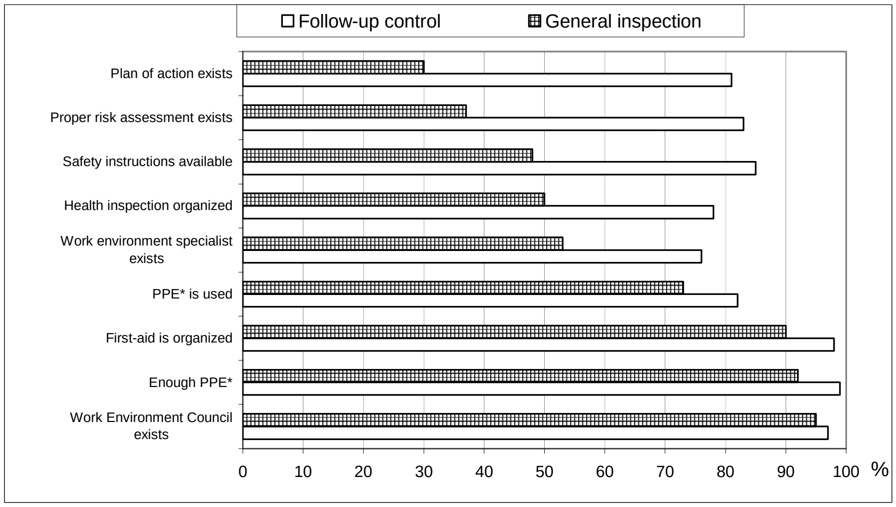

Figure 1.3 Health and safety activities in enterprises (% of inspected enterprises)
(Abbreviation: *PPE = personal protective equipment)

Problems with risk assessments have been one of the main violations for years. For instance, in 2007, workplace risk assessment was still not carried out or was not in accordance with the requirements in 63% of inspected enterprises; after prescription and follow-up inspection, it was still of poor quality in 13% of inspected enterprises (Labour Inspectorate, 2008).

The main shortages in risk assessment are:

- no specific method is followed and therefore, no consistency;
- principles for risk level estimation are confusing;
- machinery safety is underestimated;
- risk assessment is not based on work environment measurements;
- the approach to hazardous chemicals is insufficient (Labour Inspectorate, 2008).

In collaboration with NLI and risk assessment practitioners, including researchers from Tallinn University of Technology, the employers' awareness and responsibility about implementation of risk assessment has slightly increased. It is illustrated by NLI inspection strategy, where during the primary inspection the enterprises were divided into three groups according to how safe the work conditions were: low (22%), medium (58%) and high risk (20%). During the follow-up inspection, the inspectors noted that the proportion of low risk enterprises had increased and those of medium and high risk enterprises had decreased (*Paper V, Figure 1*).

It should be kept in mind, that gaining a successful safety culture in an enterprise and diminishing accidents many other factors such as management commitment to safety, workers' active participation, safety training, informational campaigns and safety programs, good communication and feedback, etc. are also important besides a comprehensive systemized risk assessment report (Saarela, 1991; Salminen et al., 1993; Vredenburgh, 2001).

The disputes about the adequacy of workplace risk assessment are an on-going subject in many other countries as well. In Denmark, researchers argue that workplace risk assessment is implemented successfully in the larger firms, but only a minor fraction of small firms comply. The stated causes are lack of time, resources and knowledge (Jensen et al., 2001). In Norway, a research (Solberg, 2007) revealed that risk assessments of transporting dangerous goods are used to satisfy the inspectorate's standards on the subject rather than to support risk based decisions. In this case study, the safety specialists in many interviewed companies indicated that they do not have the knowledge or the capacity within their organization to produce a proper risk assessment. According to this survey, almost without exception the safety specialists perceive risk assessment as a complicated quantitative mathematical process where the expert knowledge is needed. In the UK, Walker and Tait (2004) recommend intervention (in the form of assistance by information centres and outside assessors) in order to perform adequate risk assessment in small enterprises. In this survey, 19 of 24 enterprises had not assessed the risks in a systematic way before the intervention. O'Hara, Dickety and Weyman (2005) emphasize in their research that two main barriers exist for SMEs to risk assessment: time pressure and access to suitable guidance (both general and specific). Woodruff (2005) argues that existing semi-quantitative risk estimation methodologies applied within the UK are biased towards considerations of possible consequences rather than overall risk. He proposes a new approach in lower risk industrial sectors - instead of seeking an explicit value for the level or risk, it is sufficient to establish whether the risk is likely to fall within intolerable, tolerable or acceptable risk zone. French researchers (Cuny and Lejeune, 1999) claim that the need to control the severity of risk is highlighted by scientifically acquired improvements in the understanding of occupational risk and offer a method of measuring the degree of the severity of the consequences of potentially dangerous events.

Makin and Winder (2008) in Australia are concerned that during the performance of risk assessment the entire context of workplace hazards may not be considered and therefore, some hazards are overlooked. They offer a method to identify workplace hazards considering three key elements (the people, the physical workplace and the management). In the US, Hendershot (2006) states that risk quantification techniques are rather sophisticated and therefore not used appropriately.

It is clear that risk assessment in work environment needs further scientific approaches as well as clarifications in terminology (different approaches to the scope of risk analysis and risk assessment are applied in Europe and in the US). Terminological differences may exist by industrial branches, too – in the chemical industry, the term *risk analysis* is preferred over the term *risk assessment* while in the nuclear industry, *safety analysis* appears to be more common (Harms-Ringdahl, 2001).

In Estonia, when the OHS Act was implemented (1999) according to the EU legislation the term *risk analysis* was used, but for many researchers and experts in European countries (Cuny and Lejeune, 1999; Vassie and Lucas, 2001; Woodruff, 2005), the same concept was known as *risk assessment*. Those two terms are not differentiated in Estonia and are understood as the same. The clarification of the terms used describing risks in the workplace is beyond the scope of this study and the term *risk assessment* is used throughout the work according to Figure 1.4.

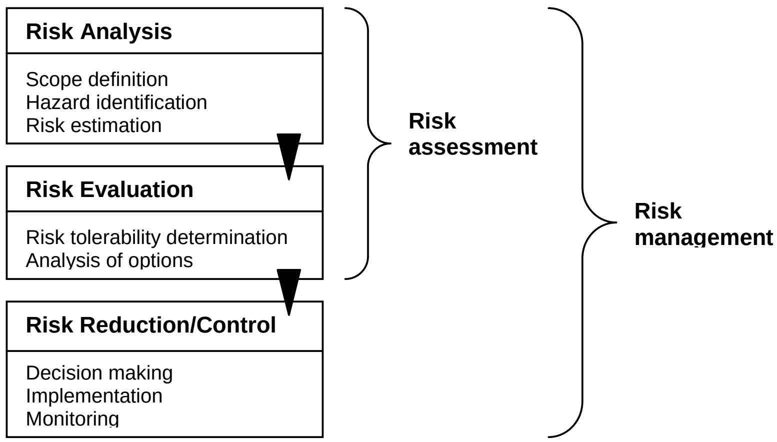

Figure 1.4 A simplified scheme of relationships between risk analysis, risk evaluation, risk assessment and risk management (Rouhiainen and Gunnerhed, 2002)

1.2.1 Problem setting – determination of risk levels

Risk assessment in the work environment has been an essential topic since 1989, when the EU regulation came into force which says that all member states of the EU have to set up national legislation to make firms establish procedures for risk assessment in enterprises of all sizes.

Certain key steps should be identifiable in any systematic approach to risk assessment and risk management (Ale, 2002; BSI, 2004; Harms-Ringdahl, 2001). The steps of risk assessment include hazards identification, risk estimation and proposal of safety measures. The central component of most risk assessments is the identification of hazards that might lead to accidents and diseases. The aim should be to discover the major sources of danger and identify factors that might trigger off an accident. Risk estimation constitutes a specific stage in the analytical process: the seriousness of an identified hazard needs to be evaluated and a basis for deciding whether the environment is acceptable as it is or not has to be provided. If needed, risks can be reduced through one or several safety measures. The reduction can apply either to consequences or the probability that such negative events will occur.

The determination of risk levels in the whole risk assessment procedure is one of the essential issues. The following factors have to be considered:

- justification of risk
- economic evaluation of risk
- the limits for risk level criteria (Ale, 2002; Le Coze, 2005).

Ethically any kind of risk is unjustified. But for economic considerations, the worker may have a free will to work in the conditions that do not meet the requirements set to the work environment. There is a balance in assigning a value to an acceptable risk between reward and risk, knowledge and risk and choice and risk. Hence the workers who are voluntarily exposed to a risk which they have been informed about and trained to deal with in a job for that they are being paid are assumed to accept a higher risk than the general public.

The sophistication of risk quantification techniques has outstripped their accuracy and utility, which has been a concern of researchers outside Estonia as well (Hendershot, 2006; Woodruff, 2005). It is essential to propose unambiguous and time-sustainable techniques for risk assessment as by the Estonian Law, employers themselves are allowed to carry out risk assessment, but they may not be experienced experts in risk theory and safety science.

1.3 The development of risk assessment models

The imperative to identify approaches to risk assessment that are both accurate and simple has led to development of various schemes for evaluating and controlling risks. Such schemes first came to prominence in the 1970s (Harms-Ringdahl, 2001; Lees, 1980; Rouhiainen, 1990). In essence, the schemes develop a risk matrix that usually describes the likelihood and probable severity of the event of concern. Risk matrices are tables in which the combination of parameter classification leads to a risk level definition of the risk of the identified hazards.

The standard risk matrix is two-dimensional (BSI, 1996; BSI, 2004; Harms-Ringdahl, 2001; Rouhiainen and Gunnerhed, 2002) but they can have up to four dimensions (Görnemann, 2007). Additionally, risk graphs are used (Aneziris, 2006; Brandsæter, 2002; ISO, 2007) which are treelike structures in which from a starting point parameter based decisions have to be taken in order to obtain the result of the estimation. Often a combination of both kinds of structures is used, but the practical use is limited by the number of decisions or thresholds (Görnemann, 2007).

1.3.1 Models in Europe, the US and Australia

According to a widely used standard in Europe, BS 8800:2004, three harm levels (slight, moderate and extreme harm) on health are determined (BSI, 2004). The number of risk categories is five (very low, low, medium, high and very high risk). Additionally, three risk variables are obtained from the evaluation of risk tolerability named as acceptable, tolerable or unacceptable risk. Very low risk is considered acceptable, very high risk unacceptable; while the other levels between acceptable and unacceptable (low, medium, high risk) require reduction to acceptable or tolerable level (acceptable risk is a smaller risk than tolerable).

Another risk model was proposed in the UK by Woodruff (2005). This model is based on the risk calculations for lower and upper limits of tolerable risk using acceptance values. In this model, the calculation of risk is given as

$$R = S \times P, \qquad [1]$$

where R is the risk, S is severity of harm (consequences) and P is the likelihood of the occurrence of that harm. Putting acceptance values into Eq. [1] two equations for the upper (R_U) and the lower (R_L) limits of tolerable risk are obtained [Eq's 2 and 3].

$$R_U = 0.001 = S \times P_U, \qquad [2]$$

$$R_L = 0.000001 = S \times P_L \qquad [3]$$

The risk matrix is created if a value of 1 is nominally assigned to a fatal injury severity of harm and can be called as straightforward risk matrix (Figure 1.5) in which severity is plotted against the likelihood of the occurrence of that harm (Woodruff, 2005). The risk levels are determined: acceptable, tolerable and unacceptable, which can be interpreted as high, medium and low risks, respectively.

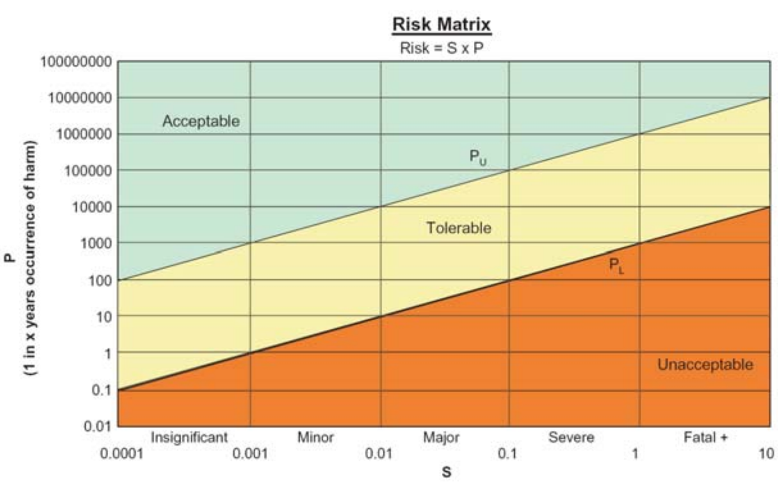

Figure 1.5 Risk matrix with 3 risk levels (Woodruff, 2005)

In recent years, a new form of logic models suitable for quantifying occupational risks has been developed (Aneziris et al., 2006; De Vries and Stein, 2008; Papazoglou, 1998; Papazoglou and Ale, 2007) are based on the concept of functional block diagrams. These models exhibit the advantages of event-trees in that they can accommodate multi-stage events and general probabilistic dependence among the events. Figure 1.6 presents the computerized tool developed for implementing functional block diagrams, where the "bowtie" scheme is outlined (the objects left of the Centre Event involve the major functional blocks of input and prevention; those to the left of Dose involve the functional blocks of mitigation, those to the left of Consequence include the Dose-Response related functional block).

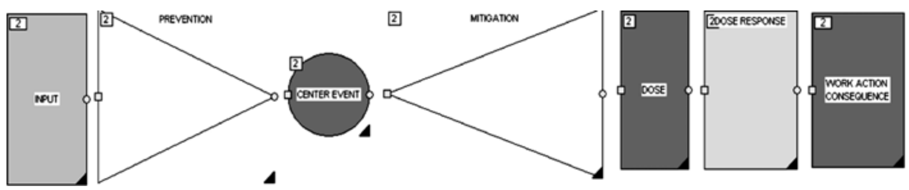

Figure 1.6 Bowtie representation of the fundamental Functional Block Diagramms (Aneziris et al., 2006)

De Vries and Stein (2008) proposed an assessment of work conditions using Fuzzy Logic approach. They claim that well-designed fuzzy rule-based systems, which can be developed by a knowledge engineer and an expert in regulative requirements, are able to assess the work conditions connected with buildings. In their case study, indoor climate, lighting level, sources of pollution and environmental psychological problems (e.g. privacy problems) were successfully assessed.

Görnemann (2007) offered a "Scram" method that uses a basic matrix with ten different levels, and is mainly aimed to machine safety to improve the quality and depth of risk assessment by adding additional parameter evaluations in a scalable structure. After the determination of the machinery limits and identification of possible hazards, a risk estimation (Figure 1.7) is used to determine the resulting risk level. For each parameter relevant tables can be used to define more precisely the threshold or limit of each value; also a risk awareness table and an avoiding possibility table are available for deeper risk assessment.

In the US, the Workplace Exposure Assessment (WORKBOOK) has been developed, which enables knowledgeable and qualified people to assess worker exposure to biological, chemical and physical agents under the guidance of a professional hygienist. It is based on questionnaires and provides conclusions about relative risks from high, medium or low exposures (Tait and Mehta, 1997). Another approach is called EAS (Booher et al., 2005); it combines worker exposure information (for chemical, biological and physical agents) with health risk information using the risk matrix shown in Figure 1.8.

RISK ELEMENTS TABLE

	Severity of Harm *	Exposure to Harm *	Harm avoidance *	Probability of Ocurrence * Low	Middle	High
START	No Harm **	-	-	0	0	0
	Low	-	Avoidable	0	0	1
			Not avoidable	0	1	2
	Middle	Low	Avoidable	1	2	3
			Not avoidable	2	3	4
		High	Avoidable	3	4	5
			Not avoidable	4	5	6
	High	Low	Avoidable	5	6	7
			Not avoidable	6	7	8
		High	Avoidable	7	8	9
			Not avoidable	8	9	10
				Resulting Risk Level		

** Only required to evaluate risk reduction

Figure 1.7 Risk elements of "Scram" scalable risk assessment method (Görnemann, 2007)

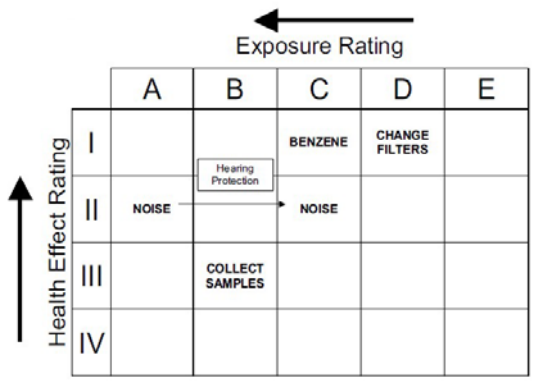

Figure 1.8 EAS Risk Matrix illustration (Booher et al., 2005)

1.3.2 Models in Estonia

Assessment of occupational risks in Estonia began in 1998, when the European document „Guidance on risk assessment at work" (European Commission, 1996) became accessible. This guidance is tightly connected with the BS 8800:1996, and therefore, all the models worked out in Estonia, are derivates of the risk matrix offered in this standard. The scheme of the *MODEL 1* (Table 1.1 (Tint, 1998)) presents the risk estimation where the determination of the risk level is not strongly connected with the exposure limits in the work environment.

Taal (1999) uses risk estimation scheme (*MODEL 2*, Table 1.2) where harmful risk with safety measures is allowed in certain conditions (jointly with measurements of work conditions). The scheme divides risks into three distinctive zones marked as green, yellow and red zone similar to the *MODEL 1*. However, in

MODEL 2, the only permitted risk without special attention is trivial risk (I), which falls to the green zone. The risk levels have the following coloration:
I, green zone – permitted risk;
II and III, yellow zone – permitted risk, with caution: the safety guidance has to be closely followed and the worker's individual peculiarities have to be considered;
IV and V, red zone – inadmissible risk, which requires mitigation/elimination or additional safety measures in order to continue the work procedures.

Table 1.1 *MODEL 1* risk estimation

Likelihood	**Consequences**		
	Slightly dangerous (no injury expected)	Dangerous (injur with sub-sequent complete recovery)	Extremely dangerous (permanent severe incapacity)
Almost impossible	Trivial risk **I**	Acceptable risk **II**	Moderate risk **III**
Considerably improbable, but possible	Acceptable risk **II**	Moderate risk **III**	Substantial risk **IV**
Probable	Moderate risk **III**	Substantial risk **IV**	Intolerable risk **V**

Table 1.2 *MODEL 2* A simple risk level estimator

Likelihood of harm	**Severity of harm**		
	Slightly harmful	Harmful	Extremely harmful
Improbable	**I** Trivial risk	**II** Tolerable risk	**III** Harmful risk
Unlikely	**II** Tolerable risk	**III** Harmful risk	**IV** Dangerous risk
Probable	**III** Harmful risk	**IV** Dangerous risk	**V** Intolerable risk

MODEL 2 was used as a starting point to develop the NLI method "Risk analysis in the work environment and the arrangement of internal audit" (Kruus et al., 2001). A similar approach is also applied in the document "Five steps of risk assessment" (1998, in Estonian), which was compiled on the basis of Health & Safety Executive (HSE, 1994).

The following model (*MODEL 3)* was worked out by the labour inspector Laurik (Table 1.3) (Tint, 1998). In *MODEL 3*, the multiplication of probability and severity is determined as a numerical risk level, which has six distinguishable levels: trivial (I), small (II), acceptable (III), medium (IV), substantial (VI) and intolerable (IX). The peculiarities in this model are the significantly greater number to intolerable risks compared to substantial risk and equalization of acceptable and tolerable risk (level III).

Table 1.3 *MODEL 3* Risk matrix developed by Laurik (Tint, 1998)

The risk level is estimated by dependence $R = S \times T$, where S is the probability and T – the severity of the occasion.

Probability (S)	**Consequence (T)**		
	Trivial injury (microinjury), some shortlasting ill-feelings	Slight injury or disease due to the dangerous, harmful work conditions	Severe injury or disease (death, disability, occupational disease)
Improbable (very seldom), occupational injury or disease appears once in 10…20 years	**I** Trivial risk	**II** Small risk	**III** Acceptable, tolerable with measurements
Unlikely (seldom), occupational injury or disease happens in some years	**II** Small risk (accepted)	**IV** Medium risk, (eliminated with measures in 3-5 months)	**VI** Substantial risk (eliminated in 1-3 months)
Probable (often), one or some accidents happen a year	**III** Acceptable, tolerable risk (eliminated in 3-5 months)	**VI** Substantial risk (eliminated in 1-3 months)	**IX** Intolerable risk (stop the activities at once)

The final improved matrix, *MODEL 4* (Table 1.4), uses the colour scheme from *MODEL 1* and *MODEL 2*, and the principle for calculation of risk levels from *MODEL 3*. The severity of the consequences is determined as follows: (i) slight (overcoming disease or trauma that does not cause permanent damage); (ii) harmful (dangerous or permanent health damages such as burnings, concussions, hearing loss, asthma, etc); (iii) very dangerous (permanent and irreversible damages such as limb loss, poisonings, fatal accidents, accidents causing health damages for several workers, etc).

Table 1.4 *MODEL 4* Risk matrix with six risk levels (Kruus et al., 2001)

Probability	**Consequences**		
	Slight (1)	**Hazardous (or harmful) (2)**	**Very dangerous** (3)
Improbable (or impossible) (1)	Trivial risk (1)	Small risk (or tolerable) (2)	Permissible risk (or hazardous) (3)
Unlikely (or slightly probable) (2)	Small risk (or tolerable) (2)	Permissible risk (or hazardous) (4)	Permitted with control (or harmful) (6)
Probable (3)	Permitted risk (or hazardous) (3)	Permitted with control (or harmful) (6)	Unpermitted risk (endangering life) (9)

The last method is considered to have the highest value in assessing risks at workplace and has been created in co-operation of several Estonian risk assessment specialists; however, it has not achieved the expected popularity among practitioners. The reasons for it are not studied in depth.

Despite several theoretical risk assessment models available, the primary shortages in risk assessment reports include, as mentioned before, the absence of a specific method and confusion with principles for risk level estimation (Labour Inspectorate, 2008). This indicates the necessity to offer a fresh approach to assessing risks at workplaces.

1.4 Chemical exposure and risk assessment at workplaces

People are continuously exposed to different chemical hazards in everyday work-life and during their leisure time continuously. According to the data gathered by the National Board for Health Protection of Estonia in 1996 (Tint, 1998), at least 25,000 workers were exposed to different types of chemicals (petroleum products, nitric and lead compounds, benzene and its derivates, manganese, nickel, phenols etc.) and 22,000 workers were exposed to different types of aerosols (organic dust, welding aerosols, oil-shale dust, mineral fibres, dust of abrasive materials, etc.)

Exposure to a chemical agent is typically the contact of that agent with the outer boundary of a subject, such as the respiratory system, skin, or digestive system (Harper, 2004). In occupational settings, the main concern is towards exposure through the respiratory system, although increasingly results of dermal exposures are a problem as well.

Currently, workplace chemical safety information is communicated primarily by means of classification listings, labels and Material Safety Data Sheets (MSDS) provided by the chemical manufacturer or supplier, while the toxicological data are rarely consulted (Fairhurst, 2003). The lack of information is expected to be overcome by new European chemicals policy. The new EC Regulation No 907/2006 on the Registration, Evaluation, and Authorisation of Chemicals (REACH) came into force on 1 June, 2007 (EC, 2006). REACH aims at improving the protection of human health and the environment through a more inclusive and focused system for the identification and assessment of the properties and uses of chemical substances produced in or imported to Europe. The detailed testing requirements under REACH have not yet been harmonized with the requirements for substance classification under the currently developed Globally Harmonized System (GHS) (Foth and Hayes, 2008).

The number of occupational diseases is a specific indicator of the influence of existing hazards and risk factors in the work environment. Exposure to chemicals may initiate various occupational diseases such as skin diseases, airway and lung diseases, neurological diseases, or exacerbate noise induced-hearing loss (Bardana, 2008; Morata et al., 1993; Sliwinska-Kowalska et al., 2005; Timbrell, 2002). To diminish the mutagenic, carcinogenic, teratogenic and other harmful effects of chemicals, the health damages have to be diagnosed in the early stage of the illness.

Therefore, tracing linkage from disease to possible causative agents by screening for the presence of specific chemicals is crucial.

Within the framework of European risk assessment of chemical substances, the occupational risks have to be assessed (EC, 1998). This risk assessment is performed considering the toxic properties of a substance on the one hand and the extent of exposure at the workplace on the other. The principles of risk assessment are described in the Technical Guidance Documents (EC, 1996), where it is recommended that the risks of workers should be determined on the basis of measured exposure levels or in the absence of measurement data by means of models. In order to perform an accurate risk assessment of chemical exposure, a health and safety expert is usually needed. However, there are often cases where an expert is not readily available, especially among SMEs. The conclusions of a scientific investigation held in the UK (Topping et al., 1998) suggest that companies lack the appropriate tools to make a thorough evaluation of chemical risks. Thus, a simplified risk assessment method that provides assessment results without expert involvement is required.

1.4.1 Existing assessment methods

In general, the methods that aim at making the analysis of chemical risks more accessible to companies can be grouped into four categories (Balsat, 2003). These methods claim to be simple and the majority of them use the R-phrases (EC, 2001) for identification of hazards. The last two groups can be interpreted as risk assessment methods since they either evaluate the acceptability of the risk (third level) or make the semi-quantitative risk assessment possible (fourth level). The use of R-phrases as the basis of a generic approach to the development of exposure control levels is not novel. For example, Gardner and Oldershaw (1991) proposed a generic approach to the development of appropriate exposure-control levels for volatile organic substances, based on R-phrases for single exposure toxicity. The most relevant shortcoming of the schemes that are built up using R-phrases as the main danger parameter is the fact that they are highly dependant on the good use by suppliers of the R-phrase classification system.

According to literature (Topping et al., 1998), there are strong indications that occupational exposure limits (OELs) could also, with additional information (for example on physical properties and use), be used to identify appropriate control measures that can be recommended to users of chemicals. Approaches that use OELs were developed by Brooke (1998) and Russell et al. (1998). The method by Brooke shows how established OELs, for which there is well documented information on the basis of the limit, can be used to validate the control strategies recommended by the scheme. The scheme identifies best-case, worst-case and midpoint margins between target airborne concentrations for chemical hazards, based on exposure limit values and toxicological data (example in Table 1.5, for vapours with the R-phrase R48 (*Harmful* case)), defines four main risk levels (hazard bands) + skin hazard, but does not make specific connections between the health hazards and risk levels.

Table 1.5 Margins between target airborne concentrations for hazard band B (R48 *Harmful*) and repeated exposure classification for cut-off values according to Brooke (1998), for vapours

			Target airborne concentration for hazard band B, ppm		
			Lower	Upper	Midpoint
Mole-cular weight	Harmful R48 classification cut-off values, equated to TWA (8 h) concentration, ppm		5	50	28
50	Upper	90	18[1]		
	Lower	9		0.18[2]	
	Midpoint	50			1.8[3]
100	Upper	45	9[1]		
	Lower	5		0.1[2]	
	Midpoint	25			0.9[3]
150	Upper	30	6[1]		
	Lower	3		0.06[2]	
	Midpoint	17			0.6[3]

(Abbreviations: [1]-best-case; [2]-worst-case; [3]-midpoint)

The scheme proposed by Russell et al. (1998) is dependant on the availability of robust OELs for a range of substances. It takes for its hazard base the R-phrases assigned to chemicals by suppliers as part of their classification, labelling and packaging duties. From its R-phrases, a chemical is assigned to one of five hazard bands that will determine the level of exposure the scheme seeks to help the employer achieve (Figure 1.9).

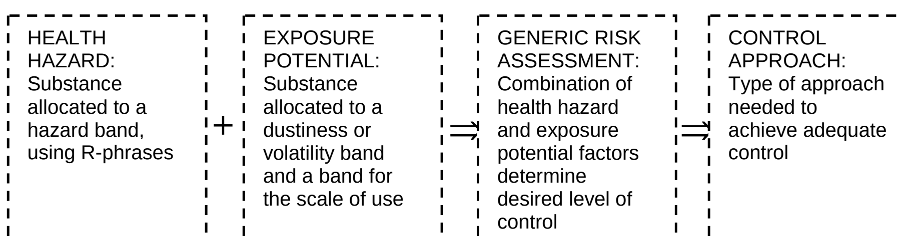

Figure 1.9 Factors used in the core model by Russell et al. (1998)

Development of various schemes for evaluating and controlling chemical risks has continued in the 21st century as well, with several schemes established and some of them implemented, including COSHH Essentials (Control of Substances Hazardous to Health), Chemical Control Toolkit, EASE model (Estimation and Assessment of Substance Exposure) and Risk-EASE model, which are designed for assessing chemical risks in working firms (Bredendiek-Kämper, 2001; HSE, 2003;

ILO, 2005; Jones and Nicas, 2006; Mäkinen et al., 2002; Rantanen and Pääkkönen, 1999; Russel et al., 1998, Tickner et al., 2005) and PRHI (Process Route Healthiness Index) developed for analysing new processes that have not yet been implemented (Hassim and Edwards, 2006).

COSHH Essentials provides a basis for categorizing the hazard of chemical substances, the estimation of likely exposures and a comprehensive approach for integrating the two to provide practical guidance for common industrial activities. This semi-quantitative risk assessment method (often referred to as the control banding method (Jones and Nicas, 2006)) is mainly used in the UK and has been verified as being valued by and useful for SMEs (Wiseman and Gilbert, 2002). The COSHH Essentials method has been found to overestimate the danger in certain cases such as mixtures of solvents or aqueous solutions (Brooke, 1998), which demonstrates that the method tends to provide a safe-sided judgement. On the other hand, Jones and Nicas (2006) compared exposure bands to measured exposures with regard to solvent vapour degreasing and powder bag filling operations and identified several "under-controlled" cases. Thus, it can be summarized that the evidence verifying the appropriateness of the COSHH model is limited. As for the proper use of COSHH the employers need information from MSDS, then the evaluation is dependant on the quality of the safety sheets compiled by suppliers or manufacturers.

Chemical Control Toolkit (CCT) is based on COSHH Essentials and uses a 5-step risk assessment scheme to perform the assessment (see Table 1.6). The indicators of toxic endpoint and potency used by CCT are either R-phrases or GHS of Classification and Labelling of Chemicals (United Nations, 2003). An exposure band is a range of target 8-hour time-weighed average airborne concentrations applicable to all chemical substances assigned to the given hazard band.

Table 1.6 The five steps of the Chemical Control Toolkit

Step	Description
1. Hazard classification	R-phrases or GSH classification are used to assign the substance to hazard band A (low hazard), B, C, D (high hazard) and/or S (skin hazard)
2. Scale of use	Volume of substance used: small, medium, large
3. Ability to become airborne	Defined as the volatility of liquids (based on the boiling point and process temperature) and the dustiness of solids – low, medium, high
4. Control approach	Answers from Steps 1-3 are used with a matrix to identify the appropriate control approach
5. Task-specific guidance	The control approach level from Step 4 is used to identify the guidance sheet for the specific task in which the substance is used

The EASE model is often applied to assess inhalative exposure at workplaces. It was developed on the basis of measured exposure levels classified according to typical exposure scenarios in the 1990s by Health and Safety Executive (UK)

(Tickner et al., 2005). These exposure scenarios were defined according to the use patterns and control patterns as well as the physiochemical properties of substances. A software tool has been developed (version 2.0 is currently used) and some researchers (Bredendiek-Kämper, 2001; Mäkinen et al., 2002) have conducted studies of comparison of EASE estimates relating to inhalative exposure and appropriate workplace measurements to show if single EASE scenarios correspond with measurement data representing "workplace reality". Two studies (Bredendiek-Kämper, 2001; Mäkinen et al., 2002) concluded that EASE overestimates exposure in several cases, e.g for workplaces where low amounts of powdery substances are handled or where medium-volatile solvents are present, etc; and underestimates exposure in a few cases as well, for instance in the paint factory where liquid substances were used. This circumstance leads to a high degree of uncertainty of some EASE scenarios and thus of the corresponding risk assessments as well.

Risk-EASE is a combination of two models (EASE and risk assessment model used in BS 8800 (BSI, 1996)), developed by Finnish researchers (Rantanen and Pääkkönen, 1999). It is based on a cross tabulation of the effect of the chemical (most severe risk phrase) and the probability of consequent adverse health hazard. The model is presented in Table 1.7, where probability is classified into three groups as the percentage of OEL (<10%, 10–50%, 50–100%) and consequences are divided into three groups as well (minor, harmful and severe effects). Cross tabulation divides the risk into five categories according to the amount of risk involved (low risk to unbearable risk). Mäkinen et al. (2002) conducted a study in 19 Finnish SMEs where the Risk-EASE model was used. It showed that the risk for chemical exposure with Risk-EASE model was categorized higher than when the original BS 8800 model was used alone. However, it was concluded that the cross tabulation methods seem to work adequately when used for their intended purposes by an experienced person. It was noted that in 19 Finnish SMEs workplaces lack information about chemicals, work processes and health effects, and the occupational healthcare units do not always have the skills required to make adequate exposure and risk assessment decisions.

PRHI has been developed to quantify the health hazards that might arise from chemical processes: the higher the index, the higher the hazards. It is influenced by the health impacts due to potential chemical releases and the concentration of airborne chemicals inhaled by workers. The PRHI index is calculated step by step using the following formula (Hassim and Edwards, 2006):

$$PRHI = ICPHI \times MHI \times HHI \times WEC_{max}/OEL_{min} \qquad [4]$$

First, ICPHI (Inherent Chemical and Process Hazard Index) is estimated where work activities and conditionals that are potentially harmful to health are identified and penalized (the sum of these gives ICPHI). Second, HHI (Health Hazard Index) is calculated considering chemicals that may cause typical occupational diseases. Third, materials at each stage of the process by healthiness are ranked, based on the

NFPA Ranking for Health (NFPA, 2007), which gives MHI (Material Harm Index). Fourth, WEC (Worker Exposure Concentration), which is the likely concentration of chemicals in the workers' immediate environment, is estimated. Fifth, the OEL (Occupational Exposure Limit) is obtained and the PRHI is calculated. The index has been implemented only in the early project stages of factories and there no attempt has been made to correlate it with measurable indicators of occupational health and safety of a working company.

Table 1.7 The Risk-EASE model according to Rantanen and Pääkkönen (1999)

	Consequences		
Probability	Minor effects (discomfort, irritation, temporary moderate illness) R20, 21,22, 36, 37, 38	Harmful effects (burns, dermatitis, severe long-term effects, moderate permanent harm) R23, 24, 25, 33, 34, 40, 43, 48, 62, 63, 64	Severe effects (poisonings, cancer, asthma, severe permanent effects, life-shortening illnesses) R26, 27, 28, 35, 39, 41, 42, 45, 46, 60, 61, 65
Improbable (severe effects: <10% of OEL; others 10%-50% of OEL)	No action needed (negligible risk)	Follow-up (low risk)	Actions needed (moderate risk)
Possible (severe effects: 10-50% of OEL, others 50%-100% of OEL)	Follow-up (low risk)	Actions needed (moderate risk)	Necessary actions needed (moderate risk)
Probable (severe effects: 50%-100% of OEL; others over OEL)	Actions needed (moderate risk)	Necessary actions needed (moderate risk)	Immediate actions needed (unbearable risk)

To conclude, it has to be underlined that various concepts have been applied to assess the risks arising from the workplace use of chemicals. From simple risk matrices, based in part upon the limited opportunities for exposure control in a defined setting, some approaches have been developed into forms where their application is widespread. Some of the recent developments also provide opportunities for targeting information to help SME users of chemicals manage risks and track performance more effectively. Each of the method has its own advantages and disadvantages. The overall disadvantage lies in the fact that some of the schemes appear to have undergone limited validation, either during their development or immediately after their implementation.

1.5 Aims of the present study

The importance of the thesis is closely connected with the policy of the EU in the field of OHS. During the years 2008–2009 a campaign for risk assessment is to be launched in each member state. The campaign seeks to demystify the risk assessment process and emphasizes the importance of workforce involvement in the risk assessment to ensure that hazards are identified not only from principles of knowledge but also by knowledge of working conditions and patterns of adverse effects upon workers.

The basis of investigation is worldwide experience, which has shown that risk assessment is a powerful tool for solving diverse problems in the work environment and promoting safety in industries and to prevent occupational accidents and diseases.

The aims of the study are:

- to analyse the existing risk assessment models and work out an original, flexible method for employers to control the hazards at workplaces;
- to provide the basis for the assessment of chemical risks at workplaces;
- to offer an overview of the hazards profile (chemicals, dust, noise, microclimate, lighting) in selected industries using the measurements of work environment hazards as well as the flexible risk assessment method;
- to implement the flexible risk assessment method in practice for solving the problems of work conditions.

The novelty of the flexible risk assessment method for manufacturing and office rooms consists in a unique approach which considers the measurements in the work environment, analyse them on the basis of the legislation requirements and scientific deliverables on exposure limits and the determination of risk levels in the work environment. The flexible risk assessment method tries to combine health and safety in one model. Health differs from safety in terms of the time for the effect to appear. Safety deals with acute, that is serious short-term events. Whereas health is a chronic matter, because it takes some time before the effects on people's health can be identified and the impact might persist over a long time.

The practical importance of the thesis involves the application of the proposed method in safety engineering. The flexible risk assessment method can be used for different purposes and at different levels: as a basis for decision-making when selecting among different remedial actions for a mined out area within time and financial restraints; a tool for deciding the acceptability of risk for the industrial activities; a basis to decide over the appropriate personal protective equipment as well as the need for health inspection by occupational physicians. The flexible risk assessment method is applicable in various fields of manufacturing and office rooms.

Limitations of the study

In the current thesis, the investigation of occupational hazards is limited to measurable hazards only. Attempts to integrate other hazards, such as psychosocial and physiological hazards, to the same model have been made, but for this, further investigation is needed and it is not covered in the current study.

The method, in the current stage, identifies the risk level of a hazard, but does not offer direct advice on the selection of adequate or suitable control measures. The general hierarchy of control measures is recommended, but detailed advice on the controls remains for future research.

2. MATERIALS AND METHODS

The present study provides an in-depth analysis of work environment based on data of measurements of occupational hazards and risk assessment performed in plastic, clothing, wood, mechanical and printing industries towards progressive improvements in OHS.

The examined physical and chemical hazards were selected considering the most common and obvious occupational hazards present in the industrial sector in Estonia.

To perform the measurements of occupational hazards, standard methods were used:

- ISO 7726:1998 "Thermal environments – Instruments and methods for measuring physical quantities" (for indoor climate)
- DIN 5035-6:1990 "Artificial lighting. Measurement and evaluation" (for lighting)
- ISO 9612:1997 "Acoustics – Guidance for the measurement and assessment of exposure to noise in a working environment" (for noise)
- EVS-EN 1231:1999 "Workplace atmospheres – Short term detector tube measurement systems – Requirements and test methods" (for chemicals)
- EN 482:1994 "Workplace atmospheres – General requirements for the performance of procedures for the measurement of chemical agents" (for chemicals)
- ISO 10882-1:2001 "Health and safety in welding and allied processes– Sampling of airborne particles and gases in the operator's breathing zone – Part 1: Sampling of airborne particles" (for chemicals)
- EN 481:1993 "Workplace atmospheres – Size fraction definitions for measurement of airborne particles" (for chemicals)
- EN 689:1996 "Workplace atmospheres – Guidance for the assessment of exposure by inhalation to chemical agents for comparison with limit values and measurement strategy" (for chemicals)
- WCB method 1150:1998 "Particulate (total) in air" (for dust).

The details of measurement procedures and apparatus used are described in *Papers II, IV and VI.*

The criteria for risk levels of occupational hazards were obtained from regulative norms, standards, directives and scientific literature. The literature scan focused on the impact of the main occupational hazards on workers' health.

Data from 18 enterprises were used for the assessment of the adequacy of the method as well as to examine the hazards profile in manufacturing. All investigated companies were assessed as SMEs. The enterprises were located in different parts of Estonia; however the majority of them were in or around the capital and western part of the country. The summary of the companies is presented in Table 2.1.

In each company, the management attitude towards health and safety was assessed on the basis of the interest in the results of outcomes of the research, the supportive actions to provide adequate information and details about the company and its investments to health and safety and the appreciation of workers' health through available protection, benefits, technical and administrative solutions present in the company and further ambitions to enhance workplace safety. The awareness of the problems of occupational health and safety and supportive actions of the company management were assessed either stimulating/supportive, neutral or impeding/negative. It has to be stressed that as regards daily routine, formal or informal assignment of OHS responsibility and participative management practices were not very common in the investigated SMEs. Although most of the managers said they entrusted their employees with some OHS responsibilities, the means available to help those employees to assume their responsibilities were not examined.

Many researchers (Gardner, 1999; Lamm, 1997; Stevens, 1999) claim that SMEs have special problems with the work environment: the risk is higher and the ability to control risk is lower. There are also studies indicating that exposure to physical and chemical hazards is higher in SMEs than in large companies (Schlunssen, 2001; Soresen et al., 2007) and there is no reason to believe the opposite concerning Estonian enterprises (no appropriate research exists).

Table 2.1 Summary of investigated companies

Industrial branch	No. of investigated companies	No. of workers in the company	Main health hazards measured	Awareness of company management
Wood processing	5	25…200	Indoor climate, lighting, noise, wood dust, formaldehyde, toluene, xylene, butanol, styrene, benzene	+ (2 cases) ± (2 cases) – (1 case)
Textile and clothing	5	120…225	Indoor climate, lighting, noise, textile dust	+ (4 cases) ± (1 case)
Printing	3	24…140	Indoor climate, lighting, noise, paper dust, isopropanol	+ (2 cases) – (1 case)
Mechanical	2	90…175	Indoor climate, lighting, noise, welding dust, O_3, CO, CO_2, NO-NO_2	± (2 cases)
Plastic	3	25…180	Indoor climate, lighting, noise, general dust, hydrogen flouride	+ (1 case) ± (2 cases)
Office rooms	18	15…100	Indoor climate, lighting, noise, formaldehyde, CO_2	+ (9 cases) ± (7 cases) – (2 cases)

(Abbreviations: "+" - stimulating, supportive; "–"- impeding, negative; "±" - neutral)

The adequacy of the method was estimated by theoretical calculations and expert estimation. The results are given in Chapter 4.

For the determination of the applicability and efficiency of the method, the case studies were conducted in different industries where risk assessment using the flexible method was performed. In the current thesis, two of the case studies are included (in Chapter 5). These were conducted in the clothing (case study A) and wood processing (case study B) industries. Previously, no risk assessment had been performed in these companies. While the main purpose of the case study B was to test the flexible method in practice on one-time basis, then the case study A was more thorough – work conditions, accident rate and safety characteristics were observed through the period from 2001 to 2006.

3. THE FLEXIBLE RISK ASSESSMENT METHOD

3.1 The origins and core criteria for the new approach

The general criteria which were stipulated in the beginning stage of the development of a new method are the following:

1. Conceptually, the approach must be user friendly. It needs to be understandable not only by those who use the schemes of a new method, but, perhaps more importantly, also by those who are affected by the outputs. Therefore, the tool serves not only as a mechanism for evaluating risks, but also one for communicating such risks.
2. The new method should engender confidence amongst those who use it and are affected by it. The confidence is determined by the nature of the outputs from the scheme (they should be suitable for successfully controlling the risks that they are intended to manage) and the actions taken by an organization to implement these.
3. The new method should be sufficiently flexible to adapt to the changing pattern of industry or the evolving regulatory requirements.
4. The new method, whilst integrating elements which may be complex in themselves, should be based upon information that is generally freely available to the user (e.g. under European or national legislation). This helps to ensure that the model is capable of being implemented with a minimum expert training or specialized resources. It also means that it can be more readily used in areas where the availability of expert skills or resources may be poor – e.g. within SMEs.

The specific requirements are formed as follows:

a. The new models of flexible method should determine the risk level using quantitative data and exposure estimates and thus, the implementation of two dimensional risk matrix is not critical.
b. The models must ensure that OELs are respected.
c. The acceptable and unacceptable risks are unambiguously defined which favours uncomplicated risk estimation and decision making as one of the main purpose of risk assessment is to support information to a specified decision process.
d. The models should be applicable for various enterprises encountering either small or large scale of occupational hazards.
e. The attempt to connect the risk levels with the health complaints derived from occupational hazards should be included. One of the targets is to alter the risk assessment report towards supporting workers' healthy work career, the other concerns physicians who should obtain maximum information about hazards as well as possible health complaints from the risk assessment report for providing the occupational health services.

3.2 Principles of the flexible risk assessment method

A flexible risk assessment method has been worked out in Tallinn University of Technology (Reinhold et.al, 2006, *Paper I*) and it is based on a two-step model that could be enlarged.

The basic model for the assessment of the magnitude of risk is presented in Figure 3.1 (*Figure 1, Paper I*).

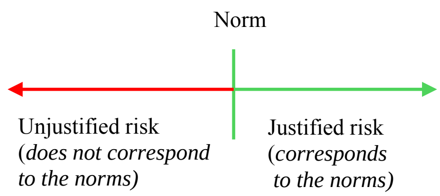

Figure 3.1 Two-step model

The two-step model is clear, understandable, argumented and simple for the user. The model has one boundary line (green on the colored scheme), which is a stable, largely spread number such as a norm or standard. The no/yes principle is used (corresponds to the norms/does not correspond to the norms → justified/unjustified risk). The model also suits small enterprises and to these that have not a complicated combination of hazards or have rather inexperienced personnel (also in work safety).

In the case of the three-step model (version 1, Figure 3.2) *(Figure 2, Paper I)* one step is added to the right side, the boundary is a dotted line (green in the case of colored scheme). In practice, such a model is rarely used. The model suits the firms where the state of the work environment is comparatively good, the level of danger is not very high and the enterprise has a desire and possibilities for improving the work conditions.

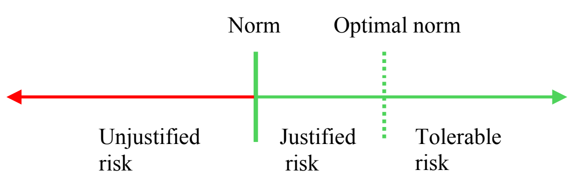

Figure 3.2 Three-step model (version 1).

A second version of the three-step model is possible as well (Figure 3.3) *(Figure 3, Paper I)*. In this case, one step is added to the left side of the scheme. The boundary line is named conditional risk (red dotted line): in practice it is not fixed. This line needs scientifically argumented statements (investigations) developed in co-operation by scientists in medicine, engineering and economics.

Temporarily, in the emergency case, the boundary line could be fixed as a subjectively argumented agreement. This scheme suits the enterprises that have a desire to improve the work conditions, making them more satisfactory and less dangerous.

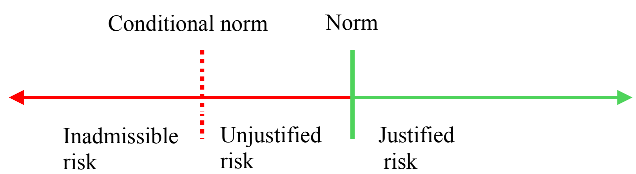

Figure 3.3 Three-step model (version 2)

As to the content, the four-step model (Figure 3.4) *(Figure 4, Paper I)* is nothing more than the result of the summation of the previous schemes. Therefore, it is also simple and understandable for the user. The model suits medium-sized enterprises (but not only), where the situation of the work environment is irregular with many different hazards, therefore the level of hazards at workplace varies a large extent and the personnel, having the relevant qualifications are able to orient in the improvement of the work environment. The main target in this activity is the left side of the model, where the risk level is higher.

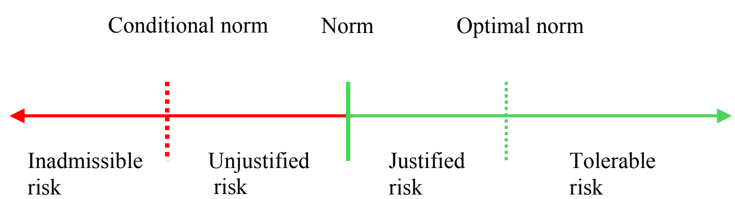

Figure 3.4 Four-step model

The five-step model (Figure 3.5) *(Figure 5, Paper I)* is a development of the previous schemes – an additional step is added to the four-step model to the left (worse) side of the scheme, the boundary line is a double dotted line (red in the case of the colored scheme).

This model is more complicated than the previous ones and it seems that there is no need for that model. The simpler (previous) models may be preferred; however, employers might be motivated to use the five-step model because of the familiar presentation of risk levels (e.g. five risk levels are recommended also by BS 8800:2004). The five-step model is especially suitable for big factories with a complicated mix of hazards and where the personnel are able to manage with one intricate model.

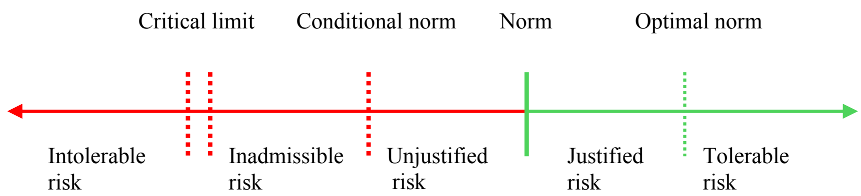

Figure 3.5 Five-step model

Finally, it is possible, but not particularly necessary, to add one stage to the right side of the five-step scheme and develop the six-step model (Figure 3.6) *(Figure 6, Paper I)*, where the boundary line is a dotted double line (colored green) that fixes zero-risk or negligible risk. In fact, we can speak of zero risk only when no hazards exist in the work environment.

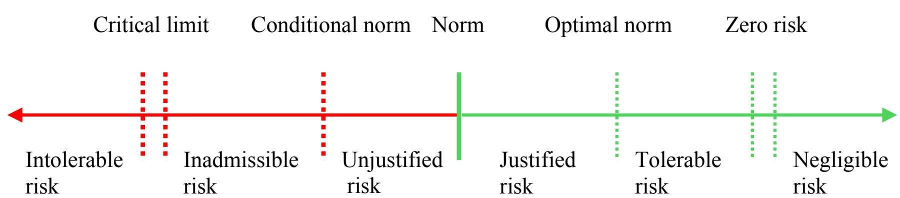

Figure 3.6 Six-step model

To conclude, the presented flexible risk assessment method offers every enterprise an opportunity to choose a suitable and feasible model for introduction into practice.

The risk levels in general way are determined as follows:

I	Negligible risk	Risk in work environment is considered *de minimis*. No action is needed.
II	Tolerable risk	No additional controls are generally required. The safety measures are welcomed when the implementation can be conducted at low costs.
III	Justified risk	Risk is still acceptable by the legislative regulations or good practice. Considerations should be given whether the risks can be lowered, where applicable, to a tolerable risk level.

IV	Unjustified risk	Risk is not justified, the exposure is higher than set in the legislation or recommendations. Efforts should be made to reduce risk within a certain time period.
V	Inadmissible risk	Substantial efforts should be made to reduce risk urgently. Working with inadmissible risk level is allowed temporarily (e.g. during implementation of a new technology), but it might be necessary to consider suspending the work until risk is reduced.
VI	Intolerable risk	The work is prohibited until risk is reduced. If it is not possible to implement appropriate safety measures, the work should remain prohibited.

Each organizations may find a need to determine their own levels of risk in more detailed way and specify timescales for the implementation of additional risk controls.

3.3 Software tool to support the model

A flexible risk assessment method (based on the five step model) for computer applications was worked out by the authors and introduced into practice, the example is shown in Figures 3.7A and 3.7B *(Figure 3, Paper III)* and *Figure 3, Paper IV* (for chemicals).

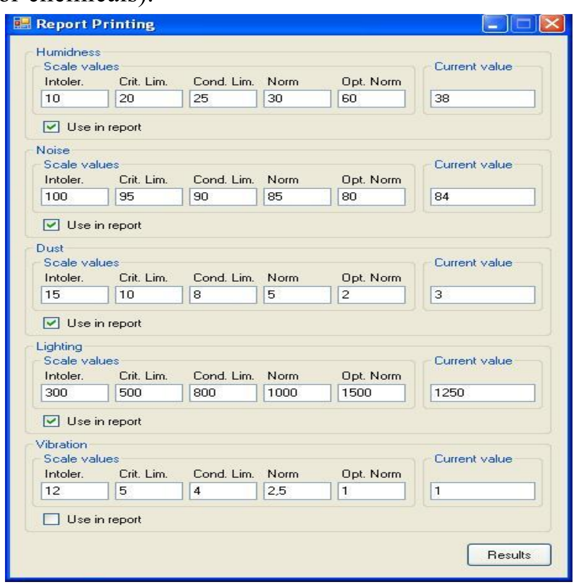

Figure 3.7A Computerized version of a flexible risk assessment method

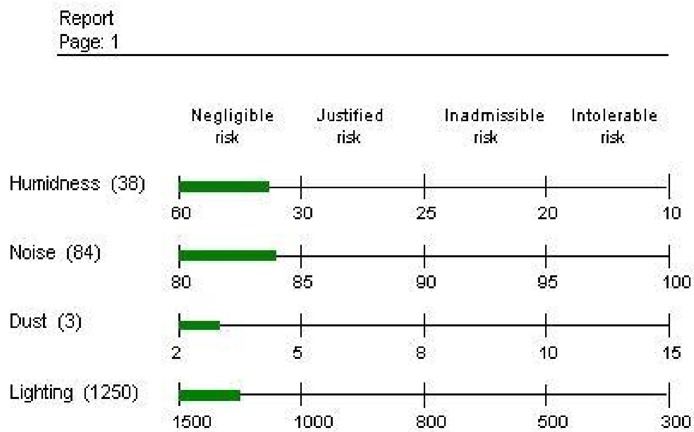

Figure 3.7B Use of the computerized method for risk assessment

The basic trial version was accepted by the test users as user-friendly, transparent and comprehensive. They emphasised the benefits of illustrative characteristics which is a valuable tool for employees to get the first information about hazards at her/his workplace without the need of deeper knowledge and large amount of time.

4. RESULTS AND DISCUSSION

To connect risk levels and health complaints, a five-step model (Figure 3.5) was used. The motivation to use five risk levels is derived from the BS 8800:2004 standard, which also recommends five risk levels and is therefore familiar and comprehensible to employers and OHS specialists. However, a scheme with fewer steps is recommended for cases where it is expected to be more effectual, especially in enterprises where the safety activities are disorganized and personnel inexperienced but willing to enhance workplace health and safety.

General results of measurements are presented in Tables 4.1, 4.2 and 4.3 (*Tables 4 and 5, Paper II; Table 2, Paper VI).* Detailed analysis of the results is presented under each paragraph of specific hazard group where examples are given and risk levels estimated.

Table 4.1 Results of measurements of indoor climate in industrial premises

Industry	Indoor air temperature, ^{0}C, U* = 0.6 ^{0}C		Indoor air humidity, %, U* = 2.0%		Air velocity, workplace, m/s, U* = 0.01 m/s
	Cold season	Warm season	Cold season	Warm season	
Clothing	20.3…23.5	22.7…25.6	44.4…53.0	48.2…53.0	0.01…0.04
Printing	21.7…22.4	22.5…24.3	38.2…52.2	44.2…62.4	0.01…0.26
Wood	21.2…24.0	24.3…26.5	34.2…42.6	35.1…47.6	0.02…0.30
Mechanical	10.8…21.4	17.6…23.2	31.3…39.9	41.4…48.7	0.01…0.21
Plastic	14.0…22.4	18.6…25.5	26.1…40.7	36.5…45.7	0.02…0.07
Offices	18.7…23.0	22.4…26.7	32.6…47.9	39.5…54.6	0.01…0.17

(Abbreviation: *U – uncertainty, k=2)

Table 4.2 Results of measurements of lighting, dust and noise in industrial premises

Industry	Illuminance, lx, U* =10.4%	Dust, mg/m^3, U* = 0.3 mg/m^3	Noise level, dB(A), U* = 2.0 dB
Clothing	525…2040	0.4…1.0 (textile dust)	62.1…89.5
Printing	264…1625	1.2…4.4 (paper dust)	66.4…90.3
Wood	320…1050	2.0…10.0 (wood dust)	84.2…94.4
Mechanical	88…1256	0.7…2.5 (welding dust)	73.0…97.5
Plastic	138…742	2.05…6.04 (general dust)	61.1…83.8
Offices	644…2640	n/m	46.7…62.4

(Abbreviations: n.m. – not measured, *U – uncertainty, k=2)

Table 4.3 Results of measurements of chemicals in industrial premises

Industry	Chemicals, ppm or mg/m^3, U* = 10…30%
Clothing	formaldehyde – n.d.
Printing	isopropanol –100 ppm
Wood	formaldehyde – 0.5 mg/m^3 toluene – 1...941 mg/m^3 xylene – 2.5...347 mg/m^3 butanols – 0.5...285 mg/m^3 styrene – 1...208 mg/m^3 benzene – 0.8...1 mg/m^3
Mechanical	ozone – 0.2 ppm carbon monoxide – 0.1…0.2 ppm carbon dioxide – 120…200 ppm nitrogen oxides – n.d.
Plastic	hydrogen fluoride – 0.5 ppm
Offices	formaldehyde – n.d. carbon dioxide – 800...3000 ppm

(Abbreviations: n.d. – not detected; *U – uncertainty, k=2)

4.1 Hazard: inconvenient microclimate

Exposure to high or low ambient temperatures while working in hot/cold indoor climate or while working outdoors is a common occupational hazard. The main health hazards caused by inconvenient microclimate are described in *Section 3.1, Paper II*.

The connections between the risk levels and stages of health complaints using the flexible risk assessment method are shown in Figure 4.1 *(Figure 2, Paper II)*. Five different risk levels are distinguished, the numerical criteria are derived from regulations (Estonian indoor climate regulation (Resolution..., 1995)), standards (ILO code of practice on ambient factors (ILO, 2001), EVS 845-1:2004 (EVS, 2004), ISO 7726:1998 (ISO, 1998)) and scientific literature (Seppänen and Vuolle, 2000; Witterseh et al., 2002).

The apparatus and methods used in measuring microclimate characteristics in practice are presented in *Section 4.1, Paper II.*

In most investigated companies, the indoor air temperature was at an acceptable level or very close to it. Some problems were encountered in the warm season in two companies of the clothing industry, two companies of the wood processing industry and one company of the plastic industry where the temperature in departments was higher than optimal due to deficiencies in ventilation systems or their lack, however, it was still between the limits of permitted temperature. In the cold season, the temperature fell to a lower level than permitted in one of the mechanical companies due to deficiencies or lack of a heating system, opened doors and poor insulation of the industrial building.

Relative humidity posed a problem during the cold season when in some companies, the air dried due to heating system and no conditioner system existed to balance the relative humidity of the air. A certain proportion of the employees complained about lippitude of eyes, skin xeric and dryness of mucus membranes, which may be caused by the low value of relative humidity during the cold season. However, no lower limit for relative humidity is fixed by Estonian regulations; any value below 70% is permitted. The values of air velocity were acceptable (up to 0.5 m/s), except shortage of air during the warm summer days in rooms where the ventilation system was not regulated to produce higher air velocity values in the warm season than in the cold one.

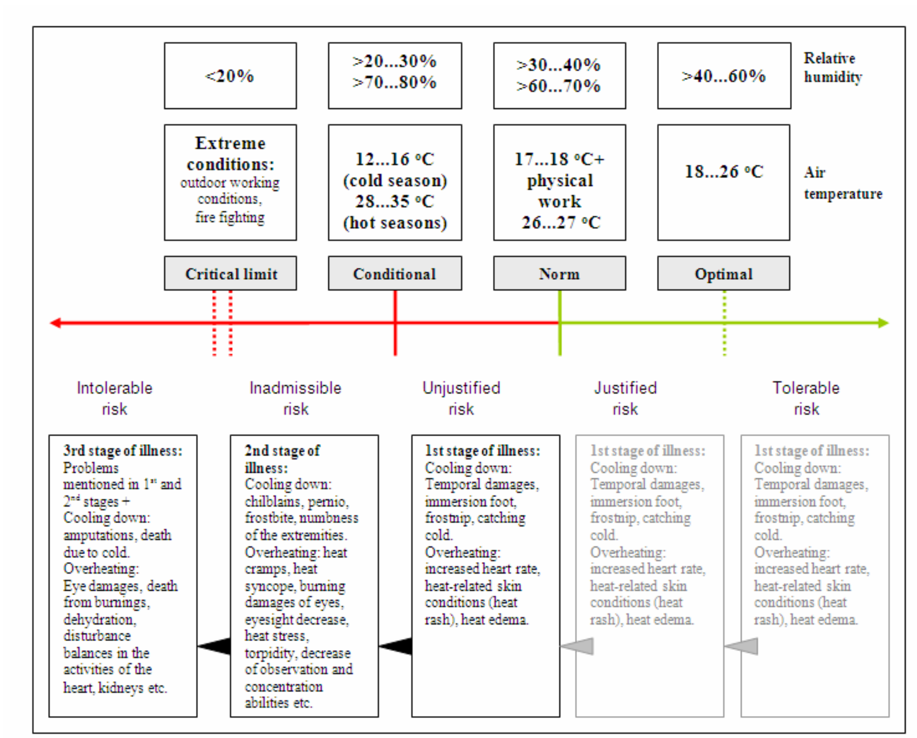

Figure 4.1 Inconvenient indoor climate and risk criteria

The example of assessing risk with flexible risk assessment method is based on selected workplaces in a company of the mechanical industry where serious concerns about the low temperature in the cold season were detected (Table 4.4).

Table 4.4 Results of microclimate in a company of the mechanical industry, selected departments

No	Department	Indoor air temperature, ^{0}C, U* = 0.6 ^{0}C		Indoor air humidity, %, U* = 2.0%		Air velocity, workplace, m/s, U* = 0.01 m/s
		Cold season	Warm season	Cold season	Warm season	
1	Preparation	15.2	19.7	31.1	44.3	0.07
2	Assembling	13.3	18.9	34.2	46.2	0.10
3	Specific work	19.0	20.5	32.1	44.1	0.21
4	Machine work	15.0	21.2	32.9	44.4	0.08
5	Welding	10.8	19.5	39.2	47.3	0.02
6	Wire winding	15.9	19.8	32.0	41.4	0.02

(Abbreviation: U* - uncertainty, k=2)

Risk of health impairment in the department 'Specific work' was assessed as *justified* instead of tolerable because of the lower value of indoor air humidity in the cold season. In the departments 'Preparation', 'Assembling', 'Machine work' and 'Wire winding' risk was assessed as *unjustified* because of the low value of indoor air temperature in the cold season and in the department 'Welding' *inadmissible* because of the very low value of indoor air temperature in the cold season.

4.2 Hazard: poorly organized lighting

Poor lighting usually means weak luminosity. However, for good lighting practice it is essential that in addition to the required illuminance, qualitative and other quantitative needs are satisfied as well. The following variables determine a good visual work environment: well-balanced luminance distribution, suitable illuminance value, absence of glare, correct direction of light, high colour rendering index of the luminaries, suitable choice of the colour appearance of a lamp, absence of flicker and availability of daylight (Eklund, 2001; Fontoynont 2002; Helland et al., 2008; Roche, 2000; Smith, 2000).

The symptoms that indicate on the health damages caused by poor lighting are presented in *Section 3.2, Paper II*.

Considering data from scientific literature and international standards (Blehm et al., 2005; Eklund, 2001; EN 12464-1:2002 (EN, 2002); ISO/CIE 8995-1:2002 (ISO, 2002); Rea and Quellette, 1991) and using the flexible risk assessment method, the connections between risk levels, values of illumination, glare, flicker, colour rendering index and health complaints can be interpreted for the occupations where required illuminance is between 300...500 lx as shown in Figure 4.2 (*Paper II, Figure 3*).

According to the measurements of lighting (the techniques and apparatus described in *Section 4.2, Paper II*), it is no concern in the case studies of the clothing industry, the wood processing industry and in workplaces at offices of the companies. Improper lighting conditions were detected in two companies of the mechanical industry, in the plastic industry and one company of the printing industry. The problems are various but mostly the luminosity is low due to expired, untended or work and torn general lighting systems and lack of local lighting devices. In some companies, observations of the workplaces revealed that some workers did not use the existing local task luminaries. Minor problems were connected with glare (constant and bright illumination from surrounding sources of light) and uniformity of illuminance. It is important to avoid dangerously deceptive shadows, which can be inadvertently produced in the vicinity of machinery.

Some complaints arouse among VDU users, mainly because of the reflection produced by large windows or local lighting sources (desk lamps), which appeared to wash out screen character images, and cause annoyance as well as possible visual fatigue.

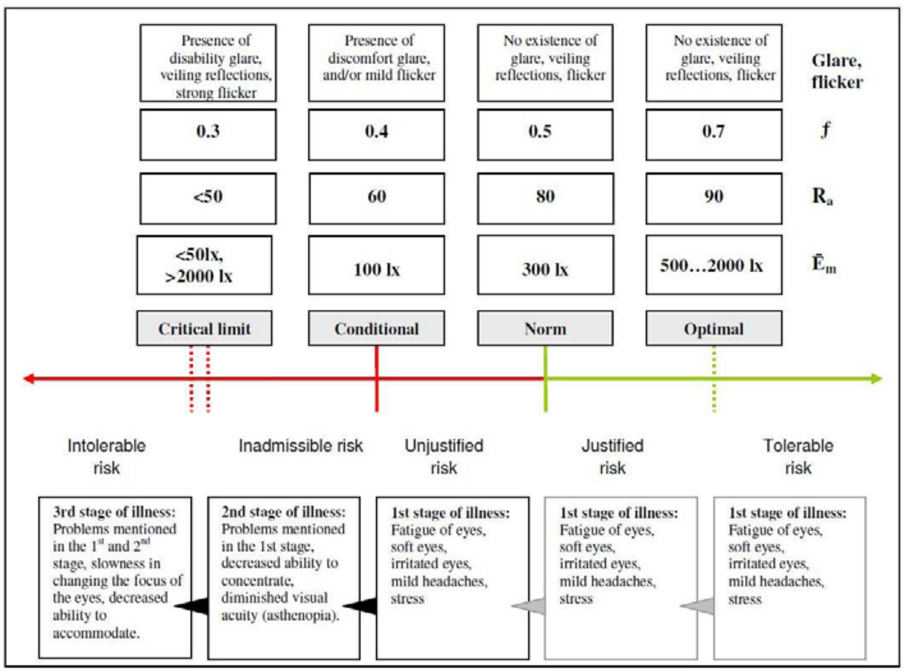

Figure 4.2 Poor lighting and risk criteria (for occupations where $\bar{E}_m$=300...500 lx is recommended)

The example of assessing risk with the flexible risk assessment method is based on selected workplaces in a company of the mechanical industry where the most serious problems were detected (Table 4.5 (*Table 6, Paper II*)). Old, fluorescent lamps were used in the preparation department which CRI value was about 50…60. Those lamps were recommended to change to lamps with better colour rendering properties. According to the standard EN 12464-1:2002, the recommended illuminance level for the work performed in the preparation department (sheet metal work, drop forging, medium assembly work) is 300 lx. Only one of the presented workplaces met the requirements, the results of illuminance $\bar{E}_m$ ranged from 123 to 325 lx. The uniformity values differed from 0.5 to 0.92. Glare was not observed in most workplaces but flicker was detected in the workplaces which were lighted by mercury fluorescent lamps.

Table 4.5 Detailed results of lighting conditions in a company of the mechanical industry, selected workplaces

No	Work station	Lamp type	Illuminance $\bar{E}_m$, lx	Uniformity, f	CRI R_a	Glare, flicker
1	Die machine Vipros S368	Incandescent	226±23.5	0.65	90	Not observed
2	Guillotine HACO TS3006	Mercury fluorescent	133±13.8	0.5	60	Mild flicker observed
3	Press K 213DC	Incandescent	325±33.8	0.92	90	Not observed
4	Blending machine Amada HFF 130-3	Mercury fluorescent	123±12.8	0.75	60	Mild flicker observed
5	Blending machine Amada HT 50-12T	Mercury fluorescent	262±27.2	0.59	60	Mild flicker observed

Risk of health impairment in workplace 3 was assessed as *justified* since all the criteria presented in Figure 4.2 were fulfilled. The risk of health impairment in workplace 1 was assessed as *unjustified risk* (due to its low illuminance value) and in workplaces 2 and 4, 5 as *inadmissible risk* (due to their low illuminance and colour rendering index values and occurrence of mild flicker).

4.3 Hazard: excessive noise

Occupational exposure to excessive noise is commonly encountered in a great variety of industrial processes. Noise-induced hearing loss is often the cause of an occupational disease (Starck et al., 2004; Toppila, 2000). But noise may cause harm in other ways as well which are described in *Section 3.3, Paper II.*

The connections between the risk levels due to noise and stages of health complaints determined using the flexible risk assessment method are presented in *Table 2, Paper II* and illustrated graphically in Figure 4.3 (*Figure 4, Paper II*). Five different risk levels are distinguished, the numerical criteria are derived from regulations (Noise directive 2003/10/EC (EC, 2003), Estonian occupational noise regulation (Resolution…, 2007a)), calculations using standards on occupational noise (ISO 1999:1990 (ISO, 1990) and ISO 9612:1997 (ISO, 1997)) and scientific publications (Atmaca et al., 2005; Eleftheriou, 2002; Johnson, 1991; Powazka et al., 2002; Rachiotis et al., 2006; Toppila, 2000).

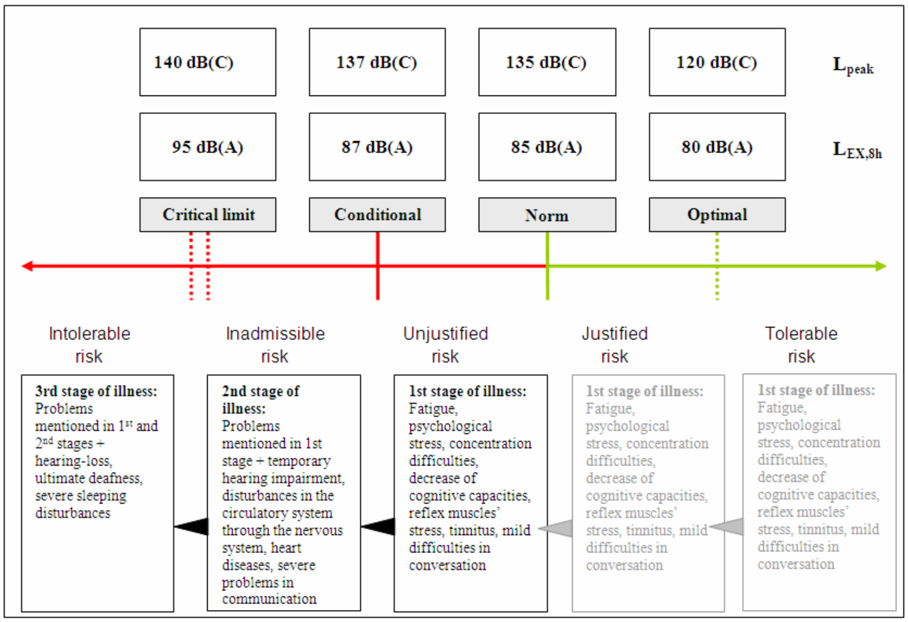

Figure 4.3 Noise and risk criteria

As noise is the most obvious health hazards in the four different industries (mechanical, wood, printing and textile) analyzed in the current study, it is necessary to study the pattern of noise in depth to be able to implement appropriate risk control measures. The apparatus and measurement techniques are described in *Section 4.3, Paper II*.

To evaluate the health hazard and determine the risk level derived from noise, it is essential to assess the noise exposure level normalized to a nominal 8 h working day. The level, $L_{EX,8h}$, in decibels, is given by Eq. 1 (ISO, 1997). In many cases (e.g. in the clothing industry where the person works with the sewing machine all day, and a similar noise pattern is produced for all procedures, 8 hours a day), T_e=T_0 and therefore, $L_{EX,8h}$ is numerically equal to $L_{Aeq,8h}$. In other cases, the noise produced by machines may occur only part of the time or the worker's shift shorter than the reference duration (8 hours), and then, the Eq. 5 is applicable.

$$L_{EX,8h} = L_{Aeq.T_e} + 10\lg(\frac{T_e}{T_0}) \text{, dB} \qquad [5]$$

where $L_{Aeq,Te}$ stands for the equivalent continuous A-weighted sound pressure level over the effective time interval T; T_e and T_0 are the effective duration of the work day and the reference duration (=8 h), respectively.

In the mechanical industry, where the time interval T was subdivided, the following formula was used to calculate the equivalent continuous A-weighted sound pressure level (ISO, 1997):

$$L_{Aeq,T} = 10\lg(\frac{1}{T}\sum_{i=1}^{m} T_i * 10^{L_{Aeq,Ti/10}}) \text{, dB} \qquad [6]$$

where $L_{Aeq,Ti}$ stands for the equivalent continuous A-weighted sound pressure level occurring over the time interval T and m is the total number of sub-intervals of time.

It should be noted, that T is equal to $\sum_{i=1}^{m} T_i$.

The results of noise measurements at various frequencies were used to identify the specific frequencies with especially high intensity. These are useful to develop control measures and select appropriate ear protection. Moreover, it gives an indication about the noise levels in most hearing-damaging frequencies (0.5…2 kHz – the speech frequencies) which are the main concern in selecting the workers' hearing apparatus and serve as basis in estimating numerically the risk of noise-induced hearing impairment/handicap if no risk control measures are applied or the worker misuses them.

The selection of results of measurements are presented in *Figures 6, 7, 8 and 9, Paper II* (four case studies in different industries – one company in the mechanical, wood processing, clothing and printing industry each; selection of machines was based on the noisiest machines).

Compared to other studied industries, the noise levels in the clothing industry presented the least concern as none exceeded 85 or 80 dB(A). Analyses of the measurements at various frequencies indicate that the noise level at work stations of machines had slightly different patterns, but all peaked in the area of 500...2000 Hz. According to the measurements, lower frequencies do not pose a concern in any of the studied industries. Knowing the prevailing damaging frequencies helps to decide which ear protection should be used. A hearing protector device can reduce the exposure significantly. The nominal attenuation, recommended by the manufacturers, varies from 11 dB to 35 dB, depending on the hearing protector device and the frequency contents of the noise (Toppila, 2000). Several methods exist for estimating the amount of sound attenuation a hearing protector provides, among them the octave-band method, which gives the Noise Reduction Rate (NRR), is clearly the most common. Choosing suitable hearing protection devices, high frequency protection should be emphasized in the studied cases.

For calculations of the risk of noise-induced hearing loss for male workers (Figure 4.4), a 25 years old man was taken as an example presuming he will work in the same noisy work environment for 15, 25 or 35 years (exposure to noise: 15, 25 and 35 years) without having any noise control measures. The two noise levels were obtained for calculations: 97.5 dB in the mechanical industry and 91.5 dB in the wood industry. For hearing handicap assessment, the frequency combinations

1, 2 and 4 kHz were assumed. The risk calculation method proposed in ISO 1999:1990 (data base A), which uses three inputs (age, exposure to noise and gender) in the evaluation of noise-induced hearing loss was used.

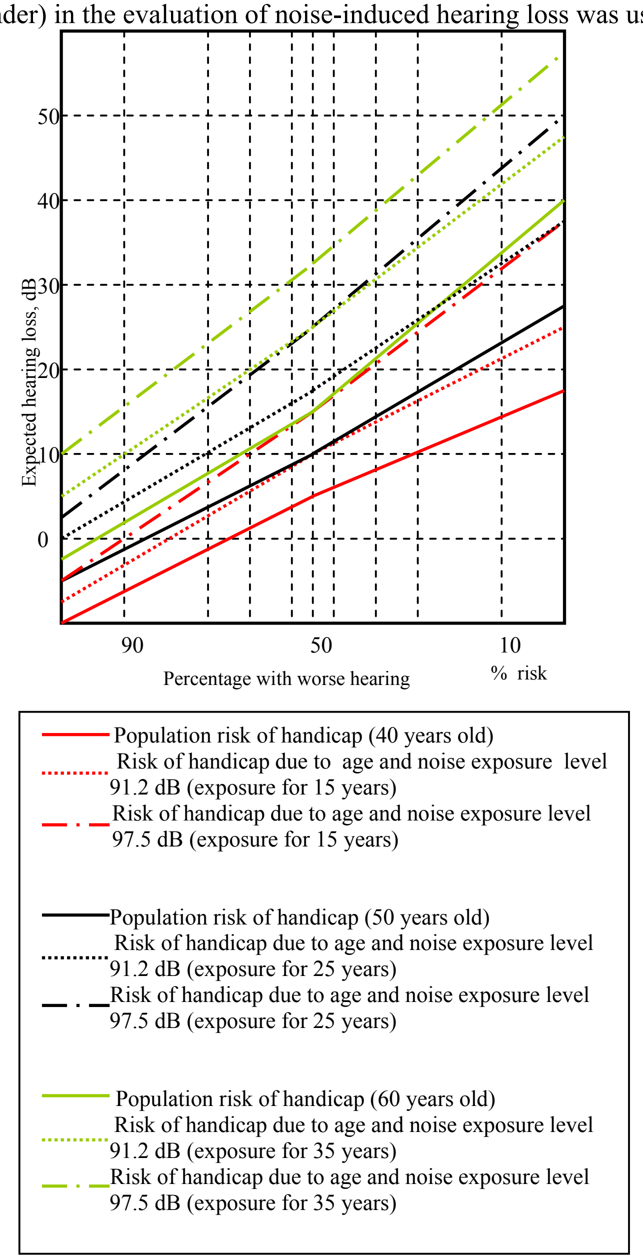

Figure 4.4 Estimation of risk induced hearing loss at two noise levels – 91.2 dB and 97.5 dB – for 15, 25 and 35 years of exposure

Figure 4.4 *(Figure 10, Paper II)* depicts the risk of handicap among people with noise exposure and non-noise exposed people. It should be noted that the risk of hearing handicap due to noise calculated with this method does not indicate the severity of the hearing handicap as such, but gives the fractile of a population whose hearing threshold level associated with age and noise exceeds the fence.

At the fence level of 25 dB (hearing threshold level) (Sataloff, 2006; Starck, 2004), the risk of handicap due to noise exposure of 91.2 dB during 15 years of occupational life is insignificant, during 25 years the risk is 17.5% and in 35 years 25.0%, while the noise exposure of 97.5 dB produces the risk of hearing handicap of 21.5%, 40.5% and 43.0%, respectively. The figure also illustrates that the risk of handicap due to noise exposure of 91.2 dB in 35 years has a similar pattern of the noise exposure of 97.5 dB in 25 years.

According to the proposed flexible risk assessment method (Figure 3.5), the risk of noise exposure of 91.2 dB (Die machine Vipros) was determined as *inadmissible risk* (level IV) and 97.5 dB (Great drill machine) as *intolerable risk* (level V), which is in good conformity with the risk calculations according to ISO 1999:1990.

4.4 Hazard: chemicals

Exposure to chemicals can be considered as the contact of a hazard with the outer boundary of a subject, including the respiratory system, the skin, and the digestive system. The most common exposure route in occupational settings is the respiratory system. In the current study, the main focus was on solvents used in manufacturing (with neurotoxic effects) as experimental data from occupational settings were available due to previous studies in Estonia (Kahn and Moks, 1998; Tuulik, 1995; Tuulik, 1996).

4.4.1 Risk criteria for neurotoxic substances

Organic solvents are in widespread use in many sectors of industry. Due to their volatile and lipophilic properties, significant amounts of solvent can enter the body via inhalation of the vapour and/or absorption through the skin, particularly where workplace practices are poor.

The effects of overexposure to solvents are well known. Typically, the primary response is central nervous system (CNS) depression, producing effects ranging from dizziness, fatigue, sleeping disturbances and headaches to anaesthesia and even death, depending on the level of exposure (Ridgway et al., 2003). To diagnose CNS poisoning it is important to tackle the symptoms in the early stage of the illness. The nervous system is one of the most sensible systems of the organism, which dynamically reacts to various exogenous factors.

In the investigation of work conditions of Tallinn bus drivers (Kahn and Moks, 1998) the functional state of workers was estimated by a neurologist. The neuropsychological investigation consisted of the determination of reaction time, measurement of dominating hand's tremor, calculation of memory index, measurement of attention, learning and seeing ability. Various CNS diseases were diagnosed in 76.8% of the investigated workers. Heart disorders were found in 16.0% and functional disorders of CNS in 44.0% of the bus drivers. On the basis of psychological investigations, various stress levels were diagnosed in 52.0% of the bus drivers and 3.5% of the respondents suffered from fatigue. The concentration of benzene and aliphatic hydrocarbons was measured in the cabins of buses. The concentration of benzene in the cabin varied from 0.27 mg/m^3 in summer to 0.01 mg/m^3 in winter.

The first attempt to find correlations between the clinical, psychological and electrophysiological symptoms of workers' long-lasting exposure to chemical substances in Estonia was made by Tuulik (1995, 1996). She examined 42 workers of dry cleaning stations and 35 workers of the furniture industry exposed to organic solvents in their everyday work. Ordinary medical examinations and additional investigations to diagnose neurotoxic damages were carried out. The control group consisted of fishermen (N=145) and students (N=41). Changes in the functional state of the CNS at syndrome level were diagnosed.

The syndromes were characterized in three stages:

1. *Hypersthenic* syndrome (mild level of asthenia, irregular speed of mental activity, deficient ability to concentrate, increased number of errors in the psychological tests;
2. *Hyposthenic* syndrome (moderate asthenia, decreased speed of mental activity, decreased ability to concentrate, prolonged reaction time);
3. *Organic psychosyndrome* (expressed asthenia, memory disorders of organic type, lowered visual-constructive ability, clearly prolonged reaction time).

Using the presented results (Tuulik, 1995; Tuulik, 1996), other scientific literature (toxicological profiles, case reports, occupational studies, and studies on volunteers), international standards (EN 481:1993 (EN, 1993); ISO 10882-1:2001 (ISO, 2001)) and regulative norms connections between risk levels and health complaints of selected neurotoxic chemicals were established (Figure 4.5 (*Figure 2, Paper VI*)). Four chemicals– toluene, butanol, xylene and styrene – were used as an example because these were the major concern in one the case studies conducted in wood processing industry. The health hazards of the examined four chemicals are presented in *Section 4, Paper VI*.

Schemes were developed considering the chemical's ability to cause typical occupational diseases such as cancer, short-term high risk effects, nervous system disturbances, respiratory effects, hematologic disturbances, etc. as classified in OSHA Instruction CPL 2.45B (OSHA, 2008) and are specific for each risk group (20 groups in total, 1 representing the most severe health effects). The current scheme is for toluene, xylene, butanol and styrene, which cause nervous system disturbances and are classified in risk ranking as groups 6-8.

Table 3, Paper VI presents essential data of investigated four chemicals (such as boiling point, odour threshold, exposure limit and IDLH value) to determine the risk levels. Odour threshold is an important factor to be considered in any risk assessment model since the olfactory symptoms or hypersensitivity towards chemicals' odours may be distracting and interfere with job performance and safety or induce cacosmia (i.e., feeling ill from the odour of xenobiotic chemicals) (Dick and Ahlers, 1998; FIOH, 2008). Odour threshold is used as an "optimal limit" in the current scheme.

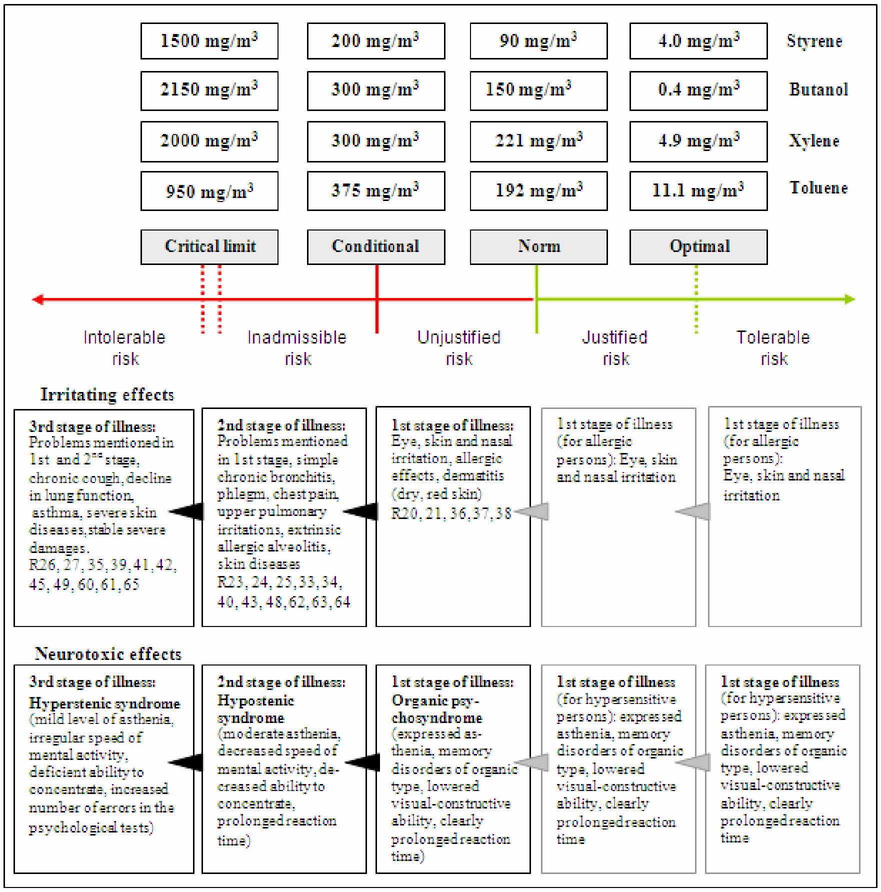

Figure 4.5 Neurotoxic chemicals and risk criteria

Worker exposure concentration is an estimate of the chemical concentration that is potentially inhaled by the workers in the workplace. OELs (Resolution…, 2007b) are specifications for the maximum airborne concentration of substances, averaged over a reference time period (in our case 8-h shift) in workplace air and are used as "norm" in the current scheme. They have been the primary expression of workplace risk management expectations and are suitable to distinguish between the acceptable and unacceptable risk area (e.g. green and red area in the scheme).

The conditional limit is determined using the highest exposure value that is not associated with any adverse symptoms, yet is derived from toxicological profiles (ATSDR, 2007; IPCS, 1983; IPCS, 1987a; IPCS, 1987b; IPCS, 1997; Van Thriel et al., 2003).

For the critical limit, half of the IDLH (immediately dangerous to life or health concentration) value is used. The purpose for establishing IDLH was to determine the concentration from which a worker could escape without injury or without irreversible health effects in the event of respiratory protection equipment failure and the concentration above which only "highly reliable" respirators would be adequate. The IDLH values have been determined considering the toxicity data of chemicals and applying suitable safety factors (FIOH, 2008; NIOSH, 1994).

In assessing risk in the case studies (measurement techniques and apparatus are described in *Sections II and IV, Paper IV*, respectively), the worst cases where the highest TWA values of four neurotoxic chemicals were measured the highest were chosen for deeper observation. All those values (toluene – 941 mg/m^3, xylene – 347 mg/m^3, butanol – 285 mg/m^3 and styrene – 208 mg/m^3) fell into the red zone of the scheme. In the work areas of our case studies, toluene, xylene and styrene were assessed as *inadmissible risk* and butanol as *unjustified risk.* Suitable safety measures were overviewed or recommended.

4.5 Hazard: dust

One of the basic occupational hazards is dust. The main sources of harmful dust emission at the workplace are technological processes. The final result of the adverse influence of industrial dust depends on the type of the inhaled dust, the place in the respiratory tract where it lingers on, which is conditioned by the size of its particles and the process of breathing.

In various systems throughout the world, the specified airborne concentrations range from 4 to 10 mg/m^3 for inhalable dust (the particles that precipitate in the vicinity of the mouth and eyes and get into the organism) and 1.5 to 4 mg/m^3 for respirable dust (the particles penetrating into the non-cartilage respiratory tract) (ACGIH, 2002; DFG, 2002; HSE, 2002).

In the current study, five different types of dusts were examined and measured, depending on the type of manufacturing. In the clothing and textile industry, dust generated from textile products was examined. In the mechanical industry, dust originating from welding processes was measured. In the printing industry, paper dust and in the plastic industry, general dust was examined. Dust was measured following an international method. The method and apparatus are described in *Section 4.4, Paper II*.

In the examined companies of the clothing and mechanical industries, dust did not present a hazard of high risk level since the values of dust are lower than OELs. In the plastic industry, some departments were identified where the amount of total organic dust was higher than the OEL value – the highest value measured was 6.04 mg/m^3 (OEL = 5.0 mg/m^3). In one company of the printing industry, higher levels of paper dust were detected as well; but in this case study, a new wet-cleaning method was implemented immediately and the further measurements showed that the levels of paper dust had lowered significantly. Wood dust in the wood processing companies presented the highest risk compared with other industries and was decided to study in detail.

4.5.1 Exposure to wood dust

The number of workers exposed to wood dust in Estonia in 1997 was 34,000 (Rjazanov, 2003). The distribution of wood-processing workers by the dust concentration in the air was: <0.5 mg/m^3: 8000 persons; 0.5–1 mg/m^3: 5000; 1–2 mg/m^3: 5000; 2–5 mg/m^3: 5000; >5 mg/m^3: 3000 (Kauppinen, 2006). The percentage of workers engaged in wood-processing from all industrial workers in Estonia was the highest in the EU (4.6%) (Rjazanov, 2003).

Exposure to wood dust is associated with an increased risk of developing adenocarcinomas of the nasal cavity (Nylander and Dement, 1993). Both occupation and type of wood dust exposure influence the increased risk for nasal cancer. The cancer of the upper respiratory tract develops after exposure to many kinds of wood dust. However, the wood dust of oak and beech seems to be most carcinogenic (IARC, 1995). The natural constituents of wood are numerous. The following agents have been suggested as possible contributing agents to the induction of nasal cancer: native mutagenic components of wood dust (such as tannins and tannic acids, 2,6-dimethoxy-1,4-benzoquinone, unsaturated aldehydes and their oxidation products, coniferyl and sinapic alcohols, etc.), pyrolytic products, and metabolites produced by wood-covering fungi (Flechsig and Nedo, 1990). The highest risk of cancer to workers of the furniture industry applies particularly those dealing with machine wood processing, cabinet making and carpentry (Maciejewska et. al, 1993).

The assessment of occupational risk and exposure to wood dust is difficult. This difficulty arises due to the inconsistency and controversy concerning many factors: first, the size and shape of dust particles, which determine where the particles precipitate in the respiratory tract, and their adverse, particularly carcinogenic influence; second, differences in the structure, composition and influence of various types of wood, taking into account the division into hard- and softwood; third, the establishment of the safe maximum level of dust concentration in the air of the work environment (Baran and Teul, 2007).

Considering the data from scientific literature (Bardana, 2008; Gustafson et al., 2007; Jacobsen et al., 2008; Shamssain, 1992; Stenton, 2004), international standard (EN 481:1993 (EN, 1993)) and Estonian norms for occupational dust in the work environment air (Resolution… 2007b) and using the flexible risk assessment method (Figure 3.5), the connections between risk levels and health complaints due to wood dust were determined as shown in Figure 4.6 (*Figure 5, Paper II*). Particle size and dust concentration in the work environment air were considered the minimal basic variables to determine the risk levels.

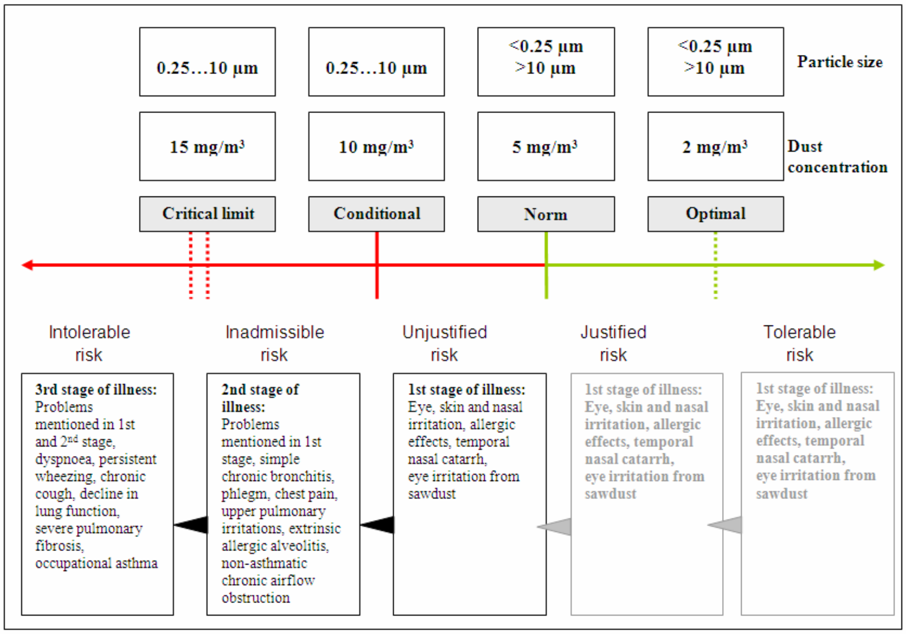

Figure 4.6 Wood dust and risk criteria

According to the measurements in the current study, the TWA concentration of wood dust in the investigated companies varied from 2.0 to 10.0 mg/m^3. The processed wood types were mainly birch (referred in the literature as sensitizer, irritant and suspected human carcinogen (IARC, 1995; Määttä et al., 2005)) and juniper (suspected allergen (Ahman et al., 1995)). The presence of high concentrations of wood dust in the workplace air is a great concern and needs further investigation to develop suitable control measures. High levels of wood dust were considered as *inadmissible risk* according to the flexible risk assessment method.

5. IMPLEMENTATION OF THE FLEXIBLE METHOD IN MANUFACTURING

Two case studies are presented for implementation of the flexible risk assessment method in manufacturing (*Paper I, Paper III, Paper V*). Case study A in the clothing industry was a larger study while case study B in the wood processing industry was a one-time basis observation.

5.1 Analysis of the work conditions in the clothing industry (case study A)

The company in case study A employees over 300 people, of which 223 are garment workers. The workforce is pre-dominantly women (98%), ethnically Russians (90%) with the mean age of 42 years. The main production of the company is work clothes (jackets, trousers, smocks, overalls, winter clothes and specific work clothes). The production departments are situated in Tallinn, the capital of Estonia.

Previously, a number of authors have investigated the work conditions and risk factors in clothing industry. They emphasize substantial ergonomic problems (Gunning et al., 2000), heavy work load and lack of the control over the job (Gunning et al., 2000; Remeza and Shestakovs, 2005), workers' acute respiratory disorders (Remeza and Shestakovs, 2005), musculoskeletal disorders (Gunning et al., 2000; Vezina et al., 1992), allergic responses and low internal transportation safety (Milczarek and Szczecinska, 2006).

Clothing manufacturing, like other industrial processes, can be hazardous work as several types of machinery are used to produce the products. The machines are operated to sew, embroider or cut patterns and cloth. Many tasks in clothing manufacturing require repetitive motions. The work is also characterized by awkward, uncomfortable working positions. To prevent ergonomic injuries workers should be encouraged to rotate tasks or take frequent, short breaks to stretch and relax muscles (Reinhold and Lell, 2003). Additionally, many other hazards exist in clothing workers' work environment such as inconvenient microclimate, noise, poor lighting, dust, chemicals such as dyes, enzymes and solvents, etc. Therefore, respiratory, eye and/or hearing protection may be essential. The psychological side of the work environment cannot be underestimated either as sewers often face a monotonous work and a constant time pressure (their wage is calculated by the price of certain operation minute).

The aims, material and methods of the study are described in *Sections 2 and 3*, *Paper III*. The ambition for the investigated company was to increase the level the safety culture and reduce the number of occupational accidents with the aid of risk assessment. The study took place in 2001-2006. In 2001 and in 2002, nine and seven occupational accidents occurred, respectively (description in *Section 3, Paper III*). In 2002, the first risk assessment was performed followed by control process (new assessments to locate the deficient parts) in every 2 years. The flexible risk assessment method was explained to the work environment specialist and the computerized version of the method was introduced to assess risks in the clothing industry.

The results of risk assessment were divided into four parts: ergonomic observations and solutions, the results on the basis of measurements of occupational hazards, the results concerning workers' satisfaction with work conditions and efficiency of safety measures (*Section 4, Paper III*).

The results of measurements were assessed by using criteria of flexible risk assessment method taking into consideration the workers' satisfaction with work conditions and their opinions (a questionnaire for workers was prepared and analysed in 2003, the results can be found in *Section 4.3, Paper III*. Previously, in 2000, another questioning was conducted which results were available as well).

As the noise level in certain areas exceeded the existing Estonian regulation (Resolution..., 2007a) and no personal protective equipment was used, it was assessed as *inadmissible risk* (*Figure 5, Paper III*). In other areas, where the noise level was in compliance with the norms, it was considered as *justified risk*. The indoor air temperature in warm seasons together with serious problems of lack of fresh air reported by workers was considered *inadmissible risk* level based on the risk criteria and workers' complaints (*Figure 5, Paper III*). The high value of physical overload was assessed as *unjustified risk* using the risk calculation method of manual handling of loads (Reinhold et al., 2008b) (*Figure 5, Paper III*).

During 2002-2004, the safety measures in needed areas have been implemented and risk levels lowered. The reflection of it will certainly take time, but even in 2003 and 2004 less work accidents occurred than in pervious years. One reason may be the fact, that during risk assessment procedure, workers got more attention, their problems were listened and taken care of and in this light, and they were more careful, positive and satisfied which may have helped reducing the work accident level. In 2003, only four occupational accidents registered of which one was a serious accident while in 2004 no serious accidents happened at all (however 4 accidents occurred). In 2005, regrettably the number was higher - six accidents occurred, but none was serious (two slips; one pricking with scissors to the palm; the other with needle into the finger etc.).

In 2005 and 2006, the risk assessment report was carefully scrutinized and the reasons of occupational accidents discussed in-depth together with management of the company. It was concluded, that the accidents occurred in 2000-2003 were often caused by the lack of safety measures or ignorance of measures by workers while in 2004-2005 the accidents occurred due to the construction principles of certain older machines or worker's inattentiveness. It is clear, that workers operating with some specific older machine types are easier subjects to occupational accidents and therefore, workers need to be specifically cautious and follow all the safety rules accurately until the company has been able to allocate financial funds to renew the machinery.

During the visits in 2005 and 2006, many changes to positive organizational and physical characteristics were identified: positive social environments, open communication between workers representatives and management, less repetitive tasks, ergonomic work-station modifications.

The final recommendations were given in 2006 for healthier work arrangements, working postures and movements to protect the female workers' health. It was concluded, that it is crucial to encourage discussions about safety in blue-collar workers level to improve the safety culture and thus, diminish the occurrence of occupational accidents and occupational diseases. Workers should realize that if the OSH personnel alone are actively implementing the measures of safety improvement, there will be no good results. The spread of information in the organization and the positive attitude for safety among workers is extremely important.

The flexible risk assessment method was assessed suitable, viable and transparent by the work environment specialist and the management of the company. The workers emphasized the benefits of illustrative characteristics to get the first information about occupational hazards and the risks through the schemes of the flexible method.

5.2 Analysis of the work conditions in the wood processing industry (case study B)

The work environment in a large wood-processing firm (approximately 1,000 workers) in western part of Estonia was analyzed to test the flexible risk assessment method outside of the scale of SMEs. A list of hazards was compiled before the investigation by the experienced work environment specialist of the firm who had worked in this factory over 20 years.

The primary hazards in this industry are hazardous tools and equipment (e.g. circular and sand saws), heavy physical load (e.g. moving the wheelbarrow), noise, wood dust, chemical health hazards (including odours of chemicals (e.g. formaldehyde with its low odour threshold level (IPCS, 1989))) originating from polishes during surface treatment or gluing the wood sheets or lists on board. The accident rate in wood processing industry is high and is dominantly caused by machine involvement and due to loss of balance (related to frequent manual material handling and the lack of proper cleaning) (Karltun and Eklund, 1997).

The results of the measurements of physical and chemical hazards are presented in *Section IV*, *Paper I*. On the basis of the measurements and observations in the wood-processing department the following risk levels according to flexible risk assessment method were determined:

- The microclimate in the department was acceptable, but considering that there is a need for improvement by raising the indoor air moisture content to favour the binding of respirable dust, it was assessed as *unjustified risk (Figure 7, Paper I)*.

- The results of noise measurements showed that workers working with machines to process wood were exposed to very high values of noise (98.0-101.2 dB(A)). Even when earmuffs were occasionally worn and rest breaks taken, it was revealed that the NNR of earmuffs wasn't sufficient; and the risk for noise-induced hearing impairment was still high. Therefore, the noise in the department was assessed as *inadmissible risk (Figure 7, Paper I)*.
- The phenol-formaldehyde varnish is a source for workers' allergic reactions and long-term health impairments. The risk phrases for this compound are R 23/24/25 (Toxic by inhalation, in contact with skin and if swallowed), R34 (Causes burns), R40 (Limited evidence of a carcinogenic effect) and R43 (May cause sensitisation by skin contact) (EC, 2001). The measured TWA concentration – 0.5 mg/m^3 – did not exceed the OEL value (0.6 mg/m^3), however, considering its carcinogenic potency (IARC, 1995) and low odour threshold value (IPCS, 1989) the risk was assessed as *unjustified (Figure 7, Paper I)*.
- The high levels of wood dust (10 mg/m^3) were assessed as *inadmissible risk (Figure 7, Paper I).*
- The high value of physical overload was assessed as *unjustified risk* using the risk calculation method of manual handling of loads (Reinhold et al., 2008b) (*Figure 7, Paper I*).

The work environment specialist was interviewed after the process of risk assessment. He noted that assessing hazards with the flexible risk assessment method had positive impact to workers' awareness about OHS and was valued as compendious by the management of company. He emphasized the need to study the health hazards of wood dust more extensively and noted the absence of clear assessment of machine safety with the flexible risk assessment method.

GENERAL CONCLUSIONS

1. A systemic approach to occupational safety is the key for optimizing workplace safety in enterprises. A consistent method for assessing the occupational hazards is recommended. The case studies showed that the flexible risk assessment method created by the authors is viable and applicable in the selected industries for assessing physical and chemical risks. The methodology can be used in any kind of company, but SMEs are preferred. Large companies with higher capacities and resources to enhance workplace safety might find a need to implement a more sophisticated and time-consuming approach.
2. Using the Estonian experiment, five or four risk levels to characterize risks in the work environment are sufficient and unsophisticated for the employer to understand and use. Triggers need to be in place, so people know how to conduct an effective risk assessment, who to involve and who to inform of the outcome. Preferably, risk assessment should be performed by a person with the necessary technical competence and contextual knowledge of the workplace.
3. In the investigated Estonian enterprises, some of the hazards were under control, but many problems were detected as well. Noise, one of the main health hazards present in many industries, was examined in depth. In the studied enterprises, the noise level exceeded the norms in several cases. The risk to experience noise-induced hearing loss among workers who misuse the protective equipment is significant. The employers should attempt to find additional technical measures to lower the noise levels and encourage the workers to use the personal protective equipment properly.
4. Assessing chemical risks with the flexible risk assessment method is an attempt to provide coherent guidance through targeting necessary information for SMEs to manage chemical risks and track performance more effectively. It is an alternative method to support companies in fulfilling governmental legislation of handling chemicals in occupational settings. Since the method has been worked out to assess other occupational hazards as well, it is consistent for approaching hazards in the workplace. The method is suitable for enterprises processing materials or handling chemicals in some stages, but cannot be applied for chemical plants where several other factors should be taken into account while assessing the risks for safety, health and environment. The risk of major hazards is not covered by the flexible risk assessment method.
5. In many of the investigated enterprises, the management's attitude towards OHS was stimulating and supportive and the management showed eagerness to enhance workplace safety. However, in several cases it was suggested that the employers should improve the dissemination of information to workers on safety matters, particularly on the results of risk assessment, on the accidents and incidents that have occurred in the enterprise in order to remind them of the importance of taking the safety measures for achieving a safe workplace.

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ABSTRACT

The present study was aimed at developing a new comprehensive risk assessment method to assess hazards at workplaces since risk assessment is considered as the foundation for pro-active occupational health and safety management in enterprises and is an important element in European legislation in occupational health and safety. Some of the existing workplace risk assessment methods were overviewed in the literature review. The core criteria and specific requirements for the new method were set before developing the new model. The main issues included user friendliness, determination of risk levels by quantitative data, clear differentiation of acceptable and unacceptable risk areas, applicability for various organizations encountering either small- or large-scale occupational hazards, etc.

As a result, the thesis offers a flexible risk assessment method based on a two-step model that could be enlarged up to a six-step model according to the size of the enterprise, combination of hazards profile and experiences of the safety personnel. Criteria for determining risk levels of the main hazards in Estonian industries – inconvenient indoor climate, poorly organized lighting, excessive noise, chemicals and dust – based on the five-step flexible risk assessment method were developed. Measurements of occupational hazards were conducted in 18 manufacturing enterprises and results were analysed. Excessive noise, as one of the main health hazards in manufacturing, was studied extensively and risk for noise-induced hearing impairment was estimated. The risk criteria for four neurotoxic chemicals (butanol, styrene, xylene and toluene) present in the wood processing industry were determined. Among dusts, wood dust was found to be of the utmost concern and therefore, risk criteria for wood dust were presented.

Two case studies were added as the implementation of the flexible risk assessment method. The studies showed that the method created by the authors is viable and applicable in the selected industries for assessing physical and chemical risks. The basic trial version of the software tool of the model was accepted by the test users as user-friendly, comprehensive and transparent. The test users emphasized the benefits of illustrative characteristics, which is a valuable tool for employees to get the first information about occupational hazards. The methodology can be used in any kind of company, but small and medium-sized companies are preferred since large companies may find a need to implement a more sophisticated and time-consuming approach.

In the current thesis, the investigation of occupational hazards is limited to measurable hazards only. Attempts to integrate other hazards, such as psychosocial and physiological hazards, to the same model have been made, but these need further investigation and are not covered in the present study. The method, in the current stage, identifies the risk level of a hazard, but does not offer direct advice on the selection of adequate or suitable control measures. The general hierarchy of control measures is recommended, but detailed advice on the controls remains for the future research.

KOKKUVÕTE

Käesoleva doktoritöö eesmärgiks oli välja töötada laiaulatuslik riskianalüüsi meetod töökeskkonna riskide hindamiseks, sest riskianalüüsi loetakse proaktiivseks tööohutuse ja töötervishoiu juhtimise aluseks ettevõtetes ning on ühtlasi oluline osa Euroopa tööohutuse ja töötervishoiualasest seadusandlusest. Valik olemasolevaid riskianalüüsi meetodeid vaadeldi kirjanduse ülevaates. Enne uue meetodi väljatöötamist sätestati meetodile põhitingimused ja spetsiifilised kriteeriumid, mis hõlmasid kasutaja sõbralikkust, selget vastuvõetava ja vastuvõetamatu riskitaseme eristamist, sobivust erineva ohtude diapasooniga ettevõtetele jne.

Doktoritöö esitab paindliku riskianalüüsi meetodi, mis põhineb kaheastmelisel mudelil, mida on võimalik laiendada kuni kuueastmeliseks sõltuvalt ettevõtte suurusest, ohtude profiilist ja ohutusalaste spetsialistide kogemuslikust baasist. Kriteeriumid riskitasemete määramiseks peamistele ohuteguritele Eesti tööstuses – ebasobiv sisekliima, vääriti organiseeritud valgustus, ülemäärane müra, kemikaalid ja tolm – töötati välja, kasutades paindliku riskianalüüsi viieastmelist skeemi. Töökeskkonna ohutegureid mõõdeti 18 erinevas ettevõttes, mille tulemusi analüüsiti, esitades riskitasemete suuruse. Ülemäärast müra kui üht tõsisemat töökeskkonnaalast probleemi tööstuses uuriti süvitsi ning hinnati riski mürast tingitud kuulmiskahjustuse arenemiseks. Puidutööstuses uuriti nelja erineva neurotoksilise kemikaali (butanool, stüreen, ksüleen ja tolueen) sisaldust töökeskkonna õhus ning esitati riskitasemete kriteeriumid. Töökeskkonnas esinevatest tolmudest uuriti puidutolmu.

Töösse on lisatud kaks ohutusalast juhtumiuuringut ettevõtetes, kus kasutati riskide hindamiseks paindlikku riskianalüüsi meetodit. Uuringud näitasid, et väljatöötatud meetod on rakendatav hindamaks füüsikalisi ja keemilisi riske. Proovikasutajad hindasid tarkvara test-versiooni kui kasutajasõbralikku ja läbipaistvat ning rõhutasid illustratiivsete omaduste olulisust töökeskkonnas esinevatest ohuteguritest ülevaate saamisel. Meetodit on võimalik kasutada erinevates ettevõtetes, kuid väikesed ja keskmised ettevõtted on eelistatud, sest suured ettevõtted, kelle vajadused ja võimalused on laiemad, võivad teha valiku aeganõudvama ning keerulisema meetodi kasuks.

Käesolevas doktoritöös on uuritud vaid mõõdetavaid ohutegureid. Samasse mudelisse on püütud integreerida ka teisi ohutegureid (psühhosotsiaalsed, füsioloogilised), kuid see vajab edasist uurimist ning ei ole antud töös esitatud. Praegusel kujul identifitseerib meetod ohuteguri riskitaseme, kuid ei esita otsest soovitust ohutusmeetmete valikul. Pakutakse küll üldist ohutusmeetmete hierarhiat, kuid üksikasjalike kontrollmeetmete esitamine võiks olla edasine uuring.

APPENDIX A

PAPER I

Reinhold, K., Tint, P., Kiivet, G.
Risk Assessment in Textile and Wood Processing Industry

Reproduced with permission from:
International Journal of Reliability, Quality and Safety Engineering,
13(2), April 2006, 115-125.

PAPER II

Reinhold, K., Tint, P.
Hazards profile in manufacturing: determination of risk levels towards enhancing the workplace safety

Reproduced with permission from:
Journal of Environmental Engineering and Landscape Management,
accepted.

PAPER III

Reinhold, K., Tint, P.
Improvement of work environment in textile industry in Estonia

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Foundations of Control and Management Sciences, 2007, 08, 61-76.

PAPER IV

Reinhold, K., Tint, P.
Chemical Risk Assessment in the Work Environment

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Environmental Research, Engineering and Management, 2008, 4(46), 48-55.

PAPER V

Reinhold, K., Järvis, M., Tint, P.
Risk Observatory—A Tool for Improving Safety and Health at the Workplace

Reproduced with permission from:
International Journal of Occupational Safety and Ergonomics, 2009, 15(1), 1-12

PAPER VI

Reinhold, K., Tint, P., Munter, R.
Indoor air quality in industrial premises

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Scientific Proceedings of Riga Technical University "Material Science and Applied Chemistry",
accepted.

APPENDIX B

ELULOOKIRJELDUS

1. Isikuandmed

Ees- ja perekonnanimi	Karin Reinhold
Sünniaeg ja -koht	27.04.1976, Tallinn
Kodakondsus	Eesti

2. Kontaktandmed

Aadress	Kiia tee 19, Saue vald
Telefon	+372-6203960
E-posti aadress	Karin.Reinhold@tseba.ttu.ee

3. Hariduskäik

Õppeasutus (nimetus lõpetamise ajal)	Lõpetamise aeg	Haridus (eriala/kraad)
Tallinna Tehnikaülikool	2003	Loodusteaduste magister
Tallinna Tehnikaülikool	1999	Materjalitehnoloogia insener
Saaremaa Ühisgümnaasium	1994	Keskharidus

4. Keelteoskus (alg-, kesk- või kõrgtase)

Keel	Tase
Eesti keel	Kõrgtase
Inglise keel	Kõrgtase
Soome keel	Kesktase
Vene keel	Algtase

5. Täiendusõpe

Õppimise aeg	Täiendusõppe läbiviija nimetus
2003–2004	Inimese toksikoloogia, ökotoksikoloogia ja riskide hindamine. Uppsala Ülikool, Rootsi
Juuni 2004, Veebruar 2005	Ohutusuuringud. I – Õnnetused ja riskid II – Ohutuse edendamine. Põhjamaade Töötervishoiu Instituut, Soome
November–Detsember 2006	Pedagoogika ja õppemetoodika. TTÜ Avatud Ülikool
Jaanuar–Veebruar 2007	Juhendamine ja tagasiside. Tartu Ülikooli Avatud Ülikool

6. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
2002–...	Tallinna Tehnikaülikool	Assistent
2001–2002	TÜV Nord Baltik OÜ	Tulekatsete ekspert
1999–2001	Päästeamet, Tehniline Uurimiskeskus	Tekstiilkatsete vaneminsener

7. Teadustegevus

V189 Tööstustoodete, -süsteemide ja -hoonete ohutus ning töökindlus (SAFERELNET)
1009e Tööterviseriskide haldamismudelite väljatöötamine ja nende rakendamine ohutusproblemaatilistel erialadel
4001re Eesti töökeskkonna riskianalüüsi mudelite väljatöötamine ja rakendamine töökeskkonna parendamiseks
7003re Arvutil põhinev riski hindamine töökeskkonnas - võimalused ja rakendused

8. Kaitstud lõputööd

Loodusteaduste magistritöö: Riski hindamine töökeskkonnas ja keemiarisk. Tallinna Tehnikaülikool, 2003. Juhendaja: Rein Munter
Kraadieelõppe diplomitöö: Euronormidele rakendamine päästetöötajate töörõivaste projekteerimisel, Tallinna Tehnikaülikool, 1999. Juhendaja: Andres Krumme

9. Teadustöö põhisuunad

Töökeskkonna riskianalüüsi meetodid, töökeskkonna ohutegurid ja terviseriskid, tööõnnetusstatistika uurimine

10. Teised uurimisprojektid

V220 Naisteadlaste teadustöö avardamine elektrotehnika, informaatika ning rakendusteaduste valdkonnas

CURRICULUM VITAE

1. Personal data

Name	Karin Reinhold
Date and place of birth	27.04.1976, Tallinn
Citizenship	Estonian

2. Contact information

Address	Kiia tee 19, Saue parish
Phone	+372-6203960
E-mail	Karin.Reinhold@tseba.ttu.ee

3. Education

Education Institution	Graduation year	Education (field of study/degree)
Tallinn University of Technology	2003	M. Nat.Sc in chemical and environmental protection technology
Tallinn University of Technology	1999	Engineer in material technology
Saaremaa Co-Gymnasium	1994	High school education

4. Language competence/skills (fluent, average, basic skills)

Keel	Level
Estonian	Fluent
English	Fluent
Finnish	Average
Russian	Basic

5. Special courses

Period	Educational or other organisation
2003–2004	Human toxicology, ecotoxicology and risk assessment. Uppsala University, Sweden
June 2004, February 2005	Safety Research. I – Accidents and risks. II – Safety Promotion. Nordic Institute for Advanced Training in Occupational Health, Finland
November–December 2006	Pedagogy and teaching methodology. TUT, Open University
January–February 2007	Supervising and Feedback. Tartu University, Open University

6. Professional employment

Period	Organisation	Position
2002–...	Tallinn University of Technology	Assistant
2001–2002	TÜV Nord Baltik Ltd	Expert of fire tests
1999–2001	Rescue Board, Technical Research Centre	Senior engineer of textile tests

7. Scientific work
V189 Safety and reliability of industrial products, systems and structures (SAFERELNET)
1009e Elaboration of models of occupational health risks and implementation in safety problematic areas
4001re Development of models for risk assessment in Estonian work environment and their applications for improvements of work environment
7003re Computer-based risk assessment in work environment – possibilities and results

8. Defended theses
M. Nat. Sc.: Risk assessment in work environment and chemical risk. Tallinn University of Technology, 2003. Supervisor: Rein Munter
Engineer's Diploma : Implementation of EU norms to design work clothes for rescue workers. Tallinn University of Technology, 1999. Supervisor: Andres Krumme

9. Main areas of scientific work/Current research projects
Workplace risk assessment methods, occupational hazards and health risks, research of occupational accidents statistics

10. Other research projects
V220 Opening up electrical engineering, computer technology and applied sciences to successful women careers

DISSERTATIONS DEFENDED AT TALLINN UNIVERSITY OF TECHNOLOGY ON *CHEMISTRY AND CHEMICAL ENGINEERING*

1. **Endel Piiroja**. Oxidation and destruction of polyethylene. 1993.

2. **Meili Rei**. Lihatehnoloogia teaduslikud alused. Fundamentals of Food Technology. 1995.

3. **Meeme Põldme**. Phase transformations in hydrothermal sintering processing of phosphate rock. 1995.

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