Methodology for Assessing Learning from Incidents - a Process Industry Perspective

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Summary

Considerable resources are used in process industries and in many other industries for reporting incidents and for utilising these experiences to prevent future incidents – from minor disturbances to accidents with major consequences. However, there are many indications that only a portion of the entire potential for learning from reported incidents is actually utilised. Several sources in the research literature provide evidence of this. The author, who has spent forty years in the process industry, also has experiences pointing in the same direction. To improve this situation, one needs to have a clear and well-founded opinion about the status of learning from incidents in an organisation. One needs to be able to assess the effectiveness of the learning in order to manage and improve it.

No adequate methods for such assessments were found by the author in the scientific literature or in the more experience-based applications in companies. Thus, a strong need was identified to develop a methodology including specific methods and tools for assessing the effectiveness of learning from incidents. This was the starting point for the research presented in this thesis.

The research is based on information on incidents compiled in databases covering a long period of time (years). Today, most process industry companies have such databases for handling a broad spectrum of incidents, from reporting to formal closure of the case. The Major Accidents Reporting System (MARS) database administered by the European Commission has also provided a basis for the research.

Several aspects of learning need to be included in a methodology for a comprehensive assessment of how effectively the learning from incidents works. One has to be able to address the following types of issues:

1. Do we handle the incidents reported in our incident learning system properly? Do the various steps in the learning cycle work effectively?
2. How much do we learn from the incidents which are reported? How does this learning compare with what could potentially have been extracted? What level of learning are we at and what level could we have achieved?
3. Do we report the incidents that are worth reporting (that have a learning potential)? What is the threshold for reporting? How big is the number of unreported cases, the "hidden number"?

Above all, in such a methodology, the effectiveness of both the process of learning and the product of learning – the two classic parts of theory of learning – have to be included. A third and independent aspect that must also be dealt with is the extent to which reportable incidents are actually reported.

In order to address issue 1, a method has been developed which assesses the effectiveness of learning in every step of the learning cycle (Reporting – Analysis – Decision – Implementation – Follow-up) for each incident, and of the aggregated material of many incidents. The method contains a tool for each step, built on a number of dimensions which in turn contain a number of aspects. By using a rating system including a scale with formulated requirements for some levels, the effectiveness of each step can be assessed numerically for each individual incident.

For issue 2, a method has been developed that builds on classifying the learning product, the measures taken, in different levels depending on how well the experiences from an incident are handled. The basis for classifying an incident is the geographical application, the degree of organisational learning, and the duration of the measures taken. Incidents are classified both in actual levels of learning based on the measures taken, and in potential levels of learning, indicating the level that could have been achieved if all the potential for learning had been utilised. The relation (the ratio) between actual and potential levels of learning is a measure of the effectiveness of the learning. A specific method for evaluating the underlying causation has been developed to draw conclusions about the potential learning. The method also contains a step for considering that there are normally a number of unreported incidents – what we can call the "hidden number". In another step, consideration is taken of possible learning from an aggregated material of incidents and in yet another step, learning from incidents via other means than through the incident learning system proper.

For issue 3, a tool has been developed for assessing the threshold for reporting as well as guidelines for what can be considered reasonable frequencies of incident reporting in the process industry. In addition to providing information about how efficient the reporting of incidents is, this will also provide input to the method for issue 2.

The research on the MARS database has been limited to cover issue 2.

Together, the methods with their tools and guidelines constitute a methodology, which allows the user to make a total assessment of the effectiveness of the learning from incidents in process industry companies.

The empirical material for the research was taken from the incident databases of six Swedish process industry companies, and from the EC MARS database for major accidents in enterprises which fall under the Seveso legislation. The author has also applied knowledge of the domain obtained from his many years of activities in the process industry.

The research methodology has mainly been based on methods in the design sciences and to some extent on case study techniques. After having established a general basis of knowledge and formulating specific research objectives, the methods were developed, tested, evaluated and modified.

The validity of the methods and tools has mainly been determined by expert judgement and through feedback from the companies participating in the research, with good results. The methods and tools have proven themselves to function very well and to provide stable results when applied to empirical material.

The results from the application of the methods have proven that learning from incidents is often limited, especially in relation to what would have been possible to achieve. Effectiveness in the learning cycle is often relatively poor, especially in the analysis and follow-up steps. However, there are large variations between the different participating companies. The results from the assessment of the learning effectiveness combined with the results from safety audits often offer valuable insight into the decisive factors for good learning.

In conclusion, the research presented in this thesis has generated a methodology containing a number of methods and tools that can be used successfully to assess how effectively a process industry company handles incidents. The results from the application of this methodology can be used to determine where weaknesses exist and where there is room for improvement. Because the methods generate numerical results, they can be used in research work to find correlations between learning from incidents and other systems or artefacts for evaluating safety performance. The methodology is meant to be used by persons with a relatively broad background in safety matters.

Sammanfattning

Stora resurser används i processindustrin, och i många andra industribranscher, på att rapportera incidenter för att utnyttja erfarenheterna från dessa för att förebygga framtida incidenter – alltifrån mindre störningar till olyckor med stora konsekvenser.

Det finns emellertid en hel del som tyder på att man ofta utnyttjar bara en del av hela den potential för lärande som finns i de incidenter som rapporteras. Flera källor i den vetenskapliga litteraturen vittnar om detta. Författaren, som tillbringat fyrtio år i processindustrin har en hel del erfarenheter som pekar på samma sak. För att skapa en grund för att förbättra denna situation måste man ha en klar och välgrundad uppfattning om hur tillståndet kring lärandet från incidenter är i en organisation. Man behöver kunna utvärdera effektiviteten i lärandet för att kunna styra och leda det mot förbättringar.

Författaren har inte funnit några bra metoder för sådana utvärderingar, varken i den vetenskapliga litteraturen eller i mer erfarenhetsmässigt baserade applikationer ute bland företag. Ett starkt behov av att utveckla en metodik, inklusive specifika metoder och verktyg, för att kunna utvärdera effektiviteten i lärandet från incidenter har alltså identifierats. Detta faktum var utgångspunkten för det forskningsarbete som presenteras i denna avhandling. En metodik för att utvärdera effektiviteten i lärandet från incidenter har tagits fram.

Forskningen är baserad på information om incidenter, som finns samlad i databaser som täcker en längre tidsperiod (år). De flesta processindustriföretag har idag sådana databaser för hantering av incidenter, från rapportering till formellt avslut av ärendet, för ett brett spektrum av incidenter. Även en databas (MARS), administrerad av Europakommissionen, för stora olyckor med allvarliga konsekvenser har utgjort material för forskningsarbetet.

För att kunna göra en allomfattande bedömning av hur effektivt lärandet fungerar i ett processindustriföretag har utgåtts från att flera aspekter i lärandet måste ingå i en sådan metodik. Man måste kunna få svar på följande typer av frågeställningar:

1. Har vi en effektiv hantering av de incidenter som rapporteras i vårt system? Fungerar de olika stegen i lärcykeln effektivt?
2. Hur mycket lär vi oss av de incidenter som rapporteras i förhållande till vad som potentiellt går att lära sig av dem? Vilken lärandenivå ligger vi på och vilken skulle vi kunna ligga på?
3. Rapporterar vi de incidenter som är värda att rapportera? Vad är tröskeln för rapportering? Hur stort är mörkertalet?

Framför allt måste i en sådan metodik ingå effektiviteten både i processen för lärande och av produkten av lärandet, de två klassiska delarna i teorin kring lärande. Som en tredje och självständig aspekt i att få en heltäckande utvärdering av hur lärandet

fungerar måste också behandlas frågan om i vilken utsträckning rapportering sker av de incidenter som är värda att rapportera.

För att kunna ge svar på frågeställning 1 ovan har utvecklats en metod som värderar effektiviteten i varje steg i vad som här benämns lärcykeln (Rapportering – Analys – Beslut – Implementering – Uppföljning) för varje enskild incident och dessutom av ett samlat material av många incidenter. Metoden innehåller verktyg för varje steg, som bygger på ett antal dimensioner, som i sin tur innehåller ett antal aspekter. Med hjälp av en konstruerad bedömningsskala med formulerade krav för ett antal nivåer kan effektiviteten i varje steg bedömas med ett numeriskt värde för varje enskild incident.

För frågeställning 2 ovan har också utvecklats en metod, som bygger på att klassificera lärandeprodukten, de genomförda åtgärderna, i olika nivåer beroende på hur väl erfarenheterna från en incident används. Grunden för att klassificera en incident är den geografiska appliceringen, graden av organisatoriskt lärande samt tidsaspekten av de vidtagna åtgärderna. Dels klassificeras en incident i lärandenivå utifrån de faktiskt vidtagna åtgärderna, dels görs en utvärdering av vilken lärandenivå som varit möjlig om hela potentialen för lärande utnyttjats. Förhållandet mellan verklig och potentiell lärandenivå blir ett mått på effektiviteten av lärandet. Ett särskilt verktyg för att utvärdera den underliggande orsaksbilden har utvecklats för att ur denna kunna dra slutsatser om det potentiella lärandet. I metoden ingår också att kunna ta hänsyn till att det oftast finns ett mörkertal av ej rapporterade, men rapportervärda, incidenter, samt ta hänsyn till eventuellt lärande från ett samlat material av incidenter och även till eventuellt lärande genom andra sätt än via incidenthanteringssystemet.

För frågeställning 3 ovan har utvecklats ett verktyg för att bedöma tröskeln för rapportering, samt riktlinjer för vad som kan vara rimliga rapporteringsfrekvenser av incidenter i processindustrin. Förutom att ge information i sig om hur effektiv rapporteringen av incidenter är, ger dessa verktyg viss input till metoden för frågeställning 2.

I forskningen på MARS-databasen har arbetet begränsats till att omfatta frågeställning 2.

Tillsammans utgör metoderna med sina verktyg och riktlinjer en metodik, som tillåter användaren att göra en utvärdering av effektiviteten i lärandet från incidenter för företag inom processindustrin.

Empirin för forskningen har varit dels material från incidentdatabaser från sex svenska processindustriföretag, dels Europakommissionens databas (MARS) för stora olyckor i verksamheter som faller under Seveso-lagstiftningen. I tillägg har författaren använt en hel del domänkunskaper som förvärvats under egen verksamhet inom processindustrin under många år.

Forskningsmetodiken har huvudsakligen byggt på metoder inom designvetenskap och i någon mån case-study-teknik. Efter att ha etablerat en allmän kunskapsbas samt formulerat specifika mål för forskningen har arbetssättet bestått av att utveckla metoder, testa dessa metoder och slutligen utvärdera och modifiera metoderna. Validiteten av metoderna och verktygen har prövats framför allt genom expertutlåtanden och genom omdömen från de företag som deltagit i forskningen, med gott resultat.

Metoderna och verktygen har vid användning på det empiriska underlaget visat sig fungera mycket väl och givit stabila resultat.

Resultaten från användning av metoderna har bekräftat att lärandet från incidenter ofta är begränsat, särskilt i förhållande till vad som hade varit möjligt att uppnå. Effektiviteten i lärcykeln är ofta också relativt svag, särskilt i analyssteget och i uppföljningssteget. Stora variationer förekommer dock mellan olika företag som deltagit i forskningsstudien. Resultaten från bedömning av effektiviteten av lärandet kombinerat med resultaten av säkerhetsrevisioner ger ofta god insyn i vad som är avgörande faktorer för att nå bra lärande.

Sammanfattningsvis kan konstateras att forskningen som redovisas i denna avhandling har genererat en metodik som innehåller ett antal metoder och verktyg som på ett kraftfullt sätt kan användas för att bedöma effektiviteten i ett processindustriföretags sätt att hantera incidenter. Resultaten från användningen av denna metodik kan användas för att avgöra var svaga punkter finns och därmed var utrymme för förbättringar finns. Eftersom metoderna genererar numeriska resultat kan metoderna också med fördel användas i forskningsarbete där man är intresserad av att finna korrelationer mellan lärandet från incidenter och andra system eller företeelser för säkerhet, vilka kan uttryckas numeriskt. Metodiken är avsedd att användas av personer med en ganska bred bakgrund i säkerhetsfrågor.

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Writing this thesis, and defending it, is for me fulfilling an old dream. Warm thanks to all the people who made it possible.

The most important people who supported me in my efforts to realise this dream and for cheering me up when things looked gloomy have been my family. My dear Bitte, thanks for your understanding and patience and for having listened to me when I needed it. To my children, Jesper and Johanna, and my wonderful grandchildren, Simon, Benjamin, and Christoffer, thanks for your encouragement during my struggle.

Forty-three years ago, I was very tempted to enter into a research career after my degree in chemical engineering from KTH (Royal Institute of Technology, Stockholm) but I finally decided to pursue a career in industry instead. After twenty years in the process industry, I wanted to do something new and started up a consulting firm, based on my great interest for safety. I was also fortunate to become involved as a teacher at the Department of Fire Safety Engineering and Systems Safety at Lund University. Here I came into contact again with academia in a way that made it possible to give my old ambitions a serious try, and now on a subject that I am really devoted to – learning for safety.

The research presented in this doctoral thesis has been carried out at the Division of Ergonomics and Aerosol Technology, Department of Design Sciences, Faculty of Engineering, Lund University. I would therefore like to thank all the people at the division who have supported me, and in particular: Professor Roland Akselsson, my primary supervisor, for guidance, constructive criticism and never-ceasing suggestions for improvements; Dr. Åsa Ek, my secondary supervisor, for dedication, and for good co-operation; Professor Gerd Johansson, my supervisor at the end of the work, for support; Eileen Deaner for excellent language assistance; Robert Olsson for IT support; and Susanne Nordbeck and Rose-Marie Akselsson for administrative support.

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Stenungsund, 20 April 2011

Anders Jacobsson

List of appended papers

This thesis is based on the following appended papers referred to in the text.

Paper I

Jacobsson, A., Ek, Å. and Akselsson, R. (2011). Learning from incidents – A method for assessing the effectiveness of the learning cycle. Submitted to an international scientific journal.

The thesis author formulated the aim of the paper, developed the method, organised the field studies, applied the method to the field objects, organised the expert judgements and wrote the paper.

Paper II

Jacobsson, A., Ek, Å. and Akselsson, R. (2011). Method for evaluating learning from incidents using the idea of "level of learning". Accepted by *Journal of Loss Prevention in the Process Industries*.

The thesis author formulated the aim of the paper, developed the method, organised the field studies, applied the method to the field objects, organised the expert judgements and wrote the paper.

Paper III

Jacobsson, A., Sales, J. and Mushtaq, F. (2009). A sequential method to identify underlying causes from industrial accidents reported to the MARS database. *Journal of Loss Prevention in the Process Industries* 22 (2), 197-203.

All authors formulated the aim of the paper. The thesis author developed the method, applied the method to the data in the MARS database (repeated by a co-author), organised the expert judgements and wrote the paper.

Paper IV

Jacobsson, A., Sales, J. and Mushtaq, F. (2010). Underlying causes and level of learning from accidents reported to the MARS database. *Journal of Loss Prevention in the Process Industries* 23 (1), 39-45.

All authors formulated the aim of the paper. The thesis author developed the method, applied the method to the data in the MARS database (repeated by a co-author), organised the expert judgement and wrote the paper.

Table of contents

1 Introduction

Learning from incidents is considered one of the most important means in the process industry to learn from experiences for safety. Most companies have a formal incident learning system in use and normally the reporting of incidents is at least decent. However, many professionals in the industry and in the safety community comprehend the possibility of gaining much more knowledge and of learning many more lessons from these systems than what is normally the case; they see potential for improving the learning processes. In order to assess the accuracy of this comprehension, one would need to assess the performance of the learning in such incident learning systems. No simple methodology that yields tangible and reliable results for this is available as far as the thesis author knows. Thus, the author has undertaken to develop one. This thesis presents a methodology for assessing learning from incidents. It can be applied to a wide variety of incident learning systems, and can be easily used by people in the process industry and in national and local authorities, with the general aim to improve learning from incidents.

1.1 Background

People at all times have used the outcomes of their activities as lessons for learning. In an enterprise, one obviously wants to learn from history to achieve better business performance in general, but also to protect the values of the company and address safety, health and environmental issues both internally and externally. Many enterprises use negative outcomes in particular as the basis for a more structured learning. We often refer to them as “incidents”. This is common today in all types of enterprises both in industry and the public sector. The process industry has traditionally been considered among the leaders in learning from incidents. This is probably related to the major risks this type of industry often incurs and the potentially very costly business interruptions they can cause.

The thesis focuses on the learning from two types of incidents. The first is on learning from the broad spectrum of incidents reported in most process industries. All types of incidents are included, with no particular emphasis on the rather few, more serious accidents. The second is on learning from major accidents, and in this case, these accidents reported to the European Commission in the Major Accident Reporting System (MARS), according to the Seveso legislation. Although several analyses have previously been performed on the accidents in MARS, the central question regarding the effectiveness of learning from the accidents has not been in focus before.

In the last ten to fifteen years, large administrative systems for learning from incidents have been developed (Van der Schaaf and Kanse, 2004), most of them computer-based. They include tools for reporting and the subsequent handling of incidents to the final close-out of the case, and check that all steps are completed and signed off with reminders if deadlines are exceeded. Some of them also include tools for investigating incidents and for carrying out statistical and other analyses of the incidents on an aggregated basis. These systems are often used in large corporations to disseminate information on a corporate basis.

In the European Community, the MARS database was established in order to learn from industrial accidents in the whole Community. Article 19 of the Seveso Directive (EC, 1997) states that the European Commission shall set up and keep at the disposal of Member States a register and information system (MARS). One of the purposes is the "distribution to competent authorities of an analysis of the causes of major accidents and the lessons learned from them".

Despite better tools for administration of the learning from incidents, the question remains: How much do we actually learn from the incidents?

The effectiveness of learning from incidents in general can often be questioned (Kletz, 2001), and so even from major accidents (Hovden, Storseth and Tinmannsvik, 2011). The explanations for this can be found in many of the activities from reporting to implementation and follow-up of measures, but the analysis of causes and conditions often appears to be a weak point. Hale (2008) claims that accident investigations often stop at the events close to the accident, which usually concern only the behaviour of the hardware and of the operators/workforce directly concerned with carrying out the activity. Hollnagel (2004) claims that we rarely look beyond the first explanation we find.

In addition, Koornneef (2000) concludes that organisations often underestimate the time and resources needed for an adequate treatment of incidents that are reported and especially the need for firmly anchoring the learning process at the level of first line operators.

Moreover, learning from the experiences from other companies and in other countries seems to be even more difficult (Goyal and Kulkarni, 2009).

Thus, several researchers have concluded that learning is often unsatisfying, and although much effort has been devoted for decades to set up systems to learn from incidents much of it has not been as successful as anticipated.

However, no methods were found in the research literature on how to assess how effective the learning from incidents actually is. Nor has the thesis author encountered any pragmatic tools used in the process industry for assessing the effectiveness of learning from incidents. The first step in improving a situation is to recognise the potential weakness. For that we need to be able to measure the current status, and then by following the motto of Drucker (1954), “What gets measured gets managed”, we can improve the situation.

The thesis contributes to this issue – how to assess the effectiveness of learning from incidents – by presenting a new methodology with special application to process industries. The author hopes that the methodology will be used by the process industry and by authorities related to that industry as well as by researchers, and that it will contribute to better management of incidents and better learning from them. The thesis offers pragmatic instruments to be used by safety professionals to assess the effectiveness of the learning from incidents.

About the thesis author

A fair amount of the description of various artefacts, organisational conditions and other phenomena in the process industry world is based on the long and extensive experience that I, the author, have from this domain. I have spent more than forty years in the process industry internationally, half the time in company line positions and half the time as a safety consultant. I have been able to benefit from this fact and utilise my domain knowledge throughout the research process for this thesis.

2 Research objectives

The research presented focuses on a methodology for assessing the effectiveness of learning from incidents. When applied to field studies, the methodology generates results that can be used to improve the process of learning from incidents and of safety in general in organisations. The results are also suitable to use as a fundament in studies that investigate links between learning from incidents and other safety improvement activities, such as results from safety audits and safety climate investigations.

The learning process as such and the mechanisms which influence learning have not been included in this research. However, a few observations from the application of the methodology relating to this subject will be mentioned in the discussion chapter.

In the thesis the word *effectiveness* is used as a general expression for the quality of the learning from incidents. *Effectiveness,* often associated with "doing the right thing", normally denotes the quality of a phenomenon – a process or the result of a process – and the extent to which the actual output meets the desired output. *Efficiency*, which is often associated with "doing things right", normally denotes the quantity of a phenomenon, especially in terms of output versus input (Ostroff and Schmitt, 1993). Thus, to denote the degree of learning (actual learning compared to possible learning), the word *effectiveness* is used as an expression for the overall <u>quality</u> of both the learning process (the learning cycle) and the learning product (the lesson learned). In one instance, however, *efficiency* is used, namely for describing the <u>quantity</u> of incident reporting. Both the terms (*effectiveness* and *efficiency*) are discussed further on in the thesis.

The research concerns both *personal safety* or *occupational health* incidents and *process safety* incidents with potential for major accidents.

The research is not linked to any specific formal incident learning system used in the process industry but based on several typical such systems (except for the research on the MARS database).

The research presented comprises a part of a research project about learning from incidents in hazardous enterprises (LINS), Study 1, and of another research project concerning learning from accidents in the EC's Major Accidents Reporting System (MARS), Study 2.

2.1 General research aims

The general aims of the research presented were to:

1. Develop a general methodology for assessing the effectiveness of the learning from incidents in the process industry.

2. Test and improve the methodology by using field data.

Through this research it was possible to gain knowledge about the effectiveness of learning from:

- incident learning systems in a selection of Swedish process industries, and
- the system for reporting major accidents in the MARS database.

2.2 Specific research objectives and research questions

The primary objective of this research was to develop a methodology suited for assessing the effectiveness of learning from incidents based on information contained in incident learning systems (from minor incidents to major accidents). A secondary objective was to express the effectiveness of learning from incidents in "figures" to be able to use the results from application of the methodology, its methods and tools in correlations with other safety measurements expressed in figures.

To reach these research objectives, research questions were formulated. The purpose and the research criteria associated with the artefacts (methodology, methods and tools) defined in the research questions were developed gradually during the work (for more details see section 4.2 and Chapter 5). However, in order to gain a reasonable overview of the main criteria for the artefacts, these are mentioned here.

The formulation in research questions RQ1, RQ2 and RQ4, "How can a method(ology) …….. be constructed", needs some comment. There can, of course, be several possible design solutions to such a research question. However, in this context only <u>one</u> such solution is sought, a solution that satisfies the design criteria, but is not necessarily the "optimum" solution.

RQ 1

How can a methodology be constructed in general for analysing and assessing the effectiveness of learning from incidents, based on information contained in incident learning systems? What considerations should be made? What elements should it contain?

Objectives of study 1

The thesis is based on two studies presented in four separate papers. The first study is about learning from the broad spectrum of incidents in process industry companies (Papers I and II). The objective of this study was to develop methods to assess the effectiveness of learning from "normal" incidents in the process industry (normal cut of incidents) and apply these methods in the field. The results from the application of the methods should be suitable for correlating with other safety results within an organisation. The additional two research questions were formulated.

RQ 2

How can methods be constructed for analysing and assessing the effectiveness of the learning from "normal" incidents in a process industry (for company-internal use), considering in particular:

a) the effectiveness in the learning cycle (i.e. the necessary steps and actions from reporting an incident to the implementation and follow-up of the measures taken),
b) the effectiveness in the lesson learned (actual learning versus the potential learning),
c) the efficiency of reporting,
d) that the results from application of the methods should be suitable for correlating with other results of measuring safety in an organisation?

A prerequisite to understand the conditions for learning from incidents is to establish the status of typical learning in the process industry. Thus, the following research question was formulated.

RQ 3

How effective is the learning from incidents in a selection of companies in the process industry in Sweden, based on:

a) the learning cycle
b) the lessons learned (both as actual lessons learned and compared to potential lessons learned)?

Objectives of study 2

The second study is about learning from the major accidents reported in the MARS database (Papers III and IV). The objectives of this study were to assess the actual level of learning of the accidents reported in the MARS database, assess whether the underlying causes had been found in the investigation reports, try to link these underlying causes to issues of safety management systems and safety culture, and to identify weaknesses in the quality of reporting and analysing.

To meet these objectives, the need to develop analytical methods and tools for assessment of the effectiveness of learning from major accidents in the MARS database was identified. This led to the formulation of the following research questions:

RQ 4

How can a method for analysing and assessing the effectiveness of learning from the major accidents contained in the MARS database be constructed, considering in particular:

a) the actual level of learning;
b) an in-depth analysis of underlying causes to reflect the potential level of learning?

RQ 5

Does the learning from accidents by companies and national authorities – based on results from application of the assessment methods – meet the objectives set for the learning from major accidents in the MARS system?

RQ 6

Based on results from the application of the assessment method, are there any (and if so, what are they):

a) Specific characteristic patterns in the underlying causes per industry type?
b) Specific national characteristic patterns in the underlying causes?
c) Industry specific characteristic patterns in the level of learning?
d) Specific national characteristic patterns in the level of learning?
e) Impact of the requirements in the Seveso II legislation of safety management systems on the causes of accidents?

3 Theoretical framework

Reason (1997) states that most people equate safety with freedom from danger or risk. The problem is that danger and risk are ever-present in hazardous technologies: they can never be entirely eliminated. However, Reason further explains that safety is determined by the quality of the organisation's processes to manage its sources of risk and that this is a never-ending guerrilla struggle with no final conclusive victory.

Learning from incidents is just one of many activities for managing safety in an organisation. The results from such learning are very often lessons that should be incorporated somewhere in the company's managing systems, especially the safety management system. This chapter considers issues particularly relevant to these aspects. Special attention is given to the issues that are needed as background for developing the methodology and its methods and tools for assessing effectiveness in incident learning systems. A broad understanding of how systems and artefacts in a process industry typically function and how they influence the safety is of great value when conducting research in the field of learning from incidents. It is not possible or necessary to cover all these systems, artefacts and other relevant issues here, but it is appropriate to cover the most important relationships between my research area and the broader area of safety management.

Safety here is used with a broad understanding of the notion, embracing safety for people, environment and property thus including both process safety and occupational safety.

3.1 Safety management

3.1.1 General

By safety management is meant the management of the technical facilities, the people and the artefacts (e.g. the formal safety management system and other written documentation) of the entire enterprise, so that a high level of safety performance is achieved. A comprehensive view of safety management can be found in the work of Health and Safety Executive (HSE, 2008).

3.1.2 Safety management systems

By safety management system is normally meant a comprehensive set of policies, procedures and practices for safety. When the enterprise is managed according to this system, it is anticipated that a high standard of safety will be obtained (HSE, 2008).

Safety management systems are normally tailor-made for each company. However, many of the same common elements will be applicable for most enterprises. A comprehensive view of the elements of safety management systems suitable for the process industry is provided in Health and Safety Executive (HSE, 2008) and in Jacobsson (2000). Many enterprises choose to follow a formal management system, such as the international standard for Occupational Health and Safety Management, BS OHSAS 18001:2007 (e.g. British Standards Institution).

3.1.3 Organisation

3.1.3.1 The company as a socio-technical system

A company can be seen as a hierarchy of organisational levels which collaborate with one another (Rasmussen, 1997). The managerial tools for the activities emanate from the top-down and become more and more detailed the closer one gets to the level of direct execution (the sharp end). At the same time, there are feedback mechanisms of the bottom-up type.

In most incidents not only one person or one organisational level is involved; the reasons and causes behind incidents are distributed among different people and organisational levels and among the artefacts that are involved (e.g. work instructions, design rules and norms, and the whole safety management system). Viewing a company as a socio-technical system is normally appropriate when analysing incidents, and has been used in this research.

3.1.3.2 The safety organisation

The way safety is organised in an organisation and what resources and competence are used have a large influence on the safety results. It is normally said that safety is the responsibility of the line organisation. In addition, most organisations also have some kind of specialist resources for safety, normally acting in an advisory role. This safety function, sometimes a whole safety department (often combined with health and environment), is headed by a safety manager.

It is normally the responsibility of the safety function to manage the incident learning system, and to see to that the information in the system is treated and utilised to its full potential for learning. Thus, the safety function has a key role here.

In addition to the safety function, there is also normally a specific “safety organisation”, comprised of employee safety representatives and of a safety committee, made up of representatives from the company and the employees. This organisation, which in most countries is legally mandated, also plays an important role in the total safety efforts and in the learning from incidents. It is common that incidents are a main topic in safety committee meetings.

3.1.4 Safety audits

Safety audits are among the most important tools for evaluating the performance of the safety work. Typically, the idea is to have an independent group of experts who audit the organisation. A typical audit includes interviews with a representative sample of employees, checks of documentation and physical observation of the facilities. There are many systems in use for this. Some companies have their own methods, others use systems developed by well-known consultant companies. Many companies also have audits performed by independent certification bodies to comply with official standards (e.g. the OHSAS 18001 standard).

If used in a scientific context, the audit method has to meet certain criteria regarding reliability and validity. Yueng-Hsiang and Brubaker (2006) write about the requirements for an audit tool to be scientifically valid in terms of reliability (test/retest reliability, internal-consistency reliability, and inter-rater reliability) and validity.

A comprehensive view of the elements of safety auditing and how to perform safety audits can be obtained from the Center for Chemical Process Safety (CCPS, 1993), Health and Safety Executive (HSE, 2008) and in the manual of the International Civil Aviation Organisation (ICAO, 2008).

Many of the audit systems generate results expressed not only in written findings and recommendations but also in quantitative measures. Such measures can be used for correlating with other safety results expressed numerically.

3.2 Safety climate/culture

Much of the research in the safety area in the last two decades has been devoted to safety climate/culture issues. It is generally assumed that the safety climate/culture in an organisation influences the performance in most areas of safety. Guldenmund (2000) defines safety culture as: ". . . those aspects of the organisational culture which will impact on attitudes and behaviour related to increasing or decreasing risk". Reason (1997) argues that safety culture is an informed culture where there is good updated knowledge on safety via, for example, good reporting of incidents. However, Hale (2000) urges us to be cautious about conclusions on the relation of safety culture/climate to other aspects of safety management and safety behaviour. Tinmannsvik and Hovden (2003) found that "general" management factors were strongly correlated with injury frequency rate, while "safety specific" management factors were less strongly correlated. Mearns (2009) claims that "recent meta-analyses have shown 'moderate' relationships between safety climate and accidents/injuries and unsafe behaviour".

Nevertheless, it is here regarded as probable that the safety climate/culture plays an important role in the learning from incidents.

3.3 Accidents and incidents

3.3.1 Accident, incident, near-miss, deviation

There are a number of notions and definitions regarding how to classify types of events. The nomenclature varies depending on context, company and other circumstances. In this research, incidents are defined as "deviating events which differ from normal conditions and which could have adverse effects on safety, health or environment" (OECD, 2008). Deviations that only affect quality or production are not included in this definition.

Disasters, accidents, near-misses and deviations are all considered to be incidents. The extent of the consequences is not decisive. The common denominator is that the events, regardless of consequences or of what they are called, contain a potential for learning in the area of safety, health and/or environment.

3.3.2 Types of incidents

It is practical to distinguish between two types of incidents in the process industry:

- the rare major accidents
- the more common minor incidents

These two types are usually treated very differently. Major accidents receive considerable attention and are normally investigated in great detail by independent experts and acted on with forceful measures (e.g. the Texas City accident in 2005), (CSB, 2007; Baker panel, 2007). Minor incidents do not receive the same attention and are often investigated by people close to the incident; the measures are often of limited scope.

Another way of distinguishing incidents is between those that are of a *process safety* type and those of an *occupational health* type. Process safety risks are directly associated with the process, its design and chemicals, while occupational health risks often are of a more general character and relatively independent of the process per se. Typical process safety events are the release of toxic or flammable substances that can result in serious intoxication injuries, fires or explosions and related major damages including fatalities, injuries and property damages. Occupational health risks in general affect individuals, sometimes with very serious consequences, but they are normally associated with events such as falls, trips, bruises, electrocution and traffic accidents rather than with large-scale chemical exposure.

According to Koornneef and Hale (2008), there are often different causes behind process safety and occupational health accidents. Occupational health accidents are normally related to the behaviour of individuals, often the injured person himself, while process safety accidents very often have a more complex causation background with many more underlying causes. Consequently, measurements that focus on the risk for occupational safety accidents are not good indicators of the risk for process safety accidents. Both areas are, of course, equally important to monitor with suitable tools and indicators.

3.3.3 Accident/incident models

In order to learn from incidents, we need to explain what happened and find the causes or explanations of why it happened. Without a clear understanding of how we arrive at such causal attributions for managerial decisions and behaviour, an epidemiology of organisational factors in accidents is not possible (Hale, 2008). We often use simplified models for visualising and understanding the complicated course of events of an incident.

In the context of this thesis, it is considered that accident models can also be representative as incident models.

There are three main types of accident/incident models:

- Sequential
- Epidemiological
- Systemic

The sequential models are the oldest, originating from the work of Heinrich (1959). They are probably the ones still used most frequently in everyday incident investigations. The starting point in what can be referred to as "domino" models is simply that when an incident occurs it is triggered by a *direct cause*. This in turn is caused by another cause and possibly other contributing or *underlying causes* in a more or less consecutive sequence, like a number of dominoes that all fall if the first one does. The deepest underlying cause is often called the *root cause*, defined by Hollnagel as "the combinations of conditions and factors that underlie accidents or incidents, or even as the absolute beginning of the causal chain" (2004). It is defined by Kjellén as the "most basic cause of an accident/incident, i.e. a lack of adequate management control resulting in deviations and contributing factors" (2000). Both definitions are similar to underlying causes or the most deeply underlying cause.

The epidemiological models can be represented by the well-known "Swiss cheese" model (Reason, 1997). The thinking is that there are a number of safety barriers which shall prevent an initiating event from propagating and finally causing damage. The slices of the Swiss cheese have holes, which illustrate weaknesses in the safety barriers (symptoms of illness, whence the name "epidemiological"). The barriers can be technical, physical and/or various forms of administrative or organisational barriers.

The most modern accident models are the systemic ones, advocated, for instance, by Hollnagel (2004) and Dekker (2006). In these, the traditional sequential causation picture has been replaced by one where many factors permanently influence the possibility of an accident to occur; at a given moment these factors are in such a state of combination that the accident occurs.

Contributing facts and circumstances can be of different types and/or have different names. They may be what Dekker calls *explanations* (2006), and what Reason calls *latent conditions* (1997). These usually refer to less obvious conditions, which can often be dormant for a long time, but which can contribute to the course of events, once a direct triggering cause occurs. Typical examples of latent conditions are decisions at a higher organisational level leading to deficiencies in the design/engineering, insufficient training, deficiencies in procedures and instructions, deficiencies in preventive maintenance, and so on. Latent conditions can also be seen as lack of or deficiencies in safety barriers of various kinds (Hollnagel, 2004). S*ituational factors* are those that are not constantly present but turn up occasionally and can make it more difficult to perform a certain task in a correct and safe manner, thereby contributing to triggering an incident. Typical examples of situational factors are high noise levels in a workplace at times, unfavourable weather, or a particularly high level of stress.

The advantages and disadvantages of the different accident models have been debated. All have their merits and they can supplement each other. Kletz (2001) warns for becoming a slave to a model and advocates a more free-range thinking to uncover the less obvious ways of preventing incidents.

Koornneef (2000) found that the adoption of a causal model was the most feasible in settings similar to those in this research study. In the empirical material for this research, the sequential models were the only ones used. This is why for the purpose of this research, a traditional sequential accident model view, including barrier thinking, close to the Swiss cheese model, was considered suitable. The most important underlying causes and the weaknesses of the safety barriers are normally easily represented and analysed by such a model for the type of incidents that made up the major part of the field material of this research.

A very important point for learning is the analysis of causes of the incidents. This must be deep enough to reveal not only the direct causes but also underlying causes, latent conditions, root causes, or situational factors, if relevant. Analysis of the latter group of causes will facilitate a more thorough understanding of the general weaknesses in an organisation, its processes and equipment.

3.4 Learning in organisations

3.4.1 Organisational learning

In this research, I am interested in *organisational learning.* Most learning starts as *individual learning* before it can become organisational learning. An organisation learns through its people. That is precisely what learning from incidents is about – to gather the information from the individual(s) involved in an incident and convert it to general knowledge for the whole organisation, or at least for those people for whom the knowledge is important.

Organisational learning regarding safety normally takes place via many activities and instruments. Learning is considered as an integral part of many activities. Among those that can be mentioned, besides incident learning, are safety audits, training, safety inspections/rounds, safety committee work, risk analysis work, inspections, and behaviour-based safety work. Most of the basic learning takes place as more or less formal training. All employees are trained for their individual tasks. This training is usually guided in a similar way for each individual by the company policy, general procedures and detailed instructions. Hence, although it is individual learning it is organisational learning at the same time – all employees receive the same "prescribed" knowledge, at least theoretically. To this should be added, of course, the continual learning in the on-the-job learning.

According to Hale (2008): "Organisational learning [from accidents] is an activity which is directed to the future; what can be done better from now on, so that the past does not repeat itself, but also that the chance of other types of accidents in the future are reduced. In this perspective, the event is only interesting for so far it has predictive value and in so far as its details can inform future choices".

In learning from events there is often a built-in conflict between getting the full unconcealed picture and finding the guilty person when investigating the event. In major events in particular, which become the subject for investigations outside the company, the search for culpable parties and persons often becomes a main goal. This is a hindrance for uncovering the whole story as well as for learning from the full potential of the event. Investigations often stop when the culpable action has been found, but the underlying reasons for it will never be found. In the context of the first study, the LINS study, which focuses on internal company learning from mostly minor incidents, it is reasonable to believe that this conflict of interests will, in general, be less than when dealing with major accidents. However, it will certainly in some way be present in internal company investigations even for small-scale incidents.

The determining factor for how full a picture will be obtained is strongly related to the safety culture of the company. The more open-minded, the less punitive, the more just the company safety culture, the fuller the picture obtained and the better the learning will be, according to Reason (1997).

3.4.2 Learning as a product and a process

Argyris and Schön (1996) discuss learning as both a *process* and a *product.* In this thesis, I view learning from incidents in the same way, the process being all the activities needed to drive the learning, from reporting the incident to converting the experience into the implemented lesson learned (see section 3.5.2). The product is the lesson learned (see section 3.5.3). Paper I deals with learning as a process and Paper II with learning as a product.

3.4.3 First, second and third order learning

A way of classifying the learning from accidents is by use of the system with 1st, 2nd, and 3rd order learning (Hale, 2008). The 1st order learning involves measures after the event that focus on correcting the situation in such a way that the original goal is still achieved with the original plan. An example is a machine safety device that fails and a person is injured. The action is to see to it that the safety device is working again. An example of 2nd order learning is if the safety device fails due to maintenance not being performed according to plan, or if the maintenance plan is found inadequate; the safety device is redesigned or changes are made in the system for maintaining or designing safety devices. The goal remains the same but the plan to reach the goal changes. In certain extreme cases, where the goal is also changed as a result of the analysis of the event, we talk about 3rd order learning.

3.4.4 Single-loop learning and double-loop learning

Classical notions in the learning process are *single-loop* and *double-loop learning.* (Argyris and Schön, 1996). The definition of double-loop learning requires that the organisation changes its guiding principles and/or values for how to perform the industrial activity as a result of the triggering event. These notions are very important and relevant in connection with major accidents with often complex causation pictures. In most of the not too serious incidents, only single-loop learning is relevant; only a few of these incidents result in double-loop learning. As a result, the concept of single-loop and double-loop learning is of minor importance in a system for classifying a typical broad spectrum of mostly minor incidents.

3.4.5 Organisational memory

To cite Kletz (1993): “Organisations have no memory”. By this he probably means that we seem to repeat the same mistakes over and over again, even though the knowledge to avoid it should be there. Avoiding mistakes is to a large extent a matter of applying what is already known.

Even though Kletz seems to be a bit pessimistic about the capability of an organisation to stay alert and keep the knowledge up-to-date in the *organisational (*or *corporate) memory*, it must be regarded as absolutely vital for an organisation. Organisational memory can be said to be the mass of data, information and knowledge, which is relevant for an organisation’s existence. It mainly consists of two repositories – the archives of the organisation (including its electronic databases) and the memories of all individuals. According to Argyris and Schön (1996), organisational knowledge may be held in the minds of individual members or in an organisation’s files. To exemplify the content of organisational memory, the structure of Nertney (1987) for *organisational readiness* can be applied: personnel system, plant/equipment system and procedural system. The following elements, typical for a process industry, are important and are grouped (by the thesis author) under the different headings.

PERSONNEL

- Accountability and authority system
- Training programmes
- Training material
- Knowledge with all the personnel
    - Operators and other technicians
    - Middle management
    - Specialists
    - Top management

PLANT

- Basic design material (Design Basis Memorandum)
- Process description (i.e. chemistry, physical and other properties)
- Engineering standards
- External, prescribing documents – legislation, standards, etc.
- Machine register (with, for example, data on design parameters for all types of equipment)
- Risk analyses
- Operational permits, etc.

PROCEDURES

- Management system, with specific procedures such as:
    - Permit-to-work system
    - Management of change
    - Project work
    - Audits
- Operating instructions
- Preventive maintenance programme
- Maintenance instructions
- Control software system
- Inspection files
- Logs
- Log books
- Incident database
- Emergency response plans

Once the useful information from an incident has been defined and extracted, the knowledge must be implemented throughout the organisation. This can involve one single measure, but many measures are often required to integrate this knowledge into the organisational memory. When the knowledge has been converted into activities which have had effects in different parts of the organisational system, we can call it a "lesson learned" (see section 3.5.3). After that, the difficult part of keeping the knowledge up-to-date and ready for use remains (Kletz, 2001).

3.4.6 Activities that generate learning for safety

Learning from incidents is perhaps the most typical of all activities in an organisation for learning from experience. However, when working on the assessment of the effectiveness of learning from incidents, one should also consider other learning mechanisms where learning experiences from events can be gained. Some other activities where learning from experience plays an important role are:

- Safety auditing
- Behaviour-Based Safety (BBS) work
- Safety inspections
- Risk analysis work
- Training of employees
- Management of change work

All of these activities have a potential for generating lessons for improving safety. Of major practical interest are safety auditing (e.g. CCPS, 1993), BBS work (e.g. Krause, 2005), and safety inspections.

The results from BBS work and safety inspections are normally treated in systems independent from the incident reporting. However, because the results to a certain extent are similar to those from incident reporting, they can sometimes be included in the incident learning system. BBS work and safety inspections, though, are performed on a planned basis as opposed to the unplanned incidents.

Thus, information from all the above activities should be taken into account when assessing the total learning from experiences in a company. A safety audit also as a rule provides information about the extent of learning from experience from other sources than the incident learning system itself.

In many companies, there are systems for reporting deviations that focus on quality and production. The reporting frequency in such systems is normally much higher than in incident learning systems. There is usually much less work involved in handling quality deviations than in handling an incident. However, there is no principle difference between these two types of systems. Some companies handle all types of deviations in the same system.

3.5 Learning from incidents

In this thesis, *learning from incidents* is defined as the learning generated by the experience from incidents within the organisation(s) concerned. For the work on the MARS database, learning outside the organisation where the accident occurred is also considered. By *effective learning* (from incidents) in an organisation is here meant that a majority of the incidents with a learning potential are reported and the full learning potential is utilised and implemented as lessons learned throughout the organisation among its employees and organisational systems in such a way that the employees and the artefacts of the organisation will perform in the long-term according to the lesson learned. Here *artefact* refers predominantly to *organisational artefacts,* defined as artefacts that direct the manner and design of operations, <u>not</u> the physical artefacts (technical devices) (Doytchev and Hibberd, 2009).

Several of the tools and concepts normally applied in the learning from incidents will be described in the next section.

Learning from incidents can be achieved in two ways: from analysis of single incidents and from statistical analysis of multiple incidents (Hale, 2008; Kletz, 2001). This thesis deals with both.

Many researchers have examined the issue of learning from incidents. Some who have contributed to this thesis in general are: Hale (2008), Kjellén (2000), Kletz (2001), Koornneef (2000), Tinmannsvik (1991), and Van der Schaaf, Lucas and Hale (1991).

3.5.1 Administrative tools – Incident learning systems

A prerequisite for effective learning from incidents is that there is some structured way of handling the information and of converting the experiences from the incident into individual and organisational learning, as a lesson learned for everyone concerned. In other words, a formal incident learning system is needed to cover the steps in the *learning cycle* (described in section 3.5.2). Cooke and Rohleder (2006) define an incident learning system as "the set of organizational capabilities that enable the organization to extract useful information from incidents of all kinds, particularly 'near-misses', and to use this information to improve organizational performance over time".

Typically, the system is intended primarily for use by the line organisation, but it is usually administered by a staff function, mostly by the safety (or safety/health/ environment) function.

Many organisations have developed their own systems; others use ones that are commercially available. In general, the systems are computer-based.

In most companies the incident learning system is a part of a larger information system for safety (S), health (H) and often environment (E). Kjellén (2000) describes a SHE information system, providing four basic functions for accident prevention: (i) reporting and collection of data, (ii) storing of data, (iii) information processing, and (iv) distribution of information to decision-makers inside the organisation.

Aven et al. (2004) have developed the requirements of a safety information system with reference to Kjellén, including how to use it for making trend analyses, expert evaluations and use for safety performance indicators.

The SINS (Systemic Incident Notification System) is an incident learning system developed from a scientific basis by Koornneef (2000), and also applied in practice at a medical centre.

The thesis author has used ideas and experiences from all of this work by other researchers in his own work.

National legislation in several countries has placed requirements on reporting incidents to the authorities. An example is the RIDDOR system (Reporting of Injuries, Diseases and Dangerous Regulations) in the UK, (RIDDOR, 1985).

An incident learning system is often mentioned as one of the most important parts of safety management systems (Lees, 1996).

It is worth mentioning that a system for learning from incidents is well suited to generate input to a system for safety performance indicators. This is especially the case for what are referred to as "reactive indicators": those that account for failures (e.g.

releases of hazardous substances or number of accidents that result in absence from work).

3.5.2 Learning cycle

A way to follow the learning from an incident is from reporting to follow-up of the measures taken. The structure that will be used here, referred to as the learning cycle, is based on the work of Kjellén (2000), Cooke and Rohleder (2006) and the Center for Chemical Process Safety (CCPS, 1993). The stepwise handling of the information relating to an incident also corresponds to the set-up of the incident learning systems of all the companies in the LINS study. The steps are:

1. Reporting (including data collection)
2. Analysis
3. Decision
4. Implementation
5. Follow-up

These five steps form a primary loop, after which a second loop is normally conducted based on aggregated material of incidents for an in-depth evaluation of underlying causes, common denominators, trends and possible lessons learned. We can call this step:

6. Evaluation (2nd loop on aggregated incidents)

"Loop" here in connection with the learning cycle should be distinguished from "loop" in the concepts of "single-loop" and "double-loop" learning. One can also add a 0 step for identification of an event as a reportable incident (Koornneef, 2000).

The learning cycle is basically structured in the same way as Deming's well-known circle of *Plan, Do, Check, Act*. A similar stepwise description can be found in Krausmann and Mushtaq (2006) in their work on the MARS database.

The steps will be developed further and described as they typically appear in the process industry based on the material in the LINS project companies.

1st loop

Reporting

The first step is reporting of an incident. In order to report it, the person(s) closest to the incident must consider it worth reporting (step 0, mentioned above). Sometimes the reporting is self-evident, but in many cases it is not at all obvious, and the decision to report or not will be influenced by many factors. One is the formal requirements of the system, particularly the definition of a reportable incident. Other factors are more related to the individual's opinion and willingness to report, considering such aspects as:

- Understanding the learning potential of the incident
- Expectations that the reporting will be utilised
- Openness to reveal possible weaknesses in one's own or colleagues' actions
- Ease of reporting in the system

Even when the decision is made to report, the ultimate learning will depend on how it is reported. The report should cover a broad enough scope of aspects and have an adequate qualitative description of the aspects for a good understanding and analysis, normally by other people in the organisation. Considering all this, it becomes apparent that the "reporting qualifications" of the reporting person are of vital importance. Typical reporters of incidents in the process industry are the first line operators, sometimes also supervisors and/or safety representatives.

The timing for reporting is important – the sooner after the incident, the better. For the ultimate learning result, it is important to inform the organisation about the incident immediately after it occurs.

Analysis

The second step is the analysis of the incident. This is based on the report, in various ways, the most important being the clarification of direct and underlying causes. The "analyser" should have a broad scope in the analysis for causes, looking at several aspects such as technical, behavioural, training, procedural and organisational ones (Kletz, 2001). Each aspect should be penetrated professionally and in sufficient detail to secure the quality dimension. Considering this, it becomes apparent that the qualifications of the analyser are very important. Typically, the analysers of the incident reports are the first line supervisors or the process unit managers who often lack specific professional training in analysing incidents and have strained agendas. In some cases, safety specialists with specific education and training in the area are used for this.

The basis for the analysis is, of course, the initial incident report, the quality of which largely determines quality of the analysis. Usually, though, it is possible to improve and amend a poor initial report by collecting more data from the people involved and from logged technical information. In reality, this tends to happen only in cases of more serious incidents.

Again, the timing and information dimensions are important. It should not take too long for the analysis to be completed and results disseminated in the organisation.

"Organisational learning requires that event analysis traces the causal factors and determinants of an event further back in the past than before, and further up the chain of management control. At each step it needs to ask whether those responsible for hardware, people, rules and procedures, communication and organisational structures had taken suitable decisions to select, prepare, instruct, supervise, monitor and improve them. Such questions lead to the heart of the safety management system, as well as uncovering generic failures which may lead to other weaknesses in safety, which could lead to very different accidents or disasters" (Hale, 2008).

Decision

The third step is the decision. Preferably, this should be performed independently of the analysis. The decision(s) can be based on the conclusions and recommendations of the analysis, but can also deviate. The decision-maker's opinions may differ from the analyser's; budget issues, for example, can limit the extent to which the recommendations can be followed.

The reality in some companies is that the analysis and decision steps are performed more or less simultaneously by the same person, often the process unit manager. This is less desirable because it can easily lead to a "quick-fix" and inexpensive solution to a more serious underlying problem.

Again, the most important dimensions here are the scope and quality of the decision, considering aspects such as technical, design, training, ergonomics, maintenance/ inspections, managerial systems and safety culture.

Once more, timing and information are important. Unless a clear decision and the reasons for it are presented to the employees in reasonable time, they will forget about the incident and start thinking that management does not care.

The decision-maker is typically a process unit manager, but lower level supervisors will also decide in many cases. Higher levels in the organisation are involved in bigger and costly decisions. Higher levels should also be involved when the decision is about more general changes in the management system, or when issues relating to safety culture are under discussion.

Implementation

A fourth and separate step is the implementation of actions following the decision(s). In practice, the implemented actions many times differ from what was decided. Thus, the extent to which the decided actions are actually implemented is an important dimension to evaluate.

Again, scope and quality similar to that in the decision step are of importance as is timing. For the employees to trust their management, it is essential that decisions are implemented as agreed and reasonably soon after the decision.

One more interesting dimension is the resources that the company is prepared to use for implementing actions after an incident.

Follow-up

The natural final step for an individual incident is the follow-up some time after the implementation of the decisions. The suitable timing for the follow-up depends on the actions that have been taken. The objective is to check that these actions work as intended.

The scope and quality of the follow-up is of utmost importance and it takes a really thorough check to see if all the intentions have been fulfilled. Consequently, the resources for this activity are a key question, and a multifaceted safety professional needs to be involved. Line managers are not usually very involved in this step; it is often a task for the administrator of the incident learning system or someone from the safety department.

This step is an activity that in reality is rather weak and often difficult to follow and assess from most incident learning systems (CCPS, 1993).

2nd loop

The accumulation of incident reports over time in a database presents the opportunity for further analysis and learning.

It is common in the process industry to make regular, often yearly or quarterly, summaries of the incidents. The treatment of the material varies from very simple summaries presenting types, locations and direct causes of incidents to more advanced studies on underlying causes, trends, etc. The end result of this work can be anything from a short presentation in a safety committee meeting and no further action, to the initiation of campaigns for better use of personal protection equipment.

However, it also can be the start of much more fundamental work to improve safety. The accumulated mass of incidents offers an opportunity to go deeper into the causation picture of the incidents. By doing this one can reveal more fundamental weaknesses in the safety performance and the safety culture. This work often needs a rather advanced analysis by skilled safety professionals, ideally independent from the line organisation. This analysis usually includes more data collection on selected incidents, deeper interviews with people in the organisation, checks that decided actions have been included in the organisational memory and work in practice. Examples:

- Training has been performed.
- Modifications to the plant have been performed.
- Operating as well as design and engineering standards and procedures have been changed and are being followed.

Based on such an analysis there will be conclusions and recommendations that lead to actions and further follow-up.

In essence, there should be a second loop for more learning from incidents with:

- data collection
- analysis
- decisions
- implementation
- follow-up

The steps, however, are not as distinct as in the first loop. It is in this process that we will see deeper learning, sometimes a true double loop learning or 3rd order learning, when the organisation changes some of its guiding principles and/or values.

3.5.3 Lesson learned

The purpose of reporting incidents is to deal with the experiences in them – to learn the lesson. The lesson to be learned is to identify the presence of negative, unsuitable work practices and/or designs of processes or equipment and find better and safer ways of working and designing. It is also to inform and educate people in the organisation about this in order to avoid repetition of similar events. A lesson learned is not necessarily a correction from a negative event, but can also be a reinforcement of a working procedure from a general observation (Aven et al., 2004). The definition of a lesson learned used in this research work is: "an effective work practice or innovative approach that is captured and shared to promote repeat application or an adverse work practice or process that is captured and shared to avoid recurrence" (Gordon, 2008).

It is important to state that it is only when the lesson has been implemented that it can be called a lesson learned (Argyris and Schön, 1996). Koornneef and Hale also state (2004): "A lesson is not learned until the operative persons in the organisation which is concerned adopt it in their mental model of the operation that generated the surprise (deviation)".

To its full extent, this means that the information has been conveyed to all people concerned and that they have accepted the content and the message and are prepared to act according to it. It is impossible to measure the extent to which all people concerned have learned the lesson. When assessing if the organisation has actually learned the lesson, one usually has to base this on the decisions that have been made and how they have been implemented in the artefacts. Finally, one can make an assessment of the extent to which these actions have been conveyed to the members of the organisation based on the information and training systems that exist in the organisation.

Gordon (2008) also proposed a format for the lesson learned:

- **Title** of the lesson
- **Date** the lesson was issued
- **Identifier** that is unique to provide reference back to the lesson
- **Learning statement** that provides an executive summary of the learning gained
- **Analysis** that documents findings of the incident review
- **Recommended action**(s) implemented to prevent recurrence
- **Significance descriptor** to identify a level of significance of the learning
- **Work function**(s) where the learning can be applied
- **Hazard**(s) defined and discussed in the lesson
- **Contact information** so the reader can, if needed, learn details that were not published with the lesson

This format has been used as a minimum requirement for what should be included in a statement of the lesson learned.

3.5.4 Level of learning and type of learning

When analysing incidents in the process industries from a practical view, one will normally find that many of the lessons learned concern only the most immediate vicinity in a plant where the incident occurred (Jacobsson, Sales and Mushtaq, 2010). Occasionally, the lesson learned will be applied on a much broader geographical scale. The organisational learning after an incident often contains limited technical measures and/or changes of working procedures and/or some training (Hale, 2008). Sometimes, measures are taken to ensure deeper organisational learning that may even extend into the safety culture of the organisation. Some measures will only be effective for a short period of time, others longer (Kjellén, 2000). From a practical point of view, these three aspects – geographical application, degree of organisational learning, and time – can be used to classify the lessons learned in terms of *level of learning*.

Kjellén (2000) designed a level of learning classification system, developed from a system by Van Court Hare (1967). It is based mainly on the time scale of the effects, the artefacts modified and the scope of the application. This has been the starting model for the classification system developed in this research.

A somewhat similar approach for classifying managing safety and learning from incidents is mentioned by Tinmannsvik (1991) with original reference to Hale (1988). The terms "micro", "meso" and "macro" level are used. Micro level learning refers to learning at a specific piece of equipment or job task, meso level learning to more general supervision and production methods, and macro level to higher managing and organisational climate.

Another common means of classifying learning from incidents is Hale's 1st, 2nd, and 3rd order learning (described in section 3.4.3) (Hale, 2008). Still another is by use of single-loop and double-loop learning (Argyris and Schön, 1996) (described in section 3.4.4). However, these two were found less suitable in the context of this study. In major accidents with complex causation pictures, double-loop learning and 2nd or 3rd order learning appear to be most relevant, whereas for the mass of ordinary small-scale incidents only single-loop learning or 1st order learning appear to be relevant, for the most part.

3.5.5 Learning potential

The learning that can be extracted from an incident varies, of course, depending on incident type and character. Some incidents only generate limited knowledge/ lessons, perhaps only involving a very local modification of a technical piece of equipment. This means that the potential learning is at a low level. Other incidents can generate lessons for the entire company and influence all safety work, which means that the potential learning is at a high level. It is important to be able to evaluate the potential for learning of an incident.

If the full explanation and causation picture of an incident is known, one can assume that it is possible to evaluate the potential learning and thereby the potential level of learning (Kletz, 2001).To make such an evaluation, a full root cause analysis would be needed of every incident. This is rather laborious and normally is only done for a small number of reported incidents. However, based on the direct causes of an incident, a reasonable evaluation of the possible and probable underlying causes can be made, using relatively simple and less time-consuming tools (Jacobsson, Sales and Mushtaq, 2009). The basis for such a tool can be taken from the description of a company as a socio-technical system. Direct causes at the sharp end often have underlying causes at the next organisational level up, which in turn can have other underlying causes at the next higher level, etc., sometimes all the way to the company or corporate management level. By using such a tool, which gives a comprehensive picture with a distribution of probable direct and contributing causes at different organisational levels, the learning potential for an incident can be evaluated.

3.5.6 Learning agency and agent

For the incident learning system to generate good lessons, we need actors in each step of the learning cycle who have sufficient competence and understanding of the relevant aspects for learning. The chain starts with reporting the facts from the incident and continues via analysis of the causes and other circumstances of the incident into converting the information to lessons learned and finally to modifications of the artefacts of the company (e.g. operating instructions, and design of equipment). But sometimes it also results in changes of behaviour, attitudes and values of the company. In the steps of analysing and onwards in the learning cycle, we need *learning agents* (functions, persons) in the organisation. Through these agents, the causes and other circumstances of an incident can be analysed and transferred into a lesson learned, and then implemented in the organisation's systems and finally transferred into organisational learning. Depending on the type of incident, greater or lesser investigating expertise is involved in the analysis step, from traditional informal investigation by the immediate supervisor, via committee-based investigation with expert judgement to multi-cause, systems-oriented investigation with increasing seriousness of the incident (CCPS, 1993). Koornneef (2000) states that the main function of the *learning agency* is to learn the lessons and retain both the experiences from the implemented lessons, and the lessons themselves on behalf of the organisation.

It is important that the "right" agent is involved in the different steps. For instance, Doytchev and Hibberd (2009) point out the importance that the results from incidents, which reveal weaknesses in the design of a process or equipment, reach the designers, so that appropriate design measures can be taken rather than changing operational artefacts.

3.5.7 Dissemination of knowledge from the incident learning system to the organisational memory

For the experience from an incident to become real, permanent learning in an organisation it must be transformed into a suitable form. Then it has to be transferred to the employees as skills and competence and to the various artefacts (e.g. administrative systems, instructions, design and engineering standards), from which it can be easily retrieved when relevant.

Some of the most common lessons from incidents in the process industries, found for example in the MARS database (Mushtaq and Christou, 2004) and in the empirical material in the LINS study, are:

- Technical modifications (changes of material and/or design)
- Changes in activities and performance in production (instructions)
- Changes in maintenance and inspection
- Changes in responsibility and authority

The incident learning system thus links to most procedures in the safety management system and to all sorts of engineering documentation, operating and maintenance instructions and programs, training programmes, etc.

The following example illustrates typical systems which can be relevant for storing experiences from an incident. Let's consider the case where a technical detail in a production system wears out, leading to a dangerous situation. The example is a pipe bend in a steam system that ruptures due to corrosion/erosion and results in an employee receiving burn injuries. One can choose to only repair or replace the damaged pipe bend with another of the same material. The lesson learned is then only local, rather limited and probably of short duration. One can also choose to replace the pipe bend with a new one of a more resistant material. For such a measure to result in broader, more valuable and long-term learning, the information of the decision must be transferred into the maintenance system in order for it to know to replace with the better material at the next opportunity as well, and to enter the information into the design specifications for piping systems for future design and engineering. One may also conclude that all pipe bends in the steam system should be inspected and replaced when required and/or plan for regular inspection of all pipe bends. Such measures also require that administrative systems are up-dated (in this case the systems for preventive maintenance and inspection) and that the people concerned consult these systems.

The same example can be used to illustrate what is required at a change of performance in the production. One could for instance conclude that it is the operating conditions that make the pipe bends wear out unexpectedly and rapidly. The best measure then would be to change these conditions. Knowledge of this must reach all people concerned in the operations department. This is provided through information in various forums (regular meetings) or in more formal training. The operating instruction should also be updated. Then, it is vital that there is an administrative process that guarantees that all people concerned keep themselves informed about the updated instruction.

In reality, it is difficult to reach all those concerned and all places in the administrative systems (Cooke and Rohleder, 2006). Here, the learning agent holds the key function of securing that the lessons are learned to their full extent.

3.5.8 Threshold for reporting and hidden number

Obviously, there is a need for identifying the incident as something worth reporting in the first place. This is a crucial point, discussed by Phimister, Kleindorfer and Kuhnreuther (2003). Many companies have definitions of what a reportable incident consists of, reading something like, "All events which lead to a personal injury or a release of hazardous chemicals or other events with serious consequences or which could have led to such consequences". However, even with such a definition the decision to report or not is normally up to the employee closest to the incident. He or she is influenced by many things such as safety procedures and the prevailing safety culture but also by personal opinions and preferences. Ideally, all incidents with a learning potential should be reported, which means a low *threshold for reporting*. However, there is a built-in problem in this, in that it is only when the incident is analysed that one will know whether there is a learning potential or not. In reality, the reporting in most organisations is based mostly on the degree of consequence or disturbance. An incident worth reporting (has a potential for learning) is not necessarily the same as a reportable incident (fulfils the definition of the organisation). Once the incident is reported, it is important that the report is handled properly, otherwise people will stop reporting. Thus, the extent of reporting often becomes a result of the individuals' willingness to report incidents and management's willingness to investigate them (Cooke and Rohleder, 2006). There will always be incidents with a potential for learning that are not reported in an enterprise. This hidden number should be as low as possible. In reality, a balance is often struck, and it is probably better for the total learning to have fewer but properly handled reports than many that are poorly handled (Rogers, Dillon and Tinsley, 2007).

It can be argued that only a selection of all the reportable incidents needs to be treated in detail, because this will probably cover most of the lessons to be learned. Although this might be true to a certain extent, there is a risk that this will only generate learning on a general level, such as modifying general procedures or providing training; many small and local, but very important lessons can be neglected. Consequently, all incidents with a learning potential should be reported in the incident learning system and treated accordingly.

3.5.9 Accident/incident investigation

The investigation of an incident and the analysis included therein is the key step to extracting the lessons that should be converted to lessons learned. The bigger or more serious the incident, the bigger the investigation and the more qualified investigation expertise involved (CCPS, 1993). In practice, most minor incidents are handled based on the facts given in the original incident report, while major accidents can require a more extensive gathering of facts. The course of events should be reconstructed to understand the incident, including failing safety barriers. This allows for an analysis of the causes behind it. In cases with a more complicated course of events, one could use specific methods such as the *STEP* (Sequential Timed Event Plotting) method to describe the event (Hendrick and Benner, 1987).

The analysis of causation and conditions are a very important part of the investigation. Above all, one has to arrive at the relevant underlying causes which can explain the event. The direct causes can be:

- personal factors, such as less suitable behaviour, direct human errors, inadequate competence of the employees carrying out the work

- technical factors, such as failing equipment or safety systems
- situational factors

The underlying causes can contain management and organisational factors such as deficiencies in instructions, training, maintenance, management systems and ultimately lack of commitment from the top management and a poor safety culture.

In practice, no formal method for causation analysis is used for all the minor incidents. Most investigators would probably refer to general powers of deduction and common sense. The question "Why?" is asked, and if a reasonable explanation is found, this becomes the cause. Often, the analysis stops when the first why question has been answered or when the investigator feels that an event has been satisfactorily explained (Freitag and Hale, 2008).

An effective and very simple method is to continue to ask the question "Why?" for every cause detected, until it is evident that the measure needed to counteract the cause is outside the normal responsibility of one's own organisation. Correctly used, this method normally generates a number of relevant underlying causes (Kletz, 2001). The method is sometimes called *5 Why's* and is a brainstorming exercise using a *free causation tree* method. It is always possible to overlook something important, of course. In order to avoid this risk, one could use some type of checklist with possible causes. Such a method is *SMORT* (Safety Management and Organisational Review Technique), which has been used by Tinmannsvik and Hovden (2003) for example.

One could also use *logical trees* in which there are proposals for probable underlying causes, based on given direct causes. A classic method of this type is *MORT* (Management Oversight and Risk Tree), originally developed by Johnson (1973). However, this method is rather laborious.

The tool for evaluation of underlying causes of incidents, which is presented in section 5.3, is based on the *5 Why's* method with elements from the *MORT* method.

At some stage one has to apply a *stop rule* as to how far one should go in trying to find underlying causes. Normally, one stops when it is no longer possible for the organisation to influence the factors giving rise to the causes (Freitag and Hale, 2008).

4 Methods and data

4.1 Research process

For ease of understanding and for convenience, it is repeated here that the research carried out was based on two research projects on learning from incidents – one directed towards the broad spectrum of primarily minor incidents (the LINS project) and the other directed towards major accidents (the MARS project).

4.1.1 A design science perspective with elements of case study techniques

The main focus of the research presented is the design of artefacts – a methodology including methods and tools – which can be used for assessment of the effectiveness in incident learning systems. Therefore, an engineering or design approach has been chosen in the research process, where the aim is to construct various artefacts able to meet a predefined purpose in an efficient manner (Cook and Ferris, 2007; Abrahamsson, 2009). In natural science there are normally two main activities: theorising and justifying (by testing). In design science there are instead two other corresponding activities: building and evaluating. "Building is the process of constructing an artefact for a specific purpose and evaluation is the process of determining how well the artefact performs" (March and Smith, 1995). One strives to create models, methods and implementations that are innovative and valuable (March and Smith, 1995).

The research also has elements of case study research (Yin, 2003), insofar as material from six process industries formed part of the basis for developing the methods and tools. Case study research was even more pronounced during the application of the methods and tools, which was performed not only to test them and to generate results on the effectiveness of learning from incidents, but also to generate results that could be used in correlation with other research results (i.e. from safety audits and safety climate investigations). The safety auditing, which has been used as a supplementary method, is typical case study research.

An overview of the research process for developing methods, which draws on design research, is presented in Figure 4.1, adapted from Hassel (2010). The various steps in the process will be described below.

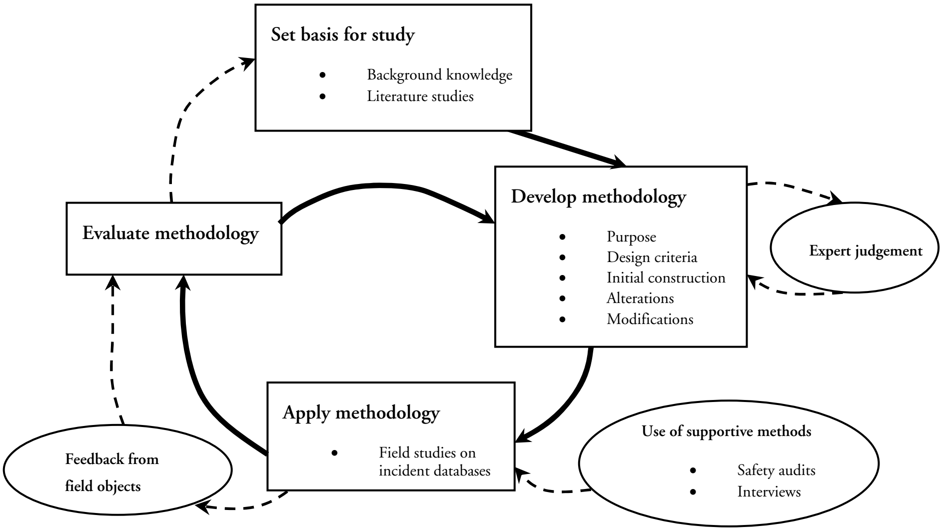

Figure 4.1 Overview of the research process (blocks) with support activities for developing the methodology (ovals) (adapted from Hassel, 2010).

4.2 Methods and techniques

4.2.1 Establishing a basis for study

4.2.1.1 Background knowledge

In order to construct a methodology for the process industry, capable of assessing the effectiveness of the process in the learning from incidents and the resulting lessons learned, it was considered necessary to have a rather extensive understanding and knowledge of that industry in general, and in particular of all the artefacts (management systems, design and engineering systems, etc.). The author has worked in the process industry in various positions for twenty years and after that as a safety consultant in the industry for another twenty years to acquire both broad and in-depth domain knowledge. This substantial domain knowledge has also led the author to believe that the learning from incidents in the process industry is often unsatisfactory, a belief that has prompted this research to develop methods and tools to be able to investigate this issue.

4.2.1.2 Literature studies

Literature studies have been performed throughout the research process. The search for relevant research literature was primarily made in the ELIN (Electronic Library Information Navigator), now LibHub, electronic database at Lund University. Several years of articles published by the "Loss Prevention and Safety Promotion in the

Process Industries" symposia have also been searched. Fellow researchers recommended several valuable articles as well. The primary purpose of the literature studies was to determine what had been done in the field of methods for assessing learning from incidents. A secondary purpose was to retrieve valuable input as to what parameters and mechanisms for learning from incidents should be taken into consideration when developing one's own methodology.

4.2.2 Development of the methodology

4.2.2.1 Establishing the purpose and design criteria

The *purpose* of the methodology was mainly derived from the anticipated needs of the potential users (the process industry and authorities active in the safety field). It was for them to have practical means that provided useful, tangible and reliable results when assessing the effectiveness of the learning from incidents. The *design criteria* specify in more detail what functions and characteristics the artefacts need in order to fulfil the specified purpose. For that, the designer must make a number of normative assumptions. These should be properly justified (e.g. based on empirical evidence, research literature or some type of rational or logical reasoning) because they affect the scientific rigour of the design (Hassel, 2010). In this work, the design criteria have been based mainly on empirical evidence, utilising the data that became available from the two research projects. This could be referred to as "archival analysis" according to Yin (2003). In addition, the domain knowledge of the author has been utilised.

4.2.2.2 Initial construction

In developing the methodology the guiding-star has been to create pragmatic, easily used methods that deliver useful and reliable results. They have been developed using notions and nomenclature which are common in the process industry. In the construction of the methods and tools, ideas from the five fellow researchers in the LINS project were also used. The development of methods and tools are described in more detail in chapter 5.

4.2.2.3 Expert judgements of methods and tools

In order to ensure that the methods would fulfil the purpose and design criteria and yield valid and reliable results when applied, they were scrutinised by experts from the safety field. According to Goossens et al. (2008), the important principles which should govern the application of expert judgement were followed: scrutability (all data and all processing tools are open to peer review and results must be reproducible by competent reviewers), fairness (experts are not pre-judged), neutrality (methods of elicitation and processing do not bias results), and performance control (quantitative assessments are subjected to empirical quality controls).

In the LINS study an expert panel was used to judge the tools by answering several questions and rating the degree to which they sympathised with statements regarding the design and contents of the methods and tools. The panel consisted of members of the safety committee of the Swedish Plastics and Chemicals Federation, the members of which are typically safety managers at Swedish chemical companies.

In the MARS study a similar inquiry was performed. Here the panel consisted of members of the "Loss Prevention Working Party" of the European Federation of Chemical Engineering, a group of prominent safety experts in Europe from academia, authorities and the process industries.

4.2.2.4 Alterations of methods and tools

As a result from the expert judgements some alterations and additions to the methods and tools were made.

4.2.2.5 Modifications of methodology

After the evaluation step, described in 4.2.4, further modifications to the methods and tools were considered in order to reflect possible valuable points in the feedback from the field objects.

4.2.3 Application of the methodology

4.2.3.1 Field studies

The methods and tools were applied full-scale to a large number of incidents.

In the LINS study, six Swedish process industry companies participated. Their databases on incident learning over a period of two years (somewhat more for one company) were obtained. The methodology was applied by the author for all incidents, a total of more than 1900.

In the MARS study, the entire database containing 653 accidents at the time of the study was analysed by the author and one of the co-authors of the MARS papers (III and IV). A comparison was made between the results from the two of the authors.

4.2.3.2 Supplementary methods for use with LINS methods/tools

Two supplementary methods were mainly used as support in the application of the methodology, but also in the development of the methodology proper: safety audits and interviews with incident learning system administrators.

Safety audits

In order to understand the incident learning system and the whole safety management system prevailing in the companies, a conventional safety audit was included in the methods used. The audit results were also used as a basis for evaluating any mechanisms for learning from incidents other than via the incident learning system. Any well recognised audit tool can be used for performing this safety audit, provided it is used professionally.

The safety audits that were carried out at each of the companies in the field studies, consisted of interviews of a cross-section of the employees in the organisation (one hour for each employee), checking of documentation and a plant observation tour.

The audit tool used was a guideline for internal auditing published by the Association of Swedish Chemical Industries (1996). This audit method has been used in many Swedish process industry companies for twenty years. Some 90 assessment points that were deemed most relevant were chosen from the system in the guideline. The procedure followed standard textbook procedures for audits, described for instance in CCPS (1993). Regarding the sample size, CCPS states that in most audit situations, it is desirable and adequate to review 10-20% of the population. This criterion was fulfilled with margin in the audits performed, where 15-25% of the personnel were interviewed.

Interviews with incident learning system administrators

Interviews with the administrators of the systems at all the companies were carried out separately for between two and four hours, primarily to gain a good understanding of each of the incident learning systems. A secondary purpose was to obtain extra material about the incidents (in addition to the basic information in the incident learning systems), when available and relevant. In all the companies, the administrators were the safety (or often safety/health/environmental) managers.

4.2.4 Evaluation of the methodology

The evaluation of the methods and tools of the methodology were carried out mainly in two ways – via direct learning during the application and via feedback from the companies on the results of the application.

4.2.4.1 Feedback from companies

Three types of feedback from the companies were requested and readily obtained, with the objective to improve the methods and tools. The first was reactions from the company when the results from the incident analyses and the safety audits were presented to the management group (in two cases a larger group).

The second type of feedback was via a formal inquiry where the safety managers answered a number of questions about the results from the incident analyses (learning cycle, level of learning and hidden number), and the degree to which they agreed with the results.

The third type of feedback was from two companies that had used part of the methods and tools themselves.

4.2.5 Modifications of the methodology

All the methods and tools were reviewed after having been applied in the field studies and after receiving feedback from the companies in order to modify and improve them. However, no major modifications were made as a result.

4.3 Data

Empirical data was needed as a basis for the development of the methodology and to test it. Two research projects on learning from incidents were available and suitable for inclusion in this research – one directed towards the broad spectrum of primarily minor incidents (the LINS project) and the other directed towards major accidents (the MARS project).

4.3.1 The LINS project

LINS stands for "Learning from INcidents for improving Safety within dangerous operations". It was a 3-year research project (Jan. 2008- Dec. 2010), funded by the Swedish Rescue Services Agency (since 2009 integrated in the Swedish Civil Contingencies Agency).

The purpose of the project was to examine the learning processes around incidents in general and the connections with the safety culture of the organisation in particular. The general objectives of the project were:

- to acquire knowledge for a more effective learning from incidents in theory and in practice
- to develop procedures and tools for more effective learning from incidents
- to disseminate knowledge for effective learning to various organisational levels.

The research team was multidisciplinary with four researchers with a technical background (representing LUCRAM, Lund University Centre for Risk Assessment and Management, at the Faculty of Engineering, Lund University), and two researchers with a social science background (representing the Department of Leadership and Management, Swedish National Defence College).

A good base for empirical studies was needed and the Swedish process industry was selected. Six company sites with different kinds of operations were selected.

Three main activities were carried out for each field object:

1. Review of the incident learning systems and application of the methods and tools developed to the incident database
2. Safety audit (including interviews, document checking and plant observation tours)
3. Safety climate investigation (based on inquiries to all personnel)

This thesis concentrates on the assessment of the effectiveness of the learning from incidents, which is one important base for the total LINS work. But there are other results from the project to which the results from assessing the effectiveness from learning from incidents will be correlated (e.g. from safety audits and safety climate investigations in order to meet the basic project objectives).

Key data concerning the companies (sites) are presented in Table 4.1. The risk potential for the six plants has been judged by the author.

Table 4.1. Key data for the six companies included in the study.

Company	Type of industry	Size of site (technical employees)	Incidents reported per year (2008)	Incidents reported per employee and year	Risk potential	Comments
A	Petrochemical	360	570	1.6	High	Part of a major multi-national corporation
B	Chemicals, general	115	270	2.3	High	Part of a major multi-national corporation
C	Food and drugs	45	30	.67	Medium	National, single-site company
D	Pulp and paper	650	220	.34	High	National, multi-site corporation
E	Energy production	100	10	.10	Medium	National, single-site company
F	Food and drugs	40	24	.60	Medium	Part of a major multi-national corporation

All the organisations had a formal incident learning system, all of which were computer based. Concerning the analyses of incidents, two years of reports (2007 and 2008) were obtained directly from the incident learning systems for companies A – E. For company F, which had comparatively few incident reports, a longer sampling period was selected (3½ years, from 2007 to mid 2010) to obtain sufficient data. A total of more than 1900 reports were analysed. When other relevant material existed (e.g. root cause analyses), this was also obtained.

4.3.2 The MARS project

MARS (Major Accident Reporting System) was established in 1984. It is the system used by the European Commission to report and process the information from major industrial accidents that occur in EU Member States, as stated in the requirements of the Seveso II Directive (EC, 1997; Mushtaq and Christou, 2004). The main objective of the MARS system is the learning aspect from accidents. One important use of the MARS database is to provide a basis for legislative actions in the EU countries. According to Kirchsteiger (1999): "What can be expected from MARS is to get in great levels of detail and completeness examples of accidents which closely match the specific interests of a user". The criteria for what is a reportable accident are defined in the Seveso II Directive. The EC Joint Research Centre at Ispra in Italy manages the database and uses it for various purposes. The reports to the MARS system, which are prepared by the competent authorities in the EU Member States, consist of the "Short report" and the "Full report" sections. (This prevailed when the research on the MARS database was carried out. Today the form for reporting has been changed and includes only one single reporting form.) The short report provides essential information concerning the accident, in a free-text format completed shortly after the accident. The full report is much more systematic and is normally completed some time later after an investigation. While there are always free-text fields available to describe facts connected with an accident, a great deal of effort has been put into the definition of descriptive codes, for the accident itself and for associated information, to enable the data to be inputted in a very structured manner. This allows the MARS database to be interrogated effectively.

Previously, different analyses have been performed on the information included in the MARS database. Studies on the MARS accidents have covered various aspects related to the causes of the accidents. Some of these analyses have been performed at a general level (Sales, Mushtaq, and Christou, 2007a; Kirchsteiger, 1999), while others were aimed at obtaining lessons to be learned, focusing on specific issues such as handling of dangerous substances (Drogaris, 1993), management issues (Mushtaq, Christou, and Duffield, 2003) or chemical reactions (Sales et al., 2007b). In most cases, the analyses have been based on the causes directly reported from the competent authorities, with little attempt at a deeper analysis of underlying causes.

In 2007 a joint project, "Deep analysis of the MARS database", was formed between the Major Accident Hazards Bureau (MAHB) of the EC Joint Research Centre, Ispra, and the National Centre for Learning from Accidents, a part of the Swedish Rescue Services Agency. It came under a special collaboration agreement between the European Community and the Swedish Rescue Services Agency.

The general objectives of the project were:

- To learn more from the accidents reported to the MARS database
- To learn more of underlying causes, especially managerial aspects
- To link underlying causes to safety culture issues
- To uncover possible trends in the underlying causes
- To transfer the additional lessons that could be learned to the competent authorities and the enterprises

The research team consisted of the thesis author who had the main responsibility and two research fellows from MAHB, Ispra.

The administrative tools associated with the MARS database allows the user to search for information in various ways. In the present work, the features of searching for the causes of the accidents and the measures taken as a result of the accidents have been of most interest.

At the time of the study of the MARS database (2008), it contained 653 reported accidents from 20 countries.

5 Development of a methodology for assessing the effectiveness of learning from incidents

5.1 General approach

The overall purpose of developing the methodology is to provide a means for the safety professional who will use it to be able to assess the effectiveness of learning from incidents, provided there is an incident learning system with reported incidents. The basic design criteria were stated:

- The methodology should comprise the two fundamental issues of learning: learning as a process and learning as a product.
- The methodology should use incident learning systems as its basic source for evaluation.
- The methods and tools of the methodology should deliver results expressed in numerical terms.
- The assessment should be possible to perform with limited resources of time and personnel.

The methodology should therefore include methods that can answer the following fundamental questions:

1. Regarding the learning process

    - Do we handle the incidents reported in our incident learning system properly? Do the various steps in the learning cycle work effectively?

2. Regarding the learning product

    - How much do we learn from the incidents which are reported? How does this learning compare with what could potentially have been extracted? What level of learning are we at and what level could we have achieved?

3. Regarding the reporting efficiency, the extent of reporting the "reportable" incidents

    - Do we report the incidents that are worth reporting (that have learning potential)? What is the threshold for reporting? How big is the number of unreported cases, the hidden number?

The third set of questions could also be considered as part of the learning process, but has been chosen as a separate issue here.

The process of learning from incidents can take many forms and include many different elements. Measuring the actual learning from incidents is very difficult. According to the earlier definition of a lesson learned, the learning has occurred only when the measures extracted from the lesson have been implemented. This means that all employees concerned with the lesson learned should have absorbed the knowledge that has been extracted and will act on it in the future. It is almost impossible, though, to assess if this has been achieved. One could possibly evaluate through interviews and inquiries the extent to which the information has reached the employees.

However, in the process industry, the basis for learning from incidents is normally a formal, more or less structured incident learning system and procedure – one of the procedures of the safety management system – with instructions for the structure, contents, work procedure, responsibilities, forms to use, etc. The information contained in such incident learning systems, especially regarding lessons learned, would at least give a good indication of the conditions for actual learning for all people concerned – although not proof of final individual and organisational learning. The presupposition here is that the information contained in incident learning systems reasonably well reflects the actual learning. Therefore, an assessment of the learning from incidents can actually be based on the information in such incident learning systems.

The administrative set-up and structure of incident learning systems normally follow the steps in the learning cycle:

1. Reporting
2. Analysis (including investigation and evaluation)
3. Decisions
4. Implementation
5. Follow-up
6. 2nd loop, on aggregated incidents

Before any organisational learning from an incident can be initiated, the incident must be recognised and reported.

The end result of the learning from an incident is the lesson learned which should be transferred to and stored in the organisational memory.

The whole process of learning from incidents is illustrated in Figure 5.1. It illustrates the learning cycle and the transfer of the lessons learned to the organisational memory.

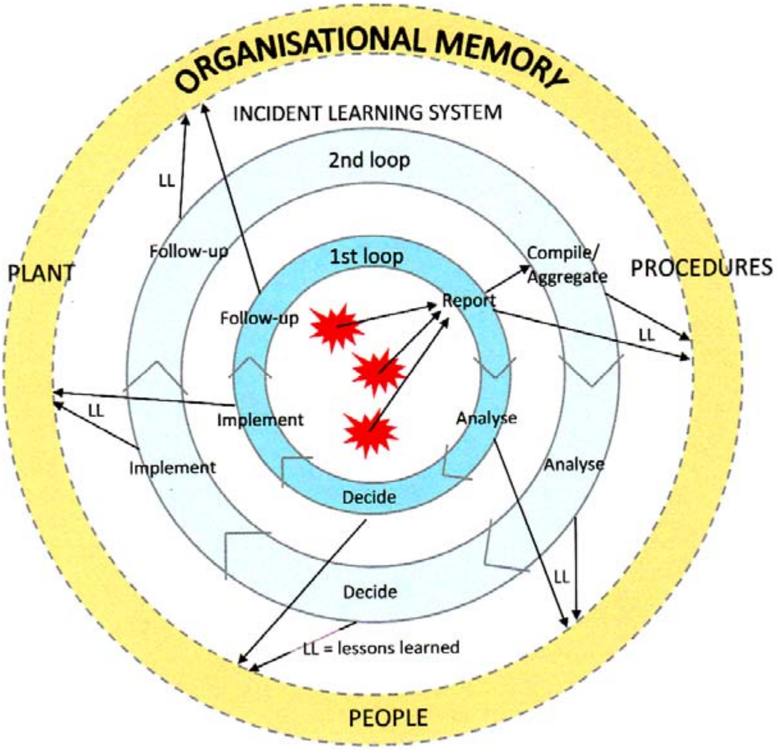

Figure 5.1 The learning cycle.

Thus, the approach for developing a methodology for assessing the effectiveness of the learning from incidents in the process industries was to first set up a model for an incident learning system according to the principles depicted in Figure 5.1. Included in this model were issues which are generally considered to be important in the learning from incidents by selecting contributions from many sources (common domain knowledge, literature sources and specific points from the field objects in the LINS study).

With a standard model for an incident learning system in place, one can focus on what issues should be included in the methods and tools for assessing the system's effectiveness. This is covered in sections 5.2 and 5.3.

For a measure of the effectiveness of the learning from incidents to be useful and reliable, it should be "calculated" as an average value based on many incidents over a given period of time. This is because each individual incident will have its own actual learning and potential learning, depending on its nature. Another reason is that variations will occur in how individual incidents are handled due to factors such as the people involved and reporting, the resources and competence for analysing, the commitment for decision and follow-up, to mention a few. Consequently, assessment of the effectiveness of overall learning must proceed via assessment of the effectiveness of learning from individual incidents. After this, average values can be calculated which are then representative for a given time period for a company or for various departments or other suitable bases for classification.

5.2 Effectiveness in the learning cycle

To answer the first type of fundamental questions – Do we handle the incidents which are reported in our incident learning system properly? Do the various steps in the learning cycle work effectively? – a method was developed with separate tools for each step in the learning cycle. The purpose (objective) was to provide a measure in quantitative or at least semi-quantitative terms of the effectiveness (an expression of the quality) of the process of learning from incidents: To what extent did the actual performance meet the desired performance?

The following design criteria were used: information found in the incident learning systems from the field objects in the LINS study, information from many other sources in the knowledge domain of the author, and input from several literature sources.

The method is meant to be applied to all individual reported incidents during a certain time period in order to then assess mean values of the effectiveness of each step, which in turn can be used for comparisons and for actions.

Paper I contains a detailed description of the method. What follows is an abbreviated version.

The method was to be based on the following four components, which become the design criteria:

- the steps in the learning cycle
- elements, which we call “dimensions”, in the various steps
- aspects of each dimension
- templates with scales for assessing numerical values for the various dimensions/aspects as a measure of the effectiveness in each step

All the steps have four dimensions (used for calculating a numerical value) that in turn contain several aspects, all of which should be well covered to fully understand and handle each step:

1. Scope (the aspects vary depending on the step; see examples in the list below that present the dimensions with aspects for each step)

2. Quality (completeness of details and depth in the treatment of the aspects under scope)
3. Time (from the event, or from the previous step, to completion of the step)
4. Information (dissemination of information in the organisation)

In addition to these four dimensions, the method contains additional dimensions, which are used more as a basis for explaining the results from the four basic dimensions, but are not included in the numerical calculation.

The dimensions used for each step with examples of aspects are listed below:

1. Reporting
    a. **Scope** includes aspects such as: Description of the event, Work situation, Stress level, Competence of person(s) involved, Support by instructions, etc, Type of equipment/item involved, Location, Date and time, Meteorological condition, Direct cause and contributing causes, Damages (personnel injuries, material, fire, environmental, product loss), Mitigating actions, Immediate suggestions, Name of reporter.
    b. **Quality** is a measure of the details of the reporting of the aspects under Scope.
    c. **Time** is the elapsed time from the occurrence of the event to when the report was written.
    d. **Information** is a measure of the immediate dissemination of event information directly in connection with the event, especially to concerned employee(s).
    e. **Who** (is reporting) signifies the person actually writing the report.

2. Analysis (especially causation analysis)
    a. **Scope** includes aspects such as: Personal shortcomings, Technical shortcomings, Design, Training, Procedures, Ergonomic factors, Situational factors, Maintenance/inspections, Other underlying causes, Managerial systems, Safety culture.
    b. **Quality** is a measure of the details regarding depth and breadth of the analysis of the various technical and organisational aspects under Scope.
    c. **Time** is the elapsed time from the occurrence of the event to when the analysis is completed.
    d. **Information** is a measure of the dissemination of the analysis results in the organisation.
    e. **Who** (is analysing) signifies the person(s) undertaking the analysis including resources (personnel, competence, time).

3. Decisions
    a. **Scope** includes aspects such as the following, depending on their relevance: Technical, Design, Training, Ergonomics, Maintenance/inspections, Other underlying causes, Managerial systems, Safety culture.
    b. **Quality** is a measure of the details regarding depth and breadth of the decisions regarding the various technical and organisational aspects under Scope.
    c. **Extent** is a measure of the extent to which the decision(s) follow the analysis and the recommendations.
    d. **Time** is the elapsed time from the completion of the analysis to when the decision is taken.
    e. **Information** is a measure of the dissemination of the decision results in the organisation.
    f. **Who** (is deciding) signifies the person(s) or the organisational level actually undertaking the decision including resources (personnel, competence, time). The basis for evaluation of this point is "relevant decision level" compared to the learning potential of the incident.

4. Implementation
    a. **Scope** is the extent of the actions actually implemented, compared with the decisions.
    b. **Quality** is a measure of the details regarding depth and breadth of the actions actually implemented.
    c. **Time** is the elapsed time from the decision to the implementation. The time depends on the topic.
    d. **Information** is a measure of the dissemination of the implementation results in the organisation.
    e. **Who** (is implementing) signifies the person(s) or the organisational level actually implementing the actions, including resources (personnel, competence, time). The basis for evaluation of this point is "relevant implementation level" compared to the learning potential of the incident.
    f. **Resources** is a measure of the resources available for (or possibly limiting) the desired actions to be implemented.

5. Follow-up
    a. **Scope** is the extent of aspects being followed-up.
    b. **Quality** is a measure of the details regarding depth and breadth of the follow-up.
    c. **Time** is the elapsed time from the implementation to the follow-up. The time depends on the topic.
    d. **Information** is a measure of the dissemination of the follow-up results in the organisation.
    e. **Who (follow-up)** signifies the person(s) or the organisational level actually carrying out the follow-up.

f. **Resources** is a measure of the resources available for follow-up.
g. **Actual result** is a measure of how well the implemented action works in relation to the intension.

One important issue considered was the treatment in an organisation of the incidents on an aggregated basis, the 2nd loop. This required a specific assessment. Here, a similar tool was used as for the individual incidents according to the primary cycle, but in a more general assessment. The tool treats the 2nd loop as one step, which is actually found to be the case in most companies. Ideally, this tool should be applied to the data provided in the incident reporting system, but this data is often incomplete and has to be supplemented with interviews of key personnel to arrive at a good assessment. Lindberg, Hansson and Rollenhagen (2010) have developed a model for experience feedback, the *CHAIN* model, where they discuss the issue of selecting incidents for investigation (i.e. similar to the 2nd loop).

6. 2nd loop
    a. **Scope** is the statistics and trends of types of events, direct/indirect causes, actions implemented, degree of success, the extent of aspects being followed-up.
    b. **Quality** is a measure of the depth of the above aspects, especially depth of analysis of underlying causes, also including some safety management system aspects, and with actions accordingly.
    c. **Time** is the frequency of the 2nd loop activities.
    d. **Information** is a measure of the dissemination of information in the organisation of the results of the 2nd loop.
    e. **Who** signifies the person(s) or the organisational level actually performing the 2nd loop.

Rating system

A rating system was created to be able to express the effectiveness of handling the incidents in the various steps in a quantitative/semi-quantitative way. The system is similar to the way *capability maturity models* are built. According to Strutt et al. (2006), capability maturity models are tools used to assess the capability of an organisation to perform the key processes required to deliver a product or a service. They can be used both as assessment tools and as a product improvement tool (Strutt et al., 2006). The concept of capability maturity models has also been incorporated in the quality standard ISO 9004 (ISO 9004, 2000), where the following five levels of maturity are used: 5, Best in class performance; 4, Continual improvement emphasised; 3, Stable formal system approach; 2, Reactive approach; 1, No formal approach.

In the system for rating the effectiveness of handling incidents, the different aspects for each of the dimensions have been described in a semi-quantitative way on a scale (from 0 to 10) in order to be able to measure the effectiveness as objectively as possible. The scale was selected to reflect the coverage of the various aspects for the dimensions – from very poor, 0 on the scale (essentially none of the information required in the tool covered), to excellent (all dimensions and aspects in the tool covered comprehensively). The requirements to fulfil a certain "score" were described by using guiding words for four levels on the 0 to 10 point scale: 2 (Poor), 4 (Fair), 7 (Good) and 10 (Excellent). There is a clear resemblance to the scale in ISO 9004 with, for example, 10 (Excellent) being similar to "best in class performance" and 0 being similar to "no formal approach". Interpolation should be used when relevant. Other dimensions should also be evaluated for the different steps, although they are not used in the calculation of the effectiveness as such, but merely as possible explanations for the results. One such dimension is "Who" (who is performing the activities in the step). Table 5.1 shows a sample of the rating system for the reporting step.

Table 5.1 Rating system for the reporting step in the learning cycle.

1 Reporting					
		2 (Poor)	**4 (Fair)**	**7 (Good)**	**10 (Excellent)**
1.1	Scope	Only a few of the relevant aspects covered. Poorly structured.	Most relevant aspects covered, but not too well structured.	All types of relevant aspects covered.	As for 7 + additional aspects when this would add to the usefulness of the report.
1.2	Quality	Relevant info on many of the aspects is missing.	Only most obvious facts reported. Difficult to make an in-depth analysis of causes, etc.	All aspects under scope covered, but some not in full detail; more information required.	All aspects under scope covered in depth, making a thorough analysis possible.
1.3	Time	> 1 week	A few days	Same day/shift	Immediately (hour[s])
1.4	Information	Virtually none.	Individual reading (on intranet or similar).	As for 4 + meetings.	As for 7 + targeted info to selected personnel.
1.5	Who (is reporting)	An administrator only, not directly involved in the incident.	Directly involved person(s) + safety representative. Also contractors covered.	Directly involved person(s) + safety representative + supervisor.	As for 7 + specially trained reporter.

Similar tools were constructed for all the steps in the learning cycle (see Paper I).

The proposed scale with its descriptive wording is meant to guide the assessor in the rating of the individual incident reports. The description in the actual incident report is compared with the description of the requirements for the rating levels and the one best matching the actual description is chosen. Interpolation between the levels should of course be done. The wording should not necessarily be taken literally, but used as a guide.

After assessment of each dimension in every step of the learning cycle, one has a set of data that can be used for calculation of mean values of the effectiveness of each step in the learning cycle for a particular incident report.

Weighting the dimensions for importance

One can apply the method without attempting any weighting of the importance of the various dimensions. However, in reality some dimensions are probably more important than others for the learning process – different dimensions in different steps. It is argued that in the reporting and analysis steps, the dimensions describing the factual circumstances of the incident (i.e. Scope and Quality) are most important, whereas in the implementation and follow-up steps, for example, the timing and information dissemination dimensions increase in importance. As a first approach however, based on input from the general domain knowledge of the author and from safety specialists in the companies in the LINS study, the various dimensions were weighted as follows to obtain a "fair" measure of the effectiveness:

- Scope 35%
- Quality 35%
- Time 15%
- Information dissemination 15%

It was further proposed to use the same weighting in all steps as a first approach, although minor changes could certainly be argued for.

5.3 Effectiveness of the lesson learned/level of learning

To answer the second type of fundamental questions – How much do we learn from the incidents which are reported? How does this learning compare with what could potentially have been extracted? What level of learning are we at and what level could we have achieved? – attention was directed to the end product of learning: the lesson learned. A method for assessing both the actual and potential lesson learned was developed. A classification system for lessons learned was introduced with six "levels of learning". This was done in order to fulfil the purpose (objective) of expressing the results of the method of assessing the effectiveness (an expression of the quality) of the learning product – the lesson learned – in quantitative terms. The system was based on already existing classification systems (by e.g. Kjellén, 2000). The modifications introduced were mainly built on information found in the incident learning systems from the field objects in the LINS study. In order to evaluate the potential learning a thorough analysis of the causation picture is necessary, and a tool for this had to be developed.

Paper II contains a detailed description of the method. What follows is an abbreviated version.

To fulfil its purpose, the method should contain the following steps, which become the design criteria:

1. Evaluation of the *actual* level of learning, based on the lessons learned from individually reported incidents.
2. Evaluation of the *potential* level of learning from individually reported incidents.
3. Calculation of the *relationship (the ratio)* between the actual and potential levels of learning for a larger number of incidents.
4. Adjusting the results from 1-3, taking into consideration incidents that are not reported (the hidden number).
5. Consideration of possible learning from incidents on an aggregated basis.
6. Consideration of other learning mechanisms related to incidents.

This method is also meant to be used on all reported incidents during a given time period in order to see the distribution among levels of learning, to calculate mean values and for making comparisons (e.g. over time, between departments and companies).

Step 1: Actual learning (expressed as level of learning)

The following description relates to the LINS and the MARS work. The first step involves classifying the lessons learned (or only the lessons, if the lessons learned cannot be clearly determined) from the reported incidents in an incident learning system according to a system based on:

- Primarily, how broadly the lesson learned is applied in the enterprise (from very locally, only where the incident occurred, to the whole site [or even broader], where similar conditions prevail).
- Secondly, how much organisational learning is involved (technical, procedural and personnel measures).
- Thirdly, how much organisational long-term memory is involved.

There are no sharp limits between the three aspects; overlaps between the geographical aspect and the other two aspects exist.

A short version of the classification system is shown in Table 5.2. As a comparison, related classifications based on the 1^{st}, 2^{nd} and 3^{rd} order learning system and on the single-loop and double-loop learning system are shown. Table 5.2 also shows that for classifying the broad range of incidents that have rather low levels of learning, the concept of single and double-loop learning in particular, but also the concept of 1^{st}, 2^{nd} and 3^{rd} order are not very suitable because a vast majority of the incidents will have single-loop and 1^{st} order learning.

Table 5.2 Classification system for levels of learning.

Level	**Characteristics**	**1^{st}, 2^{nd} , 3^{rd} order**	**Single-loop Double-loop**
0	No organisational learning	-	-
I	*Primary:* Limited local level learning *Additional:* Almost no organisational learning; short-term memory	(1st)	(SLL)
II	*Primary:* Local level learning *Additional:* Limited organisational learning; mostly long-term memory	1st	SLL
III	*Primary:* Process unit level learning *Additional:* Substantial organisational learning; long-term memory	2nd	SLL (DLL)
IV	*Primary:* Site level learning *Additional:* Substantial organisational learning; long-term memory	3rd	DLL
V	*Primary:* Higher learning, Corporate learning *Additional:* Substantial organisational learning; long-term memory	3rd	DLL

The result from step 1 is a percentage distribution of the incidents on the different levels of learning. From this information, conclusions on the effectiveness of learning can already be drawn. A “mean” value of the level of learning can now be calculated. Since an ordinal scale has been used, this is not a true arithmetical mean value, but for the purpose of the study this is of minor importance.

Step 2: Potential learning

The following description relates to the LINS and the MARS work.

To better assess the effectiveness of the learning in a way that goes beyond the assessment of actual learning in step 1, one can compare the actual learning with what could have been learned, had the full learning potential been utilised. It was decided to develop a tool to enable evaluation of the potential level of learning from incidents.

Naturally, not all incidents contain lessons at a high level of learning. Certain incidents only justify measures at a low level of learning – a local technical measure or a limited procedural or organisational measure – or even no measures at all. However, most incidents have a potential for higher levels of learning. This is based on the assumption that if one can clarify the whole causation picture around an incident, it would be possible to evaluate the potential lessons of that incident. A full root cause analysis is, however, often time-consuming. Therefore, a tool was developed for evaluation of the most probable direct and underlying causes of incidents, a tool which is efficient and less time-consuming to use. The tool is based on the same thinking used in the *MORT* (Management Oversight and Risk Tree) technique (Johnson, 1973; Koornneef and Hale, 2008) and also shows resemblance to *SMORT* (Safety Management and Organisational Review Technique) with its checklists, which have been used, for example, by Tinmannsvik and Hovden (2003). It is proposed here to use the stop rule: one stops the analysis when it is no longer possible for the organisation to influence the factors giving rise to the causes.

The tool was developed for use in clarifying the causation picture over and above what is already given in incident reports. The tool was constructed using the model of the company as a socio-technical system with different hierarchical levels (Rasmussen, 1997). Here is a list of suitable levels that can be used for many types of enterprises:

- Top level, company management (typically the site management)
- Other influencing levels (typically staff and support functions)
- Supervision at higher levels (typically process unit/middle management)
- Supervision at execution level (typically first line supervisors)
- Direct executing level (typically sharp end operators)
- Process/equipment

An abbreviated version of the tool is presented in Table 5.3. The full version can be studied in Paper II.

Table 5.3 Tool for evaluation of underlying causes of incidents.

Analysis level	**Department/ Organisation**	**Direct causes**	**Underlying causes (latent conditions)**
5. Top level	Company management	Inadequate review of systems and safety performance of organisation. Poor communication of safety priorities. Responsibility/accountability unclear.	Inadequate or weaknesses in safety management system. Inadequate or weaknesses in safety culture. Poor safety commitment and leadership.
4. Other influencing levels (support functions, etc.)	Technical department (example)	Design inadequate. Poor risk assessments.	Inadequate systems for technical standards. Inadequate risk assessment procedures. Inadequate resources/competence.
3. Supervision at higher levels (often line managers)	Operations	Supervision/review/control of systems and organisation inadequate. Inadequate operations procedures, competence, resources and training. Risk assessment inadequate. Managers "don't care".	No systematic procedures for risk assessment. Poor resources and competence. Inadequate commitment, review and control by higher management. No time for relevant training.
	Maintenance	Similar to Operations but adjusted to maintenance activities.	Similar to Operations but adjusted to maintenance activities.
2. Supervision at execution	Operations	Supervision/control of execution inadequate. Staffing, training of operator personnel inadequate. Supervisors "don't care". Other priorities higher than safety.	Inadequate commitment (from higher levels of management). Need for resources, training, competence not appreciated. Inadequate review of system and safety performance.

	Maintenance	Similar to Operations but adjusted to maintenance activities.	Similar to Operations but adjusted to maintenance activities.
1. Direct executing level ("Sharp-end operators")	Operations (operator)	Operation outside design conditions. Procedures not followed. Direct operator error. Shortcomings of individuals. Inadequate competence.	Procedures, training inadequate. Inadequate supervision and control. Staffing inadequate. Situational factors: high workload, stress or other aggravating factors.
	Maintenance (technician)	Similar to Operations but adjusted to maintenance activities.	Similar to Operations but adjusted to maintenance activities.
0. Process/ equipment		Vessel/containment/component/machinery/ equipment failure/malfunction. Loss of process control. Instrument/control/monitoring device failure.	Fabrication failure. Corrosion/erosion/fatigue. Maintenance/inspection programmes inadequate or not followed. Operation outside design conditions.

By applying this tool to a reported incident it is possible to generate the probable underlying causes and thereby the potential lesson learned that would have been possible to extract from the incident. With this done, one can again use the classification system in Table 5.2 to evaluate the level of learning for this potential lesson learned.

After applying this tool to all incidents in a given period, one will have as a result of step 2 a new set of figures describing the distribution among the levels of learning for the potential learning from the reported incidents. A "mean" value for the potential level of learning can also be calculated here.

In the MARS study, a tool similar to the one presented in Table 5.3 was developed and used to investigate the underlying causes of the accidents. The principle difference is that in the MARS tool, the first level of causes are those categories given in the official MARS system, whereas the tool presented above starts with causes typically mentioned in the incident databases of the companies in the LINS study.

Step 3: Comparison between actual and potential levels of learning

With the two sets of values – for actual level of learning and for potential level of learning – one can make comparisons between the two and draw conclusions about the effectiveness of learning from incidents. The figures, distributed among the levels of learning, can be compared and the ratio between the mean values can be used as a simple measure of effectiveness. Conclusions on areas for improvement can then be drawn.

Step 4: Adjusting the results from steps 1-3, taking into consideration incidents that are not reported (the hidden number)

The above picture is not the whole story. One ought to take into consideration the fact that a bigger or smaller number of incidents occur but are not reported; hence no organised learning takes place. In the original method published in Paper II, there is only a qualitative reasoning about this issue. One can stop with that.

However, because the issue of the hidden number can be very significant in the learning from incidents in some companies, an attempt to treat it quantitatively was felt to be worthwhile. In the next section, 5.4 Efficiency of reporting, the issue of how many reportable incidents that actually occur is treated. One has to be aware that the results of step 4 contain much more uncertainty than the results from steps 1-3. The hidden number depends on the openness, alertness and willingness in the organisation to report all incidents with a learning potential. It also depends on the threshold the company has defined for reportable incidents, or rather the incidents worth reporting. There is no given number for how many incidents would be reportable in an organisation. However, the total number of reportable incidents can be assumed to be proportional to the size of the company, and at least reasonably proportional to the number of employees. The number of reportable incidents will also depend on the type of industry and its activities. Further, the number of incidents will be dependent on the safety maturity in the company. In this first version of the method it is proposed to use only the number of employees as a base, as a first approximation.

A company would normally be in the position to make an "honest" estimate of what would be a reasonable figure to use in the calculation for correction for incidents not reported. In order to assess the order of magnitude for the number of reportable incidents, one could turn to the six companies in the LINS study. As will be discussed in 5.4.2, a reasonable figure to use, if no internal company figure is produced, is 3 reportable incidents per employee, per year. Unreported incidents can be assumed to have 0 level of learning. Regarding the potential level of learning from the unreported incidents (predominantly incidents with minor consequences and a less complex causation picture), one can assume a somewhat lower average level of learning than for the incidents actually reported. Even with all these assumptions, it is considered worthwhile to include this step in the method in this semi-quantitative way. If the purpose is to compare the level of learning between various departments, sites or companies, one needs to have a common baseline defining what a reportable incident is (i.e. the same threshold for reporting should be used). This will, however, also vary between organisations.

By making an adjustment for the hidden number in the manner described above, one will be able to arrive at numerical values of the level of learning (adjusted for non-reported incidents), which is probably a truer picture than the uncorrected values of step 3.

Step 5: Consideration of possible learning from incidents on an aggregated basis – the 2nd loop

The next step in the method considered the possible learning from the incidents when treated on an aggregated basis, if such a 2nd loop really exists and increases the learning. The same tool that was developed for evaluation of the effectiveness of the 2nd loop, and described in section 5.2 Effectiveness in the learning cycle, can be used to judge whether the results from steps 1-4 should be adjusted or not. A good treatment of the incidents in the 2nd loop can compensate in part for poor results from the step 1 evaluation. As of now, no quantitative approach has been tried in this step.

Step 6: Consideration of other mechanisms for learning from incidents

The final step in the method considers learning mechanisms for incident learning outside of the incident learning system proper. Information for such considerations is found in interviews of employees (e.g. in safety audits). No quantitative approach has as yet been tried in this step.

5.4 Efficiency of reporting

In order to answer the third type of fundamental questions – Do we report the incidents that are worth reporting (that have learning potential)? What is the threshold for reporting? How big is the number of unreported cases, the hidden number? – a tool and reasoning have been developed to help assess this vital issue. The notion "efficiency of reporting" is used here to describe the <u>quantity</u> of incident reporting (in relation to some reasonable standard value).

The purpose of the tool for assessing the threshold for reporting and the guideline for number of reportable incidents is to guide the user in determining how good the actual reporting of incidents really is. The word "efficiency" (and not "effectiveness") of reporting is used to reflect that in this case we mainly consider quantity of reporting.

For effective learning from incidents to take place, there is a need to bring as many of those incidents with a learning potential as possible to the attention of the organisation and deal with them in the incident learning system. In estimating how good an organisation is at this, a tool is proposed for determining the threshold for reporting as an indirect measure. Results from this tool are expected to be a support in estimating how high the hidden number is.

Ideally, the reporting should be based on the learning potential of the incident, but in reality in most organisations it is based on the level of consequence or disturbance (severity). The number of reports as a function of the severity of the incidents will in principle be similar to Figure 5.2, where the number of incidents actually occurring decrease with increasing severity. The number of reported incidents is close to what actually occurs for high severity incidents, but is often only a smaller fraction for low severity incidents. The area between the curves represents the unreported incidents, the hidden number. At some defined low severity, the organisation has set the limit for reporting – the reportable incident.

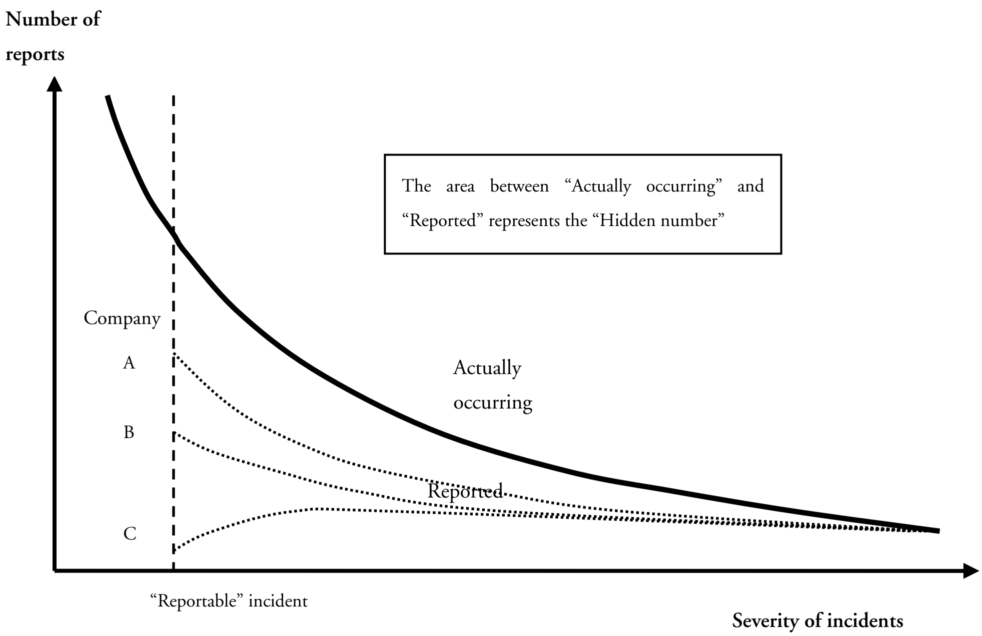

Figure 5.2 Number of incidents (occurring and reported) as a function of the severity of incidents.

5.4.1 Threshold for reporting

To be able to judge the actual threshold for reporting in an organisation, one can examine many reports and establish the lowest values on the severity scale or better yet, the learning scale (assuming that the learning potential is on the x-axis) that still result in incident reports. A significant number of incidents would be needed to support the choice of the threshold; a few would not be enough.

The tool was built primarily for the types of events that normally are reported in the process industry – events with actual consequences such as personal injuries (type 1) or loss of containment, LOC, (type 2). But the events reported can also just be deviations from normal conditions where the failure of one or more barriers could have led to an event with more serious consequences. Table 5.4 presents the tool that was developed to help in assessing this threshold. The scale used is based on the same idea as the tool for assessing the effectiveness in the learning cycle (i.e. the concept of capability maturity models). The scale was selected by the author to reflect the reporting efficiency from poor to excellent. A reported event of any of the types 1-5, is given a threshold rating value that corresponds nearest to what is expressed in the table (with the possibility to interpolate).

For instance, a report about a deviation from a normal operating procedure, where the deviation is considered minor in itself, but where the presence of another two circumstances (e.g. two failing safety barriers) would have led to an accident, (e.g. a personal injury, LOC, fire, environmental impact or financial loss) would receive a rating of 7.

Table 5.4 Tool for assessing the threshold for reporting.

Type of event (Consequence or effect)		**Rating**			
		2 (Poor)	**4 (Fair)**	**7 (Good)**	**10 (Excellent)**
1	Personal injury (actual)	Major personal injury, normally hospitalisation.	LTI (Lost Time Incident) = absence from work 1 day or more.	Medical care.	
2	Loss of containment (LOC) of dangerous substance, fires etc. (actual)	Major LOC. Major fire. Major environmental impact and/or	Small LOC. Small fire. Minor environmental impact and/or	LOC, which could possibly have lead to fire, environmental impact and/or financial cost, if 1	LOC, which could possibly have lead to fire, environmental impact and/or financial cost, if

		financial cost.	financial cost.	more barrier had failed.	2 more barriers had failed.
3	The event + one or more circumstances could have led to ….	Not applicable for this type of event.	The event + 1 more circumstance could have led to a serious accident (major personal injury, major LOC, major fire, major environmental impact and/or financial loss).	The event + 2 more circumstances could have led to an accident (personal injury, LOC, fire, environmental impact and/or financial loss).	The event + 3 more circumstance could have led to an accident (personal injury, LOC, fire, environmental impact and/or financial loss).
4	Deviations from procedures (without accident)	Not applicable for this type of event.	Major deviation from procedure + 1 more circumstance could have led to a serious accident (major personal injury, major LOC, major fire, major environmental impact and/or financial loss).	Small deviation from procedure + 2 more circumstances could have led to an accident (personal injury, LOC, fire, environmental impact and/or financial loss).	Minor deviation from procedure + 3 more circumstances could have led to an accident (personal injury, LOC, fire, environmental impact and/or financial loss).
5	Other deviations (without actual accident), such as failing safety equipment*, communication systems, etc.	Not applicable for this type of event.	The deviation + 1 more circumstance could have led to a serious accident (major personal injury, major LOC, major fire, major environmental impact and/or financial loss).	The deviation + 2 more circumstances could have led to an accident (personal injury, LOC, fire, environmental impact and/or financial loss).	The deviation + 3 more circumstances could have led to an accident (personal injury, LOC, fire, environmental impact and/or financial loss).

* Examples of safety equipment are interlock systems, safety relief valves, fire fighting equipment, emergency alarms, emergency showers.

For the event types 3, 4 and 5, some reasonable engineering judgement is necessary from the person using the tool to assess the possibilities for escalation of the reported event to more serious consequences.

The threshold "value" will be a significant guide to the ambition level of the organisation to try to learn from incidents. The lower the "threshold", the higher the rating, the better the reporting and probably the possibilities for learning. The actual level could also be compared to the official wording of the company's definition of what should be reported.

5.4.2 Hidden number

The issue of the hidden number is closely related to the threshold for reporting. The hidden number is an expression of how many incidents that are not reported, but were actually "worth reporting" or at least "reportable" and thus should have been reported. In Figure 5.2, the hidden number is represented by the area between "Actually occurring" and "Reported" incidents.

Certainly, the number of reportable incidents varies considerably in practice and depends among other things on factors such as:

- Size of enterprise – the more employees with exposure to hazardous conditions the more reportable incidents, probably
- Type of enterprise – the more complex, the more reportable incidents, probably
- Type of activities – the more manual work, the more reportable incidents, probably
- Type of plant – the tighter and more congested, the more reportable incidents, probably (to some extent related to age, indoors or outdoors location)
- Existing safety culture – the better the safety culture, the fewer reportable incidents, probably
- Existing safety culture – the better the safety culture, the larger the proportion of reported incidents of the reportable incidents, probably
- The company definition of what is a reportable incident (not necessarily the same as worth reporting)

Unreported incidents with a potential for learning will always occur. This hidden number should be as low as possible. In reality, there will always be a balance between quantity and quality. It is probably better with fewer reports, which are handled well, than many reports, which are handled poorly. Considering the variations in the above mentioned factors, the figure for reportable incidents can vary considerably between different companies and also between departments within the same company.

Because the issue of the hidden number is so important, it is essential to evaluate what could be a reasonable figure of reportable incidents in an enterprise, despite all the difficulties and uncertainties. In the LINS project, which covered six process industries, evaluations were made of a reasonable figure for reportable incidents per employee, per year. It was concluded that 3 incidents per employee, per year is reasonable in the process industry. An external, neutral expert panel was asked about this. Their figure was 3 incidents per employee, per year as an average and with a span of 1 to 7.5. The companies in the study estimated a reasonable figure for reportable incidents in their own organisation. Their answers ranged from 0.75 to 5 with an average of 2.3 reports per employee, per year based on employees in some sort of technical jobs. The actual number of reports in the companies ranged from 0.1 to 2.3 per employee, per year. Based on this information, one can estimate that reasonable figures for process industry companies are in the order of magnitude of 1 to 5 reports per employee, per year. If no real estimate of a representative figure exists, it is suggested that the figure of 3 be used as a reasonable estimate.

Figures lower than 1 incident per employee, per year would indicate that the reporting can probably be improved. The results from the evaluation of the threshold of reporting should also be consulted. If there is both a low number of reported incidents and a poor rating (say <= 4) of the threshold for reporting, this is most probably an indication that the hidden number is rather high.

Every company is probably best at making its own evaluation of how many reportable incidents there ought to be in the enterprise. A discussion in the company on how many incidents that in fact are reported compared to how many that are reportable is already a worthwhile exercise. This can result in an increase in reporting frequency. However, resources must then be secured to take care of the increased flow of reports. Otherwise, the good ambition to learn more could become a waste of effort, and in the worst case, result in decreased motivation for reporting if employees feel that the organisation is not properly attending to the reports.

5.5 General methodology for assessing the effectiveness of learning from incidents

The general methodology developed to assess the effectiveness of learning from incidents is to address the following three elements:

- The learning cycle
- The lesson learned
- The efficiency of reporting "reportable" incidents.

By using a combination of the methods and tools described above for assessing the individual elements (Figure 5.3), one will get a total picture of the effectiveness of learning from incidents. To use the general methodology, comprehensive data on the lessons learned and on every step in the learning cycle is needed.

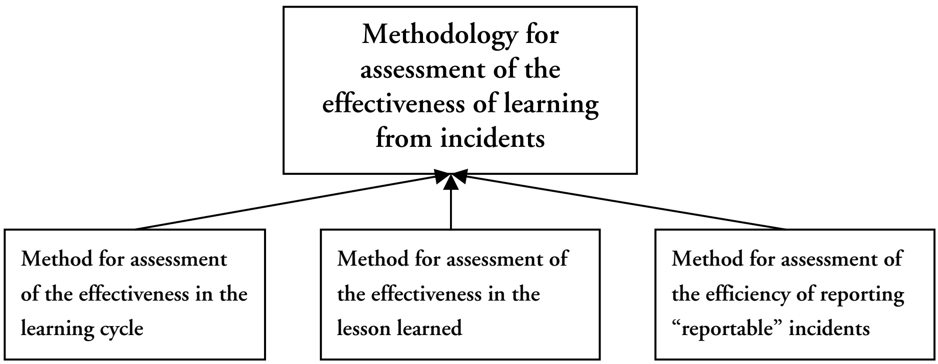

Figure 5.3 Elements of the methodology for assessment of the effectiveness of learning from incidents.

For the major accidents in the MARS project, only the method for assessment of the effectiveness of the lesson learned was relevant.

5.5.1 Summary of methodologies, methods and tools developed

Table 5.5 summarises the methodologies, methods and tools developed, including also indication of the formal support from expert judgement and feedback from companies.

Table 5.5 Summary of methodologies, methods and tools developed.

Methodology for broad range of incidents (LINS)				
Issue	**Method**	**Tools**	**Paper**	**Formal support**
Learning process	Effectiveness in learning cycle	- Reporting step - Analysis step - Decision step - Implementation step - Follow-up step - 2^{nd} loop	Paper I	Construct validity: Support by expert panel. Support from companies on the results. Reliability: Limited test by companies.
Learning product	Effectiveness of lesson learned	- Classification in level of learning	Paper II	Built on earlier research.
		- Underlying causes (for assessment of potential learning)	Paper II	Construct validity: Support by expert panel. Support from companies on the results. Reliability: Limited tests by companies.
Reporting efficiency	Reporting threshold	- Rating system	Thesis	Construct validity: Support by expert panel. Reliability: Limited tests by companies.
	Hidden number	- Target values	Thesis	Construct validity: Support by expert panel. Reliability: Limited tests by companies.
Methodology for major accidents (MARS)				
Learning product	Effectiveness of lesson learned	- Underlying causes (for assessment of potential learning)	Paper III	Construct validity: Support by expert panel. Reliability: Support through test by co-author
		- Classification in level of learning	Paper IV	Built on earlier research.

5.5.2 Validity and reliability of tools

The tools have been examined and scrutinised by experts in the field. Table 5.5 presents some comments on the issues of *construct validity* (establishing correct operational measures for the concepts being studied) and *reliability* (demonstrating that the operations of a study can be repeated, with the same results) (Yin, 2003).

What is especially important for the tools in assessing the steps in the learning cycle is that they include all relevant dimensions and aspects. Efforts have been made to secure this by studying the contents of the databases of the six participating companies and extracting information. The construct validity has also been checked through the judgements of experts.

The methods and tools were developed for use in the process industry. The *external validity* (establishing the domain to which a study's findings can be generalised) (Yin, 2003) has not been tested. However, it is claimed that the methodology is applicable in many other enterprises, as there are no fundamental differences in how incidents occur and how they can be learned from between other types of enterprises and the process industry.

The methods and tools (for the LINS project) were applied to extensive data from the six companies, participating in the LINS study. The main results from these application studies were fed back to the companies, which were also asked in a formal inquiry to give their opinion on the results. All companies strongly supported the results. Some of these companies also used the tools to a limited degree on their own and reported support for the usefulness of the methods and tools.

As a whole – the experiences during use, the feedback from the experts and the companies – did not seem to warrant any major modifications. However, as can be seen in Paper II, some suggestions for improvement of the tool for evaluating underlying causes were given by the experts. Some of those suggestions, as well as similar ones for the corresponding tool in the MARS work, would be suitable to include in future versions. In addition, before being used in another project, it would be suitable to go through all the methods and tools and possibly make minor improvements.

6 Results and research contributions

6.1 Brief summaries of papers

6.1.1 Paper I

Jacobsson, A., Ek, Å., Akselsson, R. (2011). Learning from incidents – A method for assessing the effectiveness of the learning cycle. Submitted to an international scientific journal.

This paper describes the method for assessing the effectiveness in the learning process via the steps of the learning cycle: the 1st loop with reporting – analysis – decision – implementation – follow-up, and the 2nd loop on an aggregated basis as presented in section 5.2. For each step, the dimensions considered the most relevant for the learning process (scope, quality, timing and information distribution) were defined. Further, for each dimension the most relevant aspects (e.g. completeness and detail) were defined. A method for a semi-quantitative assessment of the effectiveness of the learning cycle was developed using these dimensions and aspects. The assessment is carried out by comparing the actual information for an incident with the requirements for various ratings according to the scales of the method. The output from using the method is a measure of the effectiveness of the learning from incidents. The method can give clear indications of areas for improvement. The measures of the method can also be used for correlating results from learning from incidents with other safety parameters (e.g. results from safety audits and safety climate inquiries). The method is intended to be used on a sample of the broad range of incidents normally seen in process industry companies.

The method was tested on two-year incident reporting material from the six companies in the LINS study representing various types of process industries. It was found that the method and the tools worked very well in practice.

The results provided interesting insights into the effectiveness of learning from the incidents and what influences it. There were large variations in the results from the various companies. In general, it can be said that the companies had a large focus on the reporting step whereas those that follow received less attention. The analysis step was sometimes performed well but often rather superficially. The decision and the implementation steps were sometimes performed stringently but often only as cosmetic measures and after a long time. The follow-up step was in general poor. Differences in the learning from incidents between companies could often be explained by company-specific circumstances (e.g. management involvement, resources for dealing with safety issues, and safety training of employees).

6.1.2 Paper II

Jacobsson, A., Ek, Å., Akselsson, R. (2011). Method for evaluating learning from incidents using the idea of "level of learning". Accepted for publication in *Journal of Loss Prevention in the Process Industries*.

This paper has the same background and overall objective as Paper I, but the topic is the learning product – the lesson learned. A method is described for evaluating the effectiveness of learning, based on the level of learning. The level of learning is expressed in terms of how broadly the lesson learned is applied geographically, how much organisational learning is involved and how long-lasting the effects, according to a classification system. To evaluate the actual and the potential levels of learning and comparing the two, a 6-step method was developed.

1. Evaluation of the actual level of learning, based on the lessons learned from individual reported incidents.
2. Evaluation of the potential level of learning from individual reported incidents.
3. The relationship between the actual and potential levels of learning for a larger number of incidents.
4. Adjusting the results from 1-3, taking into consideration incidents that are not reported (the hidden number).
5. Consideration of possible learning from incidents on an aggregated basis.
6. Consideration of other learning mechanisms related to incidents.

Tools were developed to help in making concrete numerical evaluations. A key step in the method is the evaluation of the full causation picture with all its underlying causes which enable the user of the method to draw conclusions regarding the potential learning from the incidents. The method contains a specific tool for this.

The great value of the method is not the generated numbers per se but the message they convey when the numbers are related to the level of learning they stand for and when comparisons over time or between companies or departments are made. The method can give clear indications of areas for improvement. The measures of the method can also be used in efforts to correlate results from learning from incidents with other safety parameters (e.g. results from safety audits and safety climate inquiries). The method is intended to be used on a sample of the broad range of incidents normally seen in process industry companies.

The method was tested on incident reports covering two years from the six companies in the LINS study from various types of the process industry. It was found that the method and the tools developed worked very well in practice.

The results varied substantially between the companies. However, on average it can be said that 25% of the incidents resulted in level 0 learning (No learning), 50% in level I learning (Limited local level), 18% in level II learning (Local level), 6% in level III learning (Process unit level) and 1% in level IV learning (Site level). The ratio actual/potential learning varied between 0.36 and 0.86 (without adjustment for the hidden number).

Similar to Paper I, the results provided insights into what can influence the effectiveness of learning from incidents. Differences between the companies could often be explained by company-specific circumstances (e.g. management involvement, resources for dealing with safety issues and safety training of employees).

6.1.3 Paper III

Jacobsson, A., Sales, J., Mushtaq, F. (2009). A sequential method to identify underlying causes from industrial accidents reported to the MARS database. *Journal of Loss Prevention in the Process Industries* 22 (2), 197-203.

This paper presents a method designed to identify underlying causes leading to industrial accidents. The method is generic in nature but closely associated with the way the reporting to the MARS database of the European Commission denominates and structures the causes of accidents. The method developed intends to facilitate the learning process from accidents by identifying possible causes related to the accidents that were not directly stated in an accident report, but that can be deduced following the description of the event. This is particularly the case with regard to the components and quality of the safety management systems in place at the industrial establishment at the time of the accident. The method follows a sequential approach, although a combination of the philosophy behind other existing accident models has been taken into consideration. The starting point of the model is the causes for accidents included in the MARS database. These causes have been extended by considering typical operational or organisational failures that are normally related to the original reported cause(s). The extension of causes has been performed by adding three follow-on levels of possible underlying causes. The first level can be considered as a direct cause of the accident and, the last level being more applicable to the foundation of establishing safety: "Safety Management System or the Safety Culture". The objective is to determine the effectiveness of the method in identifying underlying causes in addition to those causes stated in the original reports. In this way, it is possible to establish a system to go deeper into the analysis of past accidents, in order to obtain lessons learned, and to avoid the recurrence of similar accidental scenarios in the future, as well as to give directions for a better reporting system of industrial accidents.

The method was applied to the total set of accidents reported to the MARS database. It was found that the method was easy to use and it is argued in the paper that the causation model developed is suitable for its purpose, which was to expand the causation analysis of accidents to include more underlying causes. The method also received great support from a group of experts of the European Federation of Chemical Engineering.

The main results of the analyses are that as much as three times as many underlying causes can be found when applying the method developed compared with what is given in the original reports.

The method in this paper was also developed specifically to be used for analysing the accidents of the MARS database to find possible characteristic patterns of the underlying causes, and the potential for learning from the accidents, which should be a reflection of the underlying causes.

6.1.4 Paper IV

Jacobsson, A., Sales, J., Mushtaq, F. (2010). Underlying causes and level of learning from accidents reported to the MARS database. *Journal of Loss Prevention in the Process Industries* 23 (1), 39-45.

One of the main purposes of the MARS database is to provide information for learning from the accidents to avoid similar events. The main objective of this paper was therefore to determine how good the learning from the accidents reported to MARS actually is. Other objectives were to establish whether there were any specific patterns per industry type and per country in the learning. A specific objective was to establish whether there had been any impact of the requirement in the Seveso II legislation regarding safety management system on the causes of accidents.

Two separate measures were used as indicators of the learning:

1. the extent to which relevant causes have been analysed
2. the level of learning of the lesson learned

It is argued that the most important issue for the learning from accidents is the analysis of the causes of the accident, particularly the underlying causes, which are the key to deciding on relevant measures. The sequential method, presented in Paper III, made it possible to go beyond the causes given in the original reports and to find more underlying causes. A classification system was developed to determine the level of learning from the accidents using the actions/lessons learned given in the reports. This method establishes the level of learning of the lessons learned from each case description, essentially from the breadth of application and from an organisational point of view.

The paper presents results from an analysis of all the accidents reported to the MARS system up to mid-2007 regarding the underlying causes and the extent of learning, based on the level of learning.

Both the methods used, the one for analysis of underlying causes and the one for establishing the level of learning, worked very well on the data in the MARS database. The most important underlying causes were found in weaknesses in process analysis (risk assessment) and in procedures, regardless of industry type. Weaknesses in safety management systems and in safety culture contribute as underlying causes in a very high percentage of the accidents. No major differences in the pattern of the underlying causes were found for the various industry types, neither for the various countries. The quality of reporting, measured in terms of analysis of underlying causes, vary considerably between various countries. The level of learning, as determined from the information in the reports, is found to be in general rather low, especially from some of the countries. In two thirds of the accidents the learning stops at a local level within the sites. This study resulted in ideas of improvement of the MARS system.

6.2 Addressing the research questions

The six research questions are addressed in turn.

RQ 1

How can a methodology be constructed in general for analysing and assessing the effectiveness of learning from incidents, based on information contained in incident learning systems? What considerations should be made? What elements should it contain?

A methodology with such a purpose should contain methods and tools that cover the learning effectiveness both from the learning process and learning product perspectives. The efficiency of reporting the "reportable" incidents can be considered a part of the learning process (the very first step), or be treated as a separate issue, as was chosen here. Thus, the methodology designed in this research to answer RQ 1 has three elements as seen in Figure 6.1. Each of the elements is presented in more detail in chapter 5.

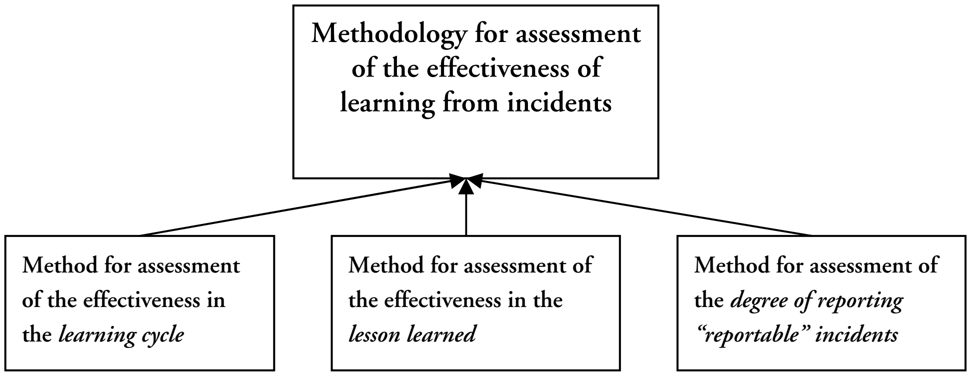

Figure 6.1 A methodology for assessment of the effectiveness of learning from incidents.

For the sake of clarity and as background for answering research questions RQs 2 and 3, the objectives of study 1 (LINS) are repeated here: to develop methods for assessment of the effectiveness of learning from incidents in the process industry (normal cut of incidents) and apply those in the field. The results from application of the methods should be suitable for correlating with other safety measures in an organisation.

RQ 2

How can methods be constructed for analysing and assessing the effectiveness of the learning from "normal" incidents in a process industry (for company-internal use), considering in particular:

- *a) the effectiveness in the learning cycle (i.e. the necessary steps and actions from reporting an incident to the implementation and follow-up of the measures taken),*
- *b) the effectiveness in the lesson learned (actual learning versus the potential learning),*
- *c) the efficiency of reporting,*
- *d) that the results from application of the methods should be suitable for correlating with other results of measuring safety in an organisation?*

The general answer to RQ 2 is the methodology above with its three elements using:

- the method for assessing the effectiveness in the learning cycle with individual tools for the different steps, described in section 5.2 and in more detail in Paper I;
- the method for assessing the effectiveness of the lesson learned (based on level of learning) with its six steps, including the system for classification into level of learning and the tool for assessing the underlying causes/potential learning as described in section 5.3 and in more detail in Paper II;
- the tool for assessing the threshold for reporting and the guideline for assessing the hidden number, as described in section 5.4.

Regarding 2d), all the methods and tools developed give results in quantitative terms. Therefore, the results will automatically lend themselves to statistical correlations with other quantified results from safety investigations.

RQ 3

How effective is the learning from incidents in a selection of companies in the process industry in Sweden, based on:

a) the learning cycle,

b) the lessons learned (both as actual lessons learned and compared to potential lessons learned)?

The methods were applied to a large number of incidents in six Swedish process industry companies. The results are presented in Papers I and II. The results concerning the effectiveness of the learning varied significantly between the companies. The effectiveness in the learning cycle, 1st loop, was in general found to be "fair" (4 on the 0-10 scale) or at the best "good" (7 on the 0-10 scale) in some respects, except for one company which was consistently "good" to almost "excellent" (10 on the 0-10 scale). The 2nd loop received comparatively lower ratings than the 1st loop for all the companies. The actual learning compared to the potential learning (based on the lesson learned) was in general rather poor except for the same company that was best in the effectiveness in the learning cycle. Expressed as the ratio between the "mean values" of actual level of learning and potential level of learning, the values were in the range of 0.36 to 0.86.

The results obtained in this research are a start in assembling a larger reference material for the process industry on which more general conclusions for the Swedish process industry can be drawn.

For the sake of clarity and as background for answering research questions RQ 4- RQ 6, the objectives of study 2 are repeated here. The second study is about learning from the major accidents in the MARS database (Papers III and IV). The objective of this study was primarily to assess the actual level of learning of the accidents reported in the MARS database. The objective was also to assess whether all underlying causes had been found in the original investigation reports. Further objectives were to try to link these underlying causes to issues of safety management systems and safety culture, and to identify weaknesses in the quality of reporting and analysing.

RQ 4

How can a method for analysing and assessing the effectiveness of learning from the major accidents contained in the MARS database be constructed, considering in particular:

a) the actual level of learning;
b) an in-depth analysis of underlying causes to reflect the potential level of learning?

The actual level of learning is assessed by using the method (classification system) described in section 5.3, step 1 and in more detail in Paper IV. The underlying causes are assessed by the method described in section 5.3, step 2 and in more detail in Paper III.

RQ 5

Does the learning from accidents by companies and national authorities – based on results from application of the assessment methods – meet the objectives set for the learning from major accidents in the MARS system?

The objective of MARS is to learn broadly within the entire European process industry. Thus, one would expect most of the lessons learned to be at level IV and V according to the system for classification used. The results from the MARS study are that a large part of the reported accidents are incompletely analysed for causes and for the potential lessons learned. The results from application of the method are that only 17% of the lessons learned were classified as a IV or V level of learning. Considering this, the answer to RQ 5 would be a clear “No”.

RQ 6

Based on results from application of the assessment method, are there any (and if so, what are they):

a) Specific characteristic patterns in the underlying causes per industry type?
b) Specific national characteristic patterns in the underlying causes?
c) Industry specific characteristic patterns in the level of learning?
d) Specific national characteristic patterns in the level of learning?

e) *Impact of the requirement in the Seveso II legislation of safety management system on the causes of accidents?*

The results from application of the methods indicated the following answers to the questions:

6a) There is a similar pattern regardless of the industry type for the most common underlying causes. All industry types have weaknesses in "Process analysis" and "Procedure" as the two most common underlying causes. The third most common is found in either "Training" or "Design". Notable is also the high percentage of weaknesses in "Maintenance" and "Inspection" for many industry types.

6b) There is a similar pattern for all countries for the most common underlying causes. All countries (except one) have weaknesses in "Process analysis" as the most common. The second most common weakness is in either "Procedure", "Training" or "Design".

6c) The pattern for level of learning is similar for most industry types. Only the petrochemical industry seemed to have a higher percentage of learning on higher levels (III, IV and V) than most other industry types.

6d) Two countries stood out positively with a high percentage of learning on higher levels (III, IV and V), whereas one country stood out negatively with a low percentage of learning on levels III, IV and V and a very high percentage on level 0 learning. For the rest of the countries, the percentages are more or less equally distributed, with higher percentages on the 0, II and III levels of learning.

6e) No significant impact was found of the introduction in the Seveso II requirements of the safety management system on the causes of accidents.

6.3 Addressing the research aim

To sum it up, as expressed in the research aim, it was possible to develop a general methodology for assessing the effectiveness of the learning from incidents in the process industry. The methodology with its methods and tools can also be tested on field data, and during the work it could also be updated and improved.

7 Discussion

7.1 Methodology issues

7.1.1 Novelty of methods and tools

No real effort to develop methods for assessing, especially not in quantitative terms, the learning from incidents was found in the scientific literature when searched for as a part of this research. It is therefore claimed that the methodology developed here is novel. It is further claimed that the methodology is new in the sense that it comprises elements (methods and tools) which when used in combination will provide a comprehensive picture of the learning from incidents in an organisation in semi-quantitative terms. Due to the nature of the topic with all its complex relationships and more or less subjective judgements, it is difficult to develop true quantitative methods and tools. What has been developed in this research could better be labelled "semi-quantitative" methods and tools.

7.1.2 Completeness of methods and tools to assess the learning from incidents

A crucial point in assessing the learning from incidents is to establish whether the lessons from the incidents are converted into true lessons learned. The methods and tools developed use primarily the information in the incident learning systems of the organisations. The data in such systems normally tell what lessons the organisation has extracted and what measures have been decided for implementation. Sometimes, it is also clear what measures have actually been implemented. But there is still a question of the extent to which these measures have been incorporated into the minds of the employees and into the artefacts, and how the information will be used in the future. So, in addition to what can be extracted directly from the incident learning system by using the methods and tools developed, there must in many cases also be an additional evaluation to establish whether the learning is effective in the end, by asking for instance:

- Do the individuals and the organisation as a whole accept the measures?
- How do the decisions and measures work in practice?
- Do the decisions and measures lead to a positive net learning effect?

The application of the methods and tools needs to be supplemented with other methods to find the answers to these types of questions. Already in the methods for assessing the effectiveness of the learning cycle and the effectiveness in terms of level of learning, considerations of these questions are included in the form of separate steps in the methods. Safety auditing, which has been used as a supportive method, and inquiries for safety climate would be such additional methods to supplement the assessment of the data in the incident learning database.

7.1.3 Usefulness of methodology

The methods and tools, although grounded in scientific methods, have been developed to be pragmatic and easily applied to typical company data in incident learning systems. A prerequisite for use of the methods and tools is a formal incident learning system, reasonably well developed according to the steps in the learning cycle and with reasonably good documentation for all steps of the learning cycle.

The author found that the methods developed worked very well in practice. This applies both for the methods and tools for assessing the effectiveness of learning from the broad spectrum of incidents in the LINS project with six Swedish process industries and for the assessment of the learning from the major accidents in the MARS database. As mentioned previously, for the methods and tools of the LINS project, information in addition to the data in the incident learning system is needed (e.g. information from safety audits) for a complete evaluation. All the methods appear to be stable based on the fact that they all worked well, both for the six companies in the LINS project in spite of six different incident learning systems and for the MARS project. It should be noted, however, that the methods and tools so far have only been tested extensively by the author (the MARS methods also by a paper co-author). Some limited practical use of methods was also carried out in a few of the participating companies.

7.1.4 Area of application

The methodology developed has focused on the process industry. However, almost any enterprise having hazards for man and environment in its operation can use the same methodology.

The methods and tools developed in the LINS project would probably suit, in their present form, almost any enterprise dealing with hazardous substances as one of its typical features. With minor modifications, a much wider area of application would be possible.

The method for evaluating the accidents in the MARS database is tailor-made for this purpose because the nomenclature for causes had to conform to the MARS system. Except for this detail, the method used in the MARS project could be universally applied to other major accidents, provided similar information as in the MARS database is given on causation and on measures taken after the accident.

7.1.5 Validity

The construct validity of the methods and tools has been examined by experts in the safety field.

The methods and tools for the LINS project were examined primarily by an expert panel from the safety committee of the Swedish Plastics and Chemicals Federation, the members of which are typically safety managers at Swedish chemical companies. The methods and tools received strong support for their coverage of the relevant contents and on the scales used. As indirect support for the relevance of the tools used, all participating companies declared in formal inquiries that they strongly supported the results that came out of the application of the methods to their activities.

For the MARS project, an expert panel consisting of the "Loss Prevention Working Party" of the European Federation of Chemical Engineering judged the causation model by using an inquiry. This group consists of prominent safety experts in Europe from academia, authorities and the process industries. Strong support for the relevance of the contents and the scales used was obtained.

7.1.6 Reliability

The results from application of the methodology will to a certain extent be dependent on the user of the methods and tools. A certain degree of subjective judgement will be involved in all the methods and tools.

In the LINS project, no independent evaluation of the data from the companies by a second evaluator was performed. However, the scales of the methods and tools used were judged by an independent expert panel, and were all judged to be very relevant.

The results from application of the methods and tools on real material will be dependent on the user's opinions of the causal pictures of the incidents and how deeply in the artefacts and the culture of the organisation that the root causes are, and thereby on the potential learning. Different evaluators will have different stop rules in the analysis of an incident. A representative from an organisation with a mature safety culture will probably be more inclined to find deeper lying causes than a representative from an immature safety culture. However, the fact that all six companies agreed very much on the results that came out of the application of the method and tools supports that they yield reliable results.

In the MARS research a formal and independent evaluation of a second researcher was performed in order to see how "stable" the results were. There was very good agreement in the results of these two assessors both in terms of finding the relevant underlying causes and the classification of levels of learning. It should be noted that the two were both safety professionals.

7.1.7 Acceptance criteria for results from the methods and tools

The methods and tools (for the LINS project) presented in this thesis lack one important aspect: acceptance criteria. During the research work, no real attempt was made to formulate any such criteria. This is because there probably is no fixed acceptable level for the results from the various methods. The acceptable level will vary from company to company and it will depend very much on where the company is in its maturity of safety culture. The company should set its own goals and criteria. The method and the tools are meant primarily as generators of ideas for improvement rather than verdicts of “approved” or “failed”. However, in some of the tools (for the steps in the learning cycle and for the threshold for reporting), there are some indirect clues from the developer of the tool by such formulations as Poor, Fair, Good, Excellent, which can give some idea of state-of- the-art levels for the process industry. Regarding the level of learning figures, it is impossible to say what would be a good distribution. The more important figure for level of learning is the ratio between actual and potential level of learning, but a fixed acceptance figure is again difficult to define. Regarding the number of reported incidents, some guidance on reasonable figures can be developed from the actual data obtained from the six companies, from the opinions of the companies on where they should be and on the opinions of the expert panel from the safety committee of the Swedish Plastics and Chemicals Federation. Based on this aggregated material a reasonable figure for the process industry for reportable incidents would be around 3 reports per year, per employee (in technical jobs), so perhaps a figure of at least 1 could be a minimum recommendation. This approach could be considered as a start to get reference values for the Swedish process industry.

7.1.8 Selection of incidents when applying the methods

The way most companies go about handling the incidents reported is that all the incidents are (or at least should be) formally dealt with. Therefore, it is also natural to base the method and tools developed for the LINS project on the same prerequisite: All reported incidents within a given time period of interest should be included in the assessment of the effectiveness of learning.

In practice, it is most likely possible to learn the majority of lessons from a selection of all the incidents occurring. Accordingly, the assessment of the effectiveness of learning from incidents can also be based on that same selection of incidents. The question is how do you know which incidents should be selected for thorough investigation to obtain this goal?

On the one hand, it can be argued that only a few reports are needed to reveal the more fundamental lessons to be learned – those about management involvement, management system, safety culture, etc. – if one picks the right ones. Sometimes only one very thoroughly investigated event will suffice (e.g. the BP Texas City accident that was covered in detail with all sorts of lessons to be learned in the Baker and the US CSB reports). However, if selecting only a few incidents, one will miss the important local lessons, such as modifications to specific types of equipment, procedures and training. So, we need them all in a way.

If one decides to choose only some of the incidents for learning, a structured approach with a tool for determining which incident should be selected for in-depth studies is needed. In certain companies, this is done by selection based on consequence. However, this is not the same as picking the ones with most learning potential. In many companies there is a tacit sifting to take certain incidents lightly and devote more resources to others.

To decide which incidents contain a great learning potential and therefore should be selected for deeper study, the tool for evaluating the underlying causes developed in this research in combination with the classification method for level of learning, can be used. The tool and the system can also provide a good idea of how many reports are actually needed to cover the lessons for more fundamental organisational learning, level III and level IV in the classification system. Another consideration is that one would probably need many incidents pointing at the same more fundamental weaknesses before the management of a company "acknowledges" these weaknesses and takes action.

7.1.9 Weighting factors for the tools assessing the learning cycle

To be able to use the method for assessment of effectiveness in the learning cycle, it is not necessary to prescribe certain weight factors for the various dimensions. The method will give valuable results without this. However, if one wishes to arrive at numerical values at the end, one should include a set of weighting factors that reflect the importance of the various dimensions. The weighting can be decided by the user. In the first version of the method, a standard weighting was proposed, the same for all steps (except a little different for the Decision step). In principle, one should weigh the dimensions individually based on the importance each dimension will have for the learning process in that particular step, also taking into consideration the aspects contained in the dimensions and design of the scale of the rating system.

The following way to view the weighting of different dimensions has matured after the preparation of the paper on this topic (Paper I). The proposal for weighting factors is based on the experiences gained during the research project.

The author would argue for reasonably high weights for Scope and Quality in the Reporting step and especially in the Analysis step, whereas Time and Information dissemination receive lower weights. Time and Information dissemination will have higher weights in the Decision and Implementation steps. The numbers (in percent) in Table 7.1 reflect some preliminary ideas of the author on what would be reasonable weighting factors for all the steps.

Table 7.1 Proposed weighting factors (expressed in %) for use in learning cycle tools.

	Learning cycle steps				
Dimension	**Reporting**	**Analysis**	**Decision**	**Implementation**	**Follow-up**
Scope	35	35	30	30	35
Quality	35	45	30	30	35
Time	15	10	20	20	15
Information dissemination	15	10	20	20	15

In this table, the Decision step, Scope and Quality include the Extent dimension.

7.2 Application issues

7.2.1 Comparison of the LINS and MARS studies

The basic difference in the two studies is that the incidents of the LINS study generally have relatively minor consequences, whereas in the MARS study the accidents have major consequences by definition. Despite this fact, similar methods and tools have been used in both studies. The method for classifying the lessons learned in levels of learning is the same in both studies, and it works well in both cases. The methods for assessing the underlying causes of an incident are very similar for both studies. Both methods were evaluated by two separate and independent expert groups and were found to be strongly supported. Both methods worked very well in practice. So, it is concluded that these methods are probably generic in nature and can be used for assessing learning from incidents in many areas.

Despite the big difference in type of incidents – typical small scale incidents in the LINS study versus major accidents in the MARS study – the same conclusion can be drawn from both studies: The learning potential of the incidents is poorly utilised in practical application.

7.2.2 Observations when applying the methodology

When applying the methods and tools in the six process industries and to some extent also the methods to the MARS database, considerable insight into various issues that influence the process of learning from incidents was gained. Data from the assessment of the effectiveness of learning combined especially with the data obtained during the safety audits provided much interesting information about the importance of various artefacts and learning agents for the effectiveness of the learning process. Although strictly belonging to research that will be accounted for separately, it would be appropriate to present some findings here. Many of these are supported by similar findings by Cooke and Rohleder (2006).

The basic prerequisite for good learning from incidents formulated by Reason (1997) – that there is a learning culture in the organisation based on openness, non-punishment, and management commitment, etc. – was felt clearly in the companies in the study. People who are supposed to report their own shortcomings, for instance, must feel that nothing that is reported will be held against them. A good way to build trust in the organisation is to involve the employees in the design and use of the incident learning system. When management asks actively for a high reporting frequency this also normally happens, but then it is important to give positive feedback when this is the case. Above all, management must see to it that reported incidents are dealt with in a good way and reasonably swiftly. It was obvious from the work that the incident learning system must not be perceived as too complicated by the employees who use it. In particular, the act of reporting has to be simple for the reporter.

The dissemination of the results from every step to all people concerned is essential. Because it is not possible to extract all lessons contained in every individual incident, an effective 2nd loop is essential where common denominators and trends can be analysed. If all personnel in the organisation have good training and understanding of how accidents are caused, this will enhance the reporting and the learning from incidents.

Work has also been performed on finding statistical correlations between results from the incident learning assessments and the audits in the LINS study. Positive correlations with statistical significance were found to exist between learning from incidents (according to the measurements of the effectiveness of the learning from incidents) and ratings in the safety audit for the following aspects:

- Safety management system
- Commitment and support of the top management
- Resources for safety/health/environment (SHE)
- SHE objectives and action plans
- Specific SHE training

From the ratings of "who" is performing the activities (in the learning cycle steps), it is obvious that the resources and competence for every step of the learning cycle is of utmost importance. An owner/learning agent in every step in the learning cycle is crucial. High competence is needed especially in the analysis step. However, this competence should not come from the person responsible for the area where the incident occurred because of the possibility of not being objective and neutral.

7.3 Further research

The methodology developed, with its methods and tools, opens up many research opportunities. The fact that the methods and tools deliver numerical answers to questions about the effectiveness in the learning from incidents, lends them to be used in incident research as a means to establish "objective" measures of the learning. Such measures would be very useful to have as a base in other incident research, when various phenomena should be explained.

The first line of further research is to utilise the methodology and its methods and tools as they are in research aimed at penetrating deeper into the mechanisms of learning from incidents for better understanding of the factors that influence the learning. In the LINS project, formal safety audits and safety climate investigations have already been carried out, both of which have generated numerical as well as other results. The obvious next stage in the research is to make statistical correlations between the results of the three activities – learning from incidents, safety audits, and safety climate investigations – to find possible correlations that explain what artefacts and other features influence the learning from incidents. Preliminary work on this has already been carried out. It will hopefully give some answers to the questions involving the general factors and artefacts in a company that influence the learning from incidents (i.e. which are favourable and which are obstructive for good learning).

A second line to pursue in further research is to develop and improve the methodology. The areas where a more solid data background would be desirable for developing the methods and for increasing the reliability of the numerical results from them are:

- The estimate of the number of reportable incidents in an organisation, and based on this the adjustment for the non-reported incidents in the method for assessing the level of learning.
- The way to properly and numerically consider 2nd loop activities and other learning activities outside the formal incident learning system in the methods (both for level of learning and for the learning cycle).
- The issue of how to assign weighting factors to the dimensions in the various steps of the learning cycle.

A third line of research would be to apply the methodology much broader in selected industry types to generate more data on the effectiveness of learning from incidents in order to draw general conclusions on strengths and weaknesses to improve the learning overall.

Specifically regarding the MARS project, suggestions for further research have already been made in Paper IV to investigate the reasons for:

- the poor analysis of underlying causes in general
- the weaknesses in various aspects, both per industry type and per country
- the weaknesses in safety management systems and safety culture, especially in some countries
- the poor level of learning (as defined in the study) from the accidents, especially in some countries and some industry types.

8 Conclusions

In the introduction it was established that many researchers have found that the learning from incidents – both from major accidents and from the broad range of smaller incidents – is often less than what is possible. There are many reasons behind this. Examples of obstacles to the learning have been given elsewhere in this thesis. However, one important reason may be that there are no simple methods and tools available for assessing the effectiveness of learning from incidents. When starting the research for the projects referred to in this thesis (LINS and MARS), the need for "objective" measurement methods of the effectiveness of the learning from incidents was identified as a necessary component.

The purpose of the methods developed was to provide instruments that can yield tangible and reliable results and simultaneously be easy to use not only to the potential users in the process industry and the authorities supervising the process industry, but to researchers as well.

By using scientific methods on a large empirical material in general and on substantial field data explicitly for this research study, the main results and conclusions can be summarised as follows:

- A general methodology for assessing the effectiveness of learning from incidents, which can be applied to all types of incidents in the process industry, was developed and tested in practice, validated by experts and modified (when there was reason for this).
- A set of methods to assess the learning from the broad range of incidents was developed, focusing on the learning process and the learning product, and
    - validated for construct validity by experts from the industry
    - applied and tested in practice in six process industry companies and found very useful, thereby
    - generating valuable results for the participating companies and for research.
- A method to assess the learning from major accidents (based on the information in the MARS database) was developed, focusing on the learning product, and
    - validated for construct validity by experts from the industry and academia
    - applied and tested in practice on all the information in the MARS database (as of mid-2007) and found very useful, thereby
    - generating valuable results for the EC Joint Research Centre, Ispra.

The developed methodology, with its methods and tools, meets the purpose and objectives of the research and constitutes a valuable contribution to the safety community for practitioners in the field and for researchers.

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I

Learning from incidents - A method for assessing the effectiveness of the learning cycle

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Abstract

This paper describes a method for assessing the effectiveness in the steps of the learning cycle: the 1st loop with reporting – analysis – decision – implementation – follow-up, and the 2nd loop on an aggregated basis. For each step, the dimensions considered the most relevant for the learning process (scope, quality, timing and information distribution) and for each dimension the most relevant aspects (e.g. completeness and detail) were defined. A method for a semi-quantitative assessment of the effectiveness of the learning cycle was developed using these dimensions and aspects and scales for rating. The method will give clear indications of areas for improvement when applied. The results of the method can also be used for correlation with other safety parameters, e.g. results from safety audits and safety climate inquiries. The method is intended to be used on a sample of the broad range of incidents normally seen in process industry companies. The method was tested on a two-year incident reporting material from six companies from various types of process industries. It was found that the method and the tools worked very well in practice. The results gave interesting insights into the effectiveness of learning from the incidents.

Key words: Incident; learning; learning cycle; process industry.

1 Introduction

1.1 Background

There is currently a lot of interest in using incidents for learning for safety in many businesses, such as in the aviation industry, in medical care, and in the process industry. However, the effectiveness of learning from incidents can often be questioned, and so even in learning from major accidents (Hovden et al., 2010). The explanations could be found in many of the activities from reporting to implementation and follow-up. Often the analysis of causes is a weak point. Hale (2008) claims that accident investigations often stop at events close to the accident, which usually concern only the behaviour of the hardware and of the operators/workforce directly concerned with carrying out the activity.

Incidents in this paper are “deviating events which differ from normal conditions and which could have adverse effects on safety, health or environment” (OECD, 2008). With this definition most of the incidents will have only small or no consequences at all, and very few will be major accidents.

Major accidents in the high-risk process industry are normally analysed in thorough accident investigations, but major events are rare and therefore seldom to learn from. However, there are numerous events with minor consequences or no consequences at all which, if analysed, could reveal weaknesses in the organisation and the equipment and processes, the same weaknesses that under other circumstances could lead to a serious accident (Reason, 1997). These events are the ones that the process industry must use and learn from to be able to avoid both major accidents and the many smaller incidents.

The learning from an incident involves a long chain of activities and also many employees in the organisation. No step can fail without affecting the end result. First, there is the crucial step of identifying events worth reporting. Then there is a sequence of activities, which we will call the *learning cycle* (Kjellén, 2000; Hale, 2008) – reporting, analysing, decision-making, implementing, and follow-up – to convert the experience from the incident into learning in the organisation via company systems such as procedures, training, and information.

In the process industries, the handling of incidents has been a standard procedure for many decades. Numerous administrative systems for handling incidents exist, normally computer-based and many of them on a commercial basis. In the following we will use the term *incident learning (system)* to include all activities from reporting to implementation and follow-up of actions in connection with incidents.

However, several difficulties are associated with learning from incidents and a key question is: How much learning is accomplished as a result of reporting incidents, and especially in relation to the learning that could have been achieved if the full learning potential had been utilised? The authors have written about this in another paper (Jacobsson et al., 2011). There is also a need for a method by which one can assess the performance – the effectiveness – of learning in the different steps in the learning cycle. If weaknesses can be identified, one can direct attention and resources to those areas in need of improvement.

1.2 Objectives

The objectives of the work presented in this paper were to

- develop a method with high objectivity for assessing the effectiveness in the various steps of the "learning cycle", i.e. reporting, analysis, decision, implementation, and follow-up, yielding results suitable for
  - evaluation of areas of improvement in the incident handling as such, and
  - use in work for correlation with other safety parameters (from e.g. safety audits and safety climate inquiries).
- test the method by applying it in six organisations; and
- give examples of results from the application of the method and discuss those results.

The aim was further to base the method and its tools on the information normally given in incident learning systems of process industry companies. The focus of the method was on learning at the site. The method was intended to be used on a sample of the broad range of incidents normally seen in process industry companies.

The intention is that the method should be used primarily by companies in a self-assessment to find opportunities for improvement in learning from incidents. It is also the intention that the method could be used in research work aimed at finding correlations between learning from incidents and other safety parameters.

1.3 Theoretical foundations

The theoretical foundations for the method developed and applied in this study will be briefly presented here. In an earlier paper, the authors have written about the same topic, "Learning from incidents", but with focus on the learning product, the lessons learned. Most of the theory that was presented in that paper is applicable also in this paper, so the interested reader is advised to read there (Jacobsson et al., 2011).

In this paper we are mainly interested in the learning as a process (Argyris and Schön, 1996). With an effective learning process it is anticipated that we can arrive at learning products – lessons learned – which can be stored in the *organizational memory* and utilized by the members of the organization when relevant (Argyris and Schön, 1996). The organizational memory consists of many things, both what is held in the minds of the individual members and what is in the files of the organization. To exemplify the content of an organisational memory, one could use the structure of Nertney (1987) for *organisational readiness*: Personnel system (e.g. training), Plant/Equipment system (e.g. engineering standards) and Procedural system (e.g. operating instructions).

For the purpose of this work, the traditional sequential *accident model* view was chosen as the most practical, considering the material from the field objects of the study. The sequential model talks about *causes* (both *direct cause(s)* and *underlying causes*), *effects (consequences)* and *barriers*. In the current study underlying causes include *latent conditions* and *situational factors*. Sometimes there are defects in the barriers and an initiating event might propagate through all the barriers and result in a major consequence – illustrated in the Swiss cheese model by Reason (1997). Also Koornneef (2000) found that the adoption of a causal model was the most feasible approach in settings similar to the one for this study.

Most companies have a formal incident learning system where the information from incidents are handled and converted into individual and organisational learning as lessons learned for everybody concerned. This normally follows the steps in the learning cycle. The incident learning system is normally a part of a bigger information system for safety (S) and health (H), often also including environment (E). Kjellén (2000) describes a SHE information system, providing four basic functions for accident prevention: (i) reporting and collecting data, (ii) storing of data, (iii) information processing, and (iv) distributing information to decision-makers inside the organisation. In order to learn from incidents the different functions must include good information both regarding quality and detail but also regarding type of aspects around the incident such as work situation, competence, support level, procedures, stress level, technical status of equipment, and knowledge of process.

Obviously, there is a need to identify the incident as something worthy of reporting before the reporting can take place. This crucial point is discussed by Phimister et al. (2003). Many process industry companies have written definitions about what should be considered as a *reportable incident*, saying something like “All events leading to a personal injury or a release of dangerous substances, or events which could have led to such results should be reported”. Whether an incident gets identified as a reportable incident or not is normally decided by the employee closest to the incident, with the exception of those incidents where the effects are so obvious that they become generally known in the organisation, and will be picked up by managers. Ideally, all incidents with learning potential should be reported, leading to a low *threshold for reporting*. There will always be incidents with learning potential that are not reported in an enterprise. This “hidden number” should be as low as possible. In reality, it is necessary to strike a balance, and it is probably better for the total learning to have fewer reports properly handled, than many reports poorly handled (Rogers et al., 2007; Freitag and Hale, 2008).

The handling of an incident, reported in the incident learning system, should end with a lesson learned. Gordon (2008) says, “a lesson learned is an effective work practice or innovative approach that is captured and shared to promote repeat application or an adverse work practice or process that is captured and shared to avoid recurrence”. This definition will be used also for this study. Koornneef (2000) also writes that learning includes the effective implementation of solutions to the problem encountered. In practical terms this normally means converting the information and conclusions regarding the incident into knowledge and modifications of the artefacts of the company – e.g. operating instructions, and design of equipment – and sometimes also leads to changes in the behaviour and attitudes and values of the company. From a practical point of view lessons learned can be classified into *levels of learning* based on geographical application, degree of organisational learning, and the time aspect according to Jacobsson et al. (2010, 2011).

A *learning agency* is very important in organisational learning (Argyris and Schön, 1996), i.e. "a collection of people that makes decisions, delegates authority for action, and monitors membership, all on a continuing basis". The main function of the learning agency is to learn the lessons and retain both the experiences regarding implemented lessons, and the lessons themselves, on behalf of the organisation (Koornneef, 2000). In practice, it is often one single person who is in charge of most of the steps in the learning cycle, for the vast majority of incidents. Therefore, we prefer to use the term *learning agent* for those individuals. For the incident learning system to generate good lessons, we need learning agents, with sufficient competence and understanding of relevant safety aspects, in each step of the learning cycle.

2 Methods and material

2.1 Development of a method for assessing the effectiveness in the learning cycle

The principle followed in the development of the method was to build upon the traditional structure of the learning cycle with its five steps (in the primary loop for individual incidents) (Hale, 2008; Kjellén, 2000):

1. Reporting
2. Analysis
3. Decisions
4. Implementation
5. Follow-up

followed by the 6th step, the secondary loop for an aggregated sample of incidents.

The basic idea of the method was that when applying it on a number of individual incidents, and thereafter calculating a mean value for each step, it should yield representative measures of the effectiveness in the various steps of the learning cycle. The normal way of operating incident learning systems in process industries, is to first let the people who have been involved in the incident give a report (normally in writing), which is then directed to the nearest line manager who sees to it that the incident is analysed and eventually that appropriate measures are taken. Other functions of the company (e.g. the safety manager and the safety committee as well as higher management) can also become involved, especially in more serious cases. Normally, every single incident reported in the system is handled in this way. Therefore, our method was built upon the idea of assessing all reported incidents to be able to evaluate the effectiveness of the process of handling incidents in the incident learning system.

A basic assumption in the work was that in order to generate a good and complete lesson learned from an incident, each step in the learning cycle must be treated with care and comprehensiveness. The treatment in each step must contain the relevant and adequate information that allows the learning process to proceed via the next steps into a full lesson learned, to finally be incorporated in the organisational memory. Therefore, in the method, various types of information that were considered relevant for such a process to be successful were included for each step in the learning cycle.

2.1.1 Framework of method

The framework for the method is illustrated in Figure 1, which depicts how the information from incidents is picked up and reported into the incident learning system, and via the 1st loop

(Reporting –> Follow-up) and the 2nd loop (Compiling –> Follow-up) is converted into lessons learned and included in the organisational memory with the assistance of learning agents.

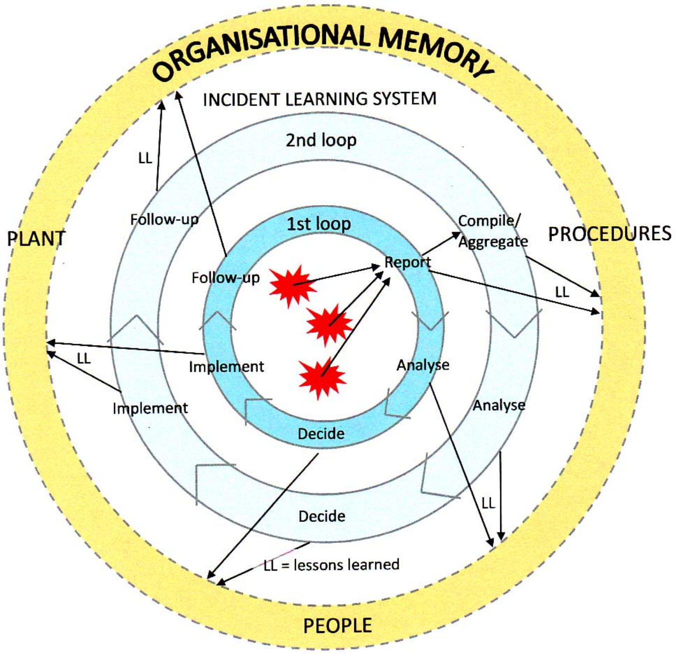

Figure 1. The learning cycle for incidents.

The method for assessing the effectiveness of the incident learning system was built upon an analysis of the effectiveness of each individual step in the learning cycle as previously defined. In order to obtain results from the method that could be used for correlation with other safety parameters using statistical methods it was decided to express the results from the method in numerical terms where possible.

The method was built on the following four components:

- the steps in the learning cycle;
- elements, which we will call dimensions, in the various steps;
- aspects of each dimension; and
- templates with scales for assessing numerical values for the various dimensions/aspects as a measure of the effectiveness in each step.

The assessment was based on the following four basic dimensions, which in turn contain several aspects that should be covered for full understanding and handling of each step.

1. Scope (the aspects vary depending on the step; see example for the reporting step in Table 1);
2. Quality (completeness of details and depth in the treatment of the aspects under Scope);
3. Time (time from one step to the next); and
4. Information (dissemination of information in the organisation).

To be able to analyse an incident and finally arrive at good conclusions about what caused it or could explain it, and to make good recommendations of measures for keeping similar events from happening again, one would need a description of the event with relevant data of the circumstances. The data that would be needed can vary depending on the incident. However, it is proposed to include the following dimensions as a standard. The first dimension, the *Scope* of the Reporting step, contains the *Aspects* indicated at the bottom of Table 1 with e.g. description of the event, the work situation, stress level etc. (the list is not exhaustive). The second dimension, the *Quality* of the Reporting step, contains the *Aspects* of completeness of details and depth in the descriptions of the aspects under Scope. The third dimension, the *Time* of the Reporting step, contains an assessment of the *Aspect* of promptness of acting, in this case the time from the incident occurrence to reporting the incident. The fourth dimension, the *Information* in the Reporting step, contains the *Aspect* of informing in the organisation, in this case the information immediately after the incident to relevant personnel. The other steps in the method were treated similarly. Dimensions and aspects that the authors deemed relevant were included (see Appendix).

2.1.2 Rating system

To be able to express the effectiveness of handling the incidents in the various steps numerically, a rating system was created. The different aspects for each dimension were described in a semi-quantitative way on a scale (between 0 and 10) to be able to measure the effectiveness as objectively as possible. The requirements to fulfil a certain "score" were described by using some guiding words for four levels on the 0 – 10-point scale – 2 (Poor), 4 (Fair), 7 (Good) and 10 (Excellent). Besides these four dimensions, other dimensions were also evaluated for the different steps, although they were not used in the calculation of the effectiveness as such (with the exception in the Decision step), but merely as possible explanations for the results. One such dimension is "Who" (who is performing the activities in the step). As an example, Table 1 shows the reporting step assessment tool.

Table 1. Assessment tool for the reporting step.

1 Reporting

		2 (Poor)	**4 (Fair)**	**7 (Good)**	**10 (Excellent)**
1.1	Scope	Only a few of the relevant aspects (see below) covered. Poorly structured.	Most relevant aspects (see below) covered, but not too well structured.	All types of relevant aspects (see below) covered.	As for 7 + additional aspects when this would add to the usefulness of the report.
1.2	Quality	Relevant info on many of the aspects is missing.	Only most obvious facts reported. Difficult to make an in-depth analysis of causes etc.	All aspects under scope covered, but some aspects not in full detail, requiring additional information.	All aspects under scope covered in depth, making a thorough analysis possible.
1.3	Time	> 1 week	A few days	Same day/shift	Immediately (hour(s))
1.4	Information	Virtually none.	Individual reading (on intranet or similar).	As for 4 + meetings.	As for 7 + targeted info to selected personnel.
1.5	Who (is reporting)	An administrator only, not directly involved in the incident.	Directly involved person(s) + safety representative. Also contractors covered.	Directly involved person(s) + safety representative + supervisor.	As for 7 + specially trained reporter.

Scope includes aspects like the following: Description of the event; Work situation; Stress level; Competence of person(s) involved; Support by instructions etc; Type of equipment/item involved; Location; Date and time; Meteorological condition; Direct cause and contributing causes; Damage (personnel injuries, material, fire, environmental, product loss); Mitigation actions; Immediate suggestions; Name of reporter.
Quality is a measure of the details of the reporting of the various aspects under Scope.
Time is the elapsed time from the time of the event to when the report was written.
Information is a measure of the immediate dissemination of information of the event directly in connection with the event, especially to concerned employee(s).
Who (is reporting) signifies the person actually writing the report.

Similar tools were constructed for all the steps in the learning cycle (see Appendix).

One important issue to take into consideration was the treatment of the incidents on an aggregated basis, the 2nd loop. This needed a specific assessment. Here a similar tool was used as for the individual incidents according to the primary cycle, but in a more general assessment (see Appendix). The tool treats the secondary loop as one step, as is actually found to be the case in reality in most companies. Ideally, this tool should be applied to the data given in the incident reporting system, but this data is often incomplete and has to be supplemented with interviews of key personnel to arrive at a good assessment. Lindberg et al. (2010) have developed a model for experience feedback, the CHAIN model, where they discuss the issue of selecting incidents for investigation, i.e. similar to the 2nd loop.

The proposed scale with its descriptive wording is meant to guide the assessor in the rating of the individual incident reports. In an assessment of an incident, the description in the actual incident report is compared with the description of the requirements for the rating levels, and the one best matching the actual description is chosen. Interpolation between the levels should be done when relevant.

After assessment of each dimension in every step of the learning cycle, one would have a set of data that could be used for calculation of mean values of the effectiveness of each step in the learning cycle for a particular incident report.

2.1.3 Weighting the dimensions for importance

One could apply the method without attempting any weighting of the importance of the various dimensions. However, in reality some dimensions are probably more important than others for the learning process, especially the dimensions containing many aspects, i.e. Scope and Quality. Therefore, in this study the various dimensions were weighted, and the following way to obtain a "fair" measure of the effectiveness was proposed (in the Decision step a somewhat different distribution was proposed):

- Scope 35 %
- Quality 35 %
- Time 15 %
- Information dissemination 15 %

In the expert judgments of the method employed in the study, five experts were asked to give weight factors for the dimensions; the result is presented below. Users of the tools might choose other weighting percentages. Initially, the same weighting in all steps was proposed, although minor changes could certainly be argued for.

2.2 Expert judgements of the method

The method for assessing the effectiveness of the six steps in the learning cycle was evaluated by five experts using a short questionnaire where the statements were answered using a six-point scale (0 = disagree completely, 5 = agree completely). The experts were also asked to indicate their opinion on how important each dimension in the method is by giving weight factors in percent for the dimensions in the Reporting and Analysis steps respectively. The experts consisted of members of the safety committee of the Swedish Plastics and Chemicals Federation, where the members are typically safety managers from Swedish chemical companies.

2.3 Test of the method

The developed method and its tools presented above were tested by application at six plants in the Swedish process industry.

2.3.1 Material
Some key data of the companies (sites) where the method was tested are presented in Table 2. The authors have judged the risk potential for the six plants.

Table 2. Key data for companies in the study.

Company	Type of industry	Size of site, persons (in technical jobs)	Risk potential	Comments
A	Petrochemicals	360	High	Part of major multi-national corporation
B	Chemicals, general	115	High	Part of major multi-national corporation
C	Food and drug	45	Medium	National 1-site company
D	Pulp and paper	650	High	National multi-site corporation
E	Energy production	100	Medium	National 1-site company
F	Food and drug	50	Medium to high	Part of major multi-national corporation

All the organisations have formal incident learning systems, all of which are computer-based. For analyses of the incidents, two years of reports (2007-2008) were obtained directly from the incident learning systems for companies A – E. For company F, which had comparatively few incident reports, we selected a longer sampling period (3½ years, from 2007 to mid 2010). A total of more than 1900 reports were analysed. When relevant extra material existed, e.g. root cause analysis, this was also obtained.

2.3.2 Safety audit for supportive information
In addition to the incident analysis study, a general safety audit, containing approximately 90 elements, was also performed at all sites in which a representative selection (from top management to workers) of 15-25 % of the personnel was interviewed, one hour with each person. During the interviews also the incident learning system was discussed as well as the issue about other mechanisms for learning from incidents. Moreover, special interviews were conducted with those persons responsible for the incident learning system, especially to gain information about performance of the 2nd loop.

3 Results

3.1 The method and the tools

The main results of the study are the method and the tools as presented above under the section Methods, namely

- A method for assessing the effectiveness in the steps of the learning cycle, with tools for each step of the cycle.

3.2 Evaluation of the method

The researchers could establish during the practical application of the method
that it worked very well and satisfactorily in assessing the effectiveness of the steps in the learning cycle. It worked as such in all steps, but because of lack of sufficiently detailed information in steps 4 (Implementation) and 5 (Follow-up), greater uncertainty appeared in those. A potential assessor would have to be reasonably familiar with incident learning systems and with general safety work in order to be able to assess the effectiveness.

Reporting: The assessment of the Reporting step was mostly fairly simple and unambiguous to perform for all companies based on the information in the reports. A total of 7 % of the reports were of low quality and could not be assessed.
Analysis: The Analysis step was also rather straightforward but somewhat more difficult to perform because of poorer information in the incident reports. A few additional percent of the total material did not contain enough information for assessment of a reasonably objective view.
Decision: The Decision step was about equivalent with step 2 to perform, although sometimes there was no good distinction in the information between analysis and decision.
Implementation: The Implementation step was sometimes a bit difficult to assess because of poor information.
Follow-up: The Follow-up step was very difficult to assess for some companies because of lack of information.
The 2nd loop: All six companies in our study had moderate to low activities in this step. Therefore, the evaluation of the applicability of this step of the method is weaker than for the other steps. However, based on the method it could be assessed that none of the companies had any activity in this 2nd loop, which would indicate significantly different effectiveness than shown in the results from steps one to five. The assessment of this 2nd loop merely confirmed the results obtained by the analysis of the first loop.

All in all, the developed method with its tools appears to be very useful in practice. The method has consistency, which is based on the fact that the method and tools worked well when applied in all six companies despite six different incident learning systems and other differences. Additions and refinements to the method, e.g. in evaluating the influence of the incidents not reported, could make it even more useful. We conclude that the method could be used to assess the effectiveness of the steps in the learning cycle in order to find areas for improvement.

The method was considered to yield reasonably good assessments for each individual incident. However, as the quality of handling incidents will vary from case to case, it was concluded that a larger number of incidents was necessary to be able to conclude something in general about the effectiveness of the learning cycle. For instance, the scores obtained from application of the tool in Table 1 could be used for calculating average scores for the reporting step for all the incidents for a certain time period. Sets of values could then be used for comparison between time periods for a certain company or between companies.

The results in terms of figures for the effectiveness in the various steps of the learning cycle would be suitable to use for correlation with other safety parameters.

3.3 Results of the application in six companies in the process industry

3.3.1 Effectiveness in the steps of the learning cycle

The method of assessing the effectiveness of the steps in the learning cycle was applied in the six companies. The results from the assessment of steps 1 – 5 (1st loop), using all the incident reports obtained for a period of two years (company F 3.5 years), are presented in Table 3.

Table 3. Effectiveness in steps of the learning cycle for the six companies, based on incident reports from 2007 and 2008 respectively (Company F: 2007-mid 2010).

Company		**A**		**B**		**C**		**D**		**E**		**F**
	Weight factor	**-07**	**-08**	**-07**	**-08**	**-07**	**-08**	**-07**	**-08**	**-07**	**-08**	**-07-10**
Report		**4.4**	**4.5**	**4.0**	**4.9**	**4.4**	**5.0**	**3.3**	**3.8**	**4.0**	**3.7**	**7.3**
Scope	0.35	3.91	4.16	3.39	4.43	4.08	4.63	2.71	2.91	3.75	3.00	6.96
Quality	0.35	4.15	4.19	3.72	4.76	4.15	4.74	3.78	4.60	4.00	3.80	7.00
Time	0.15	7.37	7.39	7.00	6.87	5.54	6.32	5.00	5.19	4.87	5.70	7.80
Info	0.15	3.36	3.41	3.06	4.23	4.77	5.00	2.04	2.55	3.75	3.10	7.96
Analysis		**4.5**	**4.5**	**4.2**	**4.9**	**4.4**	**5.0**	**3.0**	**3.8**	**2.8**	**4.4**	**7.5**
Scope	0.35	4.07	4.23	3.69	4.52	3.85	4.42	2.39	2.74	3.25	3.50	6.87
Quality	0.35	4.09	4.29	3.88	4.64	3.77	4.63	3.15	4.52	3.63	4.60	7.07
Time	0.15	7.10	6.78	6.98	6.82	7.00	7.37	5.36	5.92	4.25	6.30	9.78
Info	0.15	3.56	3.59	3.08	4.33	4.23	4.79	2.00	2.59	3.75	4.00	7.84
Decision		**5.1**	**5.6**	**4.9**	**5.8**	**4.9**	**5.6**	**3.3**	**4.4**	**4.3**	**4.9**	**8.1**
Scope	0.25	4.35	4.91	4.43	5.54	4.00	4.42	2.23	2.84	3.38	3.20	7.22
Quality	0.25	4.35	5.03	4.23	5.23	3.92	4.68	2.87	4.61	4.00	4.40	7.51
Extent	0.20	6.39	6.99	6.41	6.61	6.31	6.89	4.90	5.84	5.38	6.80	9.00
Time	0.15	6.87	6.90	6.82	6.86	6.15	7.74	4.75	6.03	4.75	6.80	9.42
Info	0.15	3.88	4.37	3.08	4.75	4.54	5.00	2.36	2.98	4.13	4.00	7.78
Implement		**5.5**	**6.1**	**5.2**	**5.7**	**6.0**	**6.3**	*****	*****	**4.4**	**4.4**	**8.7**
Scope	0.35	6.11	6.73	6.20	5.70	6.38	6.68			4.75	3.30	9.95
Quality	0.35	5.45	5.81	4.47	5.40	6.00	6.16			4.25	4.60	7.72
Time	0.15	5.86	6.67	6.83	6.65	6.62	6.74			4.88	6.60	9.60
Info	0.15	4.02	4.76	3.18	5.29	4.54	5.00			3.38	4.30	7.23

*No result for the Implementation step is included for company D due to poor data.

Some general comments on the results can be made. Company F stands out with remarkably higher values than the other companies in all the steps of the learning cycle. In the case of company F, the additional safety audit revealed a very strong safety culture, high management commitment and effective systems for incident reporting, which could all probably contribute to the high effectiveness in the learning cycle. For all the other companies, the effectiveness in the learning cycle is in general “fair” or at best “good” in some respects. Company D trails in most respects. In general the dissemination of information about the incidents appears to be an especially weak point, whereas the timing dimension seems to be reasonably good. The important analysis step seems to be rather weak for all companies, except for company F.

Some differences between the years seem to be significant: Company B, company C and company D have all improved effectiveness in all steps from 2007 to 2008. For company B the improvement coincides with a change in the organisation when a specific safety coordinator was appointed. For company D the improvement coincides with a very clear change in safety commitment from the site manager, with a focus on incident reporting. The improvement for company C cannot be easily explained.

No figures for the Follow-up step are included in Table 3 because of poor data.

The assessment of the learning in the 2nd loop was primarily based on information gathered during material sampling and interviews, in particular with those people responsible for the incident learning systems, and during interviews in the safety audits. The results are presented in Table 4. No company was very strong in the 2nd loop – some in fact were rather weak.

The figures reflect the 2008-2009 incident reports, except for company F, which reflect the 2007 – mid 2010 incident reports.

Table 4. Effectiveness in the 2nd loop of the learning cycle for the six companies in the study.

Company		**A**	**B**	**C**	**D**	**E**	**F**
2nd loop evaluation	**Weight factor**	**6.0**	**5.7**	**2.4**	**3.2**	**2.0**	**6.2**
Scope	0.35	7	6	2	3	2	6
Quality	0.35	5	5	3	3	2	7
Time	0.15	7	7	2	4	2	6
Info	0.15	5	5	2	3	2	5

3.4 Results from the expert judgments of the method

The dimensions and aspects included in the method for assessing the six steps of the learning cycle were evaluated by five experts. For each of the steps, the experts were to agree/disagree with two statements on a scale from 0 – 5. The statements for each step and the average values of the experts' judgments were the following:
'The dimensions and aspects used for the _____ step cover all issues for a complete and relevant evaluation of this step.'
Expert judgments: Reporting (5), Analysis (5), Decisions (4.6), Implementation (5), Follow-up (4.8), 2nd loop (4.4).
'The key phrases for the 2, 4, 7 and 10 rating levels describe a relevant and fair evaluation of the issues.'
Expert judgments: Reporting (4), Analysis (4), Decisions (4), Implementation (4), Follow-up (4.2), 2nd loop (4.6).

The experts were also asked to give comments concerning the dimensions and aspects. Many valuable comments were given, but none of such gravity that they would greatly affect the content of the method and they will therefore not be presented in this paper.

3.4.1 Weight factors

As stated above, some of the dimensions in each step are probably more important than others for the learning process, and therefore a weight factor is attached to the dimensions when calculating the results in an evaluation. The experts were asked to indicate how important they believed the dimensions in the Reporting and Analysis steps were by assigning weight factors in percent. In Table 5 the weight factors suggested for the method are compared with the range and average weight factors suggested by the five experts.

Table 5. Suggested weight factors and experts' weight factors (range and mean values) for the dimensions in the Reporting and Analysis steps in the learning cycle.

Dimension	Suggested weight factors (%)	Expert weight factors (%)			
		Reporting		Analysis	
		Range	Mean	Range	Mean
Scope	35	20-40	28	30	30
Quality	35	10-30	22	30-40	32
Time	15	10-40	26	10-20	14
Information	15	20-30	24	20-30	24

4 Discussion

4.1 Usefulness of the method

We found that the method presented can be very useful for assessing the effectiveness of the learning cycle in general. The uniqueness of the method is

- the systematic assessment of the effectiveness in all steps of the learning cycle, yielding semi-quantitative measures that can be used for improvement and for benchmarking.

We anticipate the main usefulness of the method to be for individual companies to evaluate their effectiveness in learning from incidents. The method is primarily intended for use at a specific site, but it can also be used for comparing various departments on a site or various sites within the same corporation. It could also be used for comparing various enterprises and, via the results from the assessment of the effectiveness in the learning cycle together with other information about the enterprises, give insight into what influences their learning from incidents. The authors have already used the results in this way with promising results.

We are aware that the rating levels used are to some extent subjectively chosen, and other opinions about appropriate levels could be held by other people. However, we claim that the method could be applied in real cases with valuable results.

The method is intended for use by safety professionals both in industry and in academia. The method could be used not only in the process industry but also in various other businesses with similar types of incident learning systems.

Based on the experts' judgments, the issue of weighting the dimensions of the various steps is apparently not so easy. There was reasonable agreement between the weighting factors suggested by the authors and the experts´ opinions, but there were also wide variations. A larger expert panel is probably needed to arrive at a firmer opinion. Different values should probably also be used in the different steps.

By choosing a rather homogenous group – six companies within the process industry – we believe that results emerging from the application of the method could form reference material with typical results from this industry type. The results could also be used for comparison of companies regarding the effectiveness in learning from incidents.

4.2 Possible explanations between variations in results between the companies

There are several possible explanations of the results from application of the method on these six companies. However, we believe the following findings can be concluded. The importance of having a learning agent, or a prime mover for safety, in the organisation is rather evident from our results. In company F, which is outstanding in the learning process, this is very clear. There is also a very strong commitment from top management in this company. The reason for company C coming out relatively well, we would ascribe to the small size and the high commitment from top management as well as the departmental resources for safety. Also in company B, there are very clear focal points for learning from incidents in terms of very committed persons both for administrating the incident learning system and for working with these questions on a departmental level.

Company A has good resources for administrating the system and for departmental resources, but here there does not seem to be the same support from top management, which could explain why this company is not as good as company B.

The poor results of company D are ascribed to the lack of competence and resources for learning agent and to the immature safety culture.

One can also see variations in the reporting and the learning from incidents between departments within the companies. This could also be ascribed to differences in resources and learning agents.

The importance of having a formal system for incident learning is often stressed. We agree that it is important to have a good system, which drives the process and the necessary activities in the learning cycle. However, there is no evidence from our results that a more elaborate system would result in better learning from incidents.

4.3 Further research

The method as described in this paper is already a useful aid for assessment of the effectiveness in the learning cycle. However, there are opportunities to refine it further. In particular, there is a need to further test the tool for taking the 2nd loop work into account. The issue of how to assign weighting factors to the dimensions in the various steps is another area for improvement of the method. Yet another interesting project would be to investigate how one would best select those incidents that are worth analysing and treating in detail to learn the lessons, without having to deal with all reported incidents in detail. Finally, it would be of great interest to see which general factors in a company influence learning from incidents, i.e. which are favourable and which are obstructive for good learning. One way of doing this could be to link the results from safety audits and safety culture measurements with those from the analysis of learning from incidents, as described above.

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Appendix
Tools for ASSESSMENT of LEARNING from INCIDENTS regarding the INDIVIDUAL STEPS in the LEARNING CYCLE

1 Reporting

		2 (Poor)	4 (Fair)	7 (Good)	10 (Excellent)
1.1	Scope	Only a few of the relevant aspects (see below) covered. Poorly structured.	Most relevant aspects (see below) covered, but not too well structured.	All types of relevant aspects (see below) covered.	As for 7 + additional aspects when this would add to the usefulness of the report.
1.2	Quality	Relevant info on many of the aspects is missing.	Only most obvious facts reported. Difficult to make an in-depth analysis of causes etc.	All aspects under scope covered, but some aspects not in full detail, requiring further more information.	All aspects under scope covered in depth, making a thorough analysis possible.
1.3	Time	> 1 week	A few days	Same day/shift	Immediately (hour(s))
1.4	Information	Virtually none.	Individual reading (on intranet or similar).	As for 4 + meetings.	As for 7 + targeted info to selected personnel.
1.5	Who (is reporting)	An administrator only, not directly involved in the incident.	Directly involved person(s) + safety representative. Also contractors covered.	Directly involved person(s) + safety representative + supervisor.	As for 7 + specially trained reporter.

Scope includes aspects like the following: Description of the event; Work situation; Stress level; Competence of person(s) involved; Support by instructions etc; Type of equipment/item involved; Location; Date and time; Meteorological condition, Direct cause and contributing causes, Damages (personnel injuries, material, fire, environmental, product loss); Mitigation actions; Immediate suggestions; Name of reporter.
Quality is a measure of the details of the reporting of the various aspects under Scope.
Time is the elapsed time from the time of the event to when the report was written.
Information is a measure of the immediate spreading of information of the event directly in connection with the event, especially to concerned employee(s)
Who (is reporting) signifies the person actually writing the report.

2 Analysis (and recommendations)

		2 (Poor)	4 (Fair)	7 (Good)	10 (Excellent)
2.1	Scope	Only aspects dealt with are “operator error” and “technical failure” – no more.	Technical aspects, broadly + some organisational aspects.	Technical + organisational aspects reasonably covered.	“All” aspects covered:
2.2	Quality	Analysis shallow. Stopping at first direct cause, normally operator error or technical failure. Very local view. Recommendations are only to prevent exactly the same incident to happen at the same place.	Analysis somewhat deeper than for 2, including some aspects of procedures and training etc. Mostly rather local view.	Analysis deeply into direct causes and also underlying causes. Analysis includes design, procedures, training etc. Recommendations are on “process unit” level.	Analysis deeply into direct causes, various underlying causes, situational factors etc. Analysis includes general design, general procedures and safety management system. Recommendations are broad; “site” level.
2.3	Time	> 1 year	3-6 months	2-3 weeks	< 1 week
2.4	Information	Virtually none.	Individual reading (on intranet or similar).	As for 4 + meetings.	As for 7 + targeted info to selected personnel.
2.5	Who (is analysing)	Only directly involved person. Little time.	Supervisor/department manager + safety representative, but none with any particular training in analysis methods. Limited time.	Internal, but independent person, with some training in incident analysis. Reasonable time + assistance from persons = for 4.	Highly competent personnel resources with broad experience. Skilled in investigation methods. Ample time to do the job. Use of external specialists on occasions + assistance from persons = for 7.

Scope includes aspects like the following: Personal shortcomings – Technical shortcomings – Design – Training – Procedures – Ergonomic factors – Situational factors – Maintenance/inspections – Other underlying causes – Managerial systems – Safety culture etc.
Quality is a measure of the details regarding deepness and width of the analysis of the various technical and organisational aspects under Scope.
Time is the elapsed time from the time of the event to when the analysis is ready.
Information is a measure of the spreading of information in the organisation of the results of the analysis.
Who (is analysing) signifies the person(s) actually undertaking the analysis including resources (personnel, competence, time).

3 Decision

		2 (Poor)	4 (Fair)	7 (Good)	10 (Excellent)
3.1	Scope	Decisions limited to repair and/or simple procedure change only.	Decisions limited to a few number of aspects, mostly technical and/or procedures. No organisational or administrative aspects.	Most aspects considered.	"All" aspects considered seriously: as for 7 + • Managerial systems • Change in organisation • Safety culture etc.
3.2	Quality	Decision "shallow". Only minor "cosmetic" changes to procedures or technical installations. Actions are only to prevent exactly the same incident to happen at the same place.	Decision somewhat deeper than for 2, including some aspects of procedures and training etc. Mostly rather local view.	Well worked out decisions based on the conclusions and recommendations from the analysis step. Considerations to underlying causes. Decision includes design, procedures, training aspects etc. Decision is on "process unit" level.	As for 7 + additional decisions on a higher managerial level concerning the management system and safety culture. Decisions are broad, on a "site" level.
3.3	Extent, to which decision follow analysis and recommendations	Conclusions and recommendations followed only to a very small extent.	Conclusions and recommendations followed to a reasonable extent.	Most conclusions and recommendations followed.	All conclusions and recommendations followed closely + extended decisions on a higher organisational level.
3.4	Time	> 3 months	1 month	1-2 weeks	< 2 days
3.5	Information	Virtually none.	Individual reading (on intranet or similar).	As for 4 + meetings.	As for 7 + targeted info to selected personnel.
3.6	Who (is deciding),	Low, unclear level	Supervisor level	Process unit manager level	Site manager level

Scope includes aspects like the following, including the relevance of them: Technical – Design – Training – Ergonomics – Maintenance/inspections – Other underlying causes – Managerial systems – Safety culture etc.
Quality is a measure of the details regarding deepness and width of the decisions regarding the various technical and organisational aspects under Scope.
Time is the elapsed time from the time of the completed analysis to when the decision is taken.
Information is a measure of the spreading of information in the organisation of the results of the decision.
Who (is deciding) signifies the person(s) or the organisational level actually undertaking the decision including resources (personnel, competence, time). The basis for evaluation of this point is "relevant decision level" compared to the learning potential of the incident.

4 Implementation

		2 (Poor)	4 (Fair)	7 (Good)	10 (Excellent)
4.1	Scope	Only a few decisions implemented.	Half of decisions actually implemented.	Almost all decisions implemented.	All decisions fully implemented.
4.2	Quality	Low (e.g. quality of procedures, training, maintenance/inspection activities).	Medium.	High	Very high
4.3	Time	Long.	Medium.	Short	Very short
4.4	Information	Virtually none.	Individual reading (on intranet or similar).	As for 4 + meetings.	As for 7 + targeted info to selected personnel.
4.5	Who (is implementing)	Low, unclear level.	Supervisor level.	Process unit manager level	Site manager level
4.6	Resources	Poor; severely limiting the implementation.	Fair; limiting the implementation to some degree.	Good; not limiting the implementation in practice.	"Unlimited"

Scope is here meant to be the extent of the actions actually implemented, compared with the decisions.
Quality is a measure of the details regarding deepness and width of the actions actually implemented.
Time is the elapsed time from the decision to the implementation. The time depends on the topic.
Information is a measure of the spreading of information in the organisation of the results of the implementation.
Who (is implementing) signifies the person(s) or the organisational level actually implementing the actions, including resources (personnel, competence, time). The basis for evaluation of this point is "relevant implementation level" compared to the learning potential of the incident.
Resources is a measure of the resources available (or possibly limiting) the wanted actions to be implemented.

5 Follow-up (Control, check)

		2 (Poor)	4 (Fair)	7 (Good)	10 (Excellent)
5.1	Scope (complete-ness)	Virtually no follow-up.	Half of decisions followed-up.	Almost all decisions followed-up.	All decisions followed-up.
5.2	Quality	Very shallow follow-up; no action if there is deviation from decision intent.	Some limited follow-up; limited action if there is deviation from decision intent.	Thorough follow-up; action if there is deviation from decision intent.	Very thorough follow-up; prompt action if there is deviation from decision intent.
5.3	Time	> 2 years	1 year	3-6 months	2 weeks – 2 months
5.4	Information (feed-back) in organisation	Virtually none.	Individual reading (on intranet or similar).	As for 4 + meetings.	As for 7 + targeted info to selected personnel.
5.5	Who (follow-up)	No one dedicated for follow-up.	Respective line manager.	Line manager + independent internal person (when relevant).	As for 7 + higher management (when relevant).
5.6	Resources	Poor; severely limiting the follow-up.	Fair; limiting the follow-up to some degree.	Good; not limiting the follow-up in practice.	“Unlimited”
5.7	Actual result (“Did it work?”)	Only to a minor extent and/or with poor quality.	To some extent and with reasonable quality.	To a major extent and with good quality.	To full extent and with highest quality.

Scope is here meant to be the extent of aspects being followed-up.
Quality is a measure of the details regarding deepness and width of the follow-up.
Time is the elapsed time from the implementation to the follow-up. The time depends on the topic.
Information is a measure of the spreading of information in the organisation of the results of the follow-up.
Who (follow-up) signifies the person(s) or the organisational level actually making the follow-up.
Resources is a measure of the resources available for follow-up.
Actual result is a measure of how well the implemented action works in relation to the intension.

6 2nd loop on aggregated incidents

		2 (Poor)	4 (Fair)	7 (Good)	10 (Excellent)
6.1	Scope (complete-ness)	Only very limited statistics and trends of - types of events - direct causes	Some statistics and trends of - types of events. - direct causes - action implemented	Statistics and trends of - types of events - direct/indirect causes - action implemented - degree of success	As for 7 + emphasise on common causes, organisational points.
6.2	Quality	Only very limited analysis of underlying causes; very limited actions.	Some analysis of underlying causes and with reasonable actions accordingly.	Deep analysis of underlying causes, also including some safety management system aspects, and with actions accordingly.	As for 7 + analysis of impact on safety management system and safety culture aspects + strong action of top management if actions implemented have not been successful.
6.3	Time (from incident to evaluation)	Seldom and at random.	Sometimes, but not scheduled, evaluation of agglomerated results; a year after particular events.	Once per year for evaluation of agglomerated results and 3 months after particular events.	4 times per year for evaluation of agglomerated results and 1-2 months after particular events.
6.4	Information (feed-back) in organis-ation, especially to concerned employee(s)	Virtually none.	Individual reading (on intranet or similar).	As for 4 + meetings.	As for 7 + targeted info to selected personnel.
6.5	Who (organisatio nal level)	No one dedicated.	Some evaluation performed by the safety committee.	Top management + internal specialist.	As for 7 + independent external specialist.

II

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Method for evaluating learning from incidents using the idea of "level of learning"

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A B S T R A C T

Learning from incidents is considered a very important source for learning and improving safety in the process industries. However, the effectiveness of learning from reported incidents can often be questioned. Therefore, there is a need to be able to evaluate the effectiveness of learning from incidents, and for that purpose we need methods and tools. In this paper, a method is described for evaluating the effectiveness of learning, based on the idea of "level of learning" of the lessons learned. The level of learning is expressed in terms of how broadly the lesson learned is applied geographically, how much organizational learning is involved and how long-lasting the effect of learning is. In the 6-step method, the incidents reported in a typical incident learning system are evaluated both for the actual and the potential level of learning in a semi-quantitative way with different tools. The method was applied in six process industries on a large number of incidents. The method was found to be very useful and to give insights of aspects that influence the learning from incidents.

1. Introduction

1.1. Background

Incidents are defined in this paper as "deviating events which differ from normal conditions and which could have adverse effects on safety, health or environment" (OECD, 2008).

With learning from incidents we here mean the capability of an organization to extract experiences from incidents that happen in the organization and convert them into measures and activities which will help in avoiding future incidents and in improving safety overall. There is currently a great deal of interest in using incidents for learning in many sectors, such as the aviation industry, medical care and the process industry. One would obviously like the process of learning from incidents to be as effective as possible and to yield end products which are effective in preventing further incidents. However, the effectiveness of learning from incidents can often be questioned. In many cases the learning process stops at the reporting step. The analysis of the incident reports and the following implementation of appropriate measures and improvements are often ineffective and the full lessons are therefore seldom learned. Accident investigations often stop at the events close to the accident, which usually concern only the behavior of the hardware and of the operators/workforce directly concerned with carrying out the activity (Hale, 2008). The goal should be to achieve organizational learning, both single-loop and double-loop learning (Argyris & Schön, 1996). Incident analyses need to be so deep that latent conditions (Reason, 1997) and situational factors that triggered the incident are revealed.

Major accidents sometimes occur in high-risk process industries. They are normally dealt within thorough accident investigations including real root cause analysis, resulting in far-reaching actions to avoid a recurrence of the event. However, such major events are very rare, which means there is only seldom an opportunity to learn. However, often there are numerous events with minor consequences or no consequences at all, which, if analyzed properly, could reveal weaknesses in the organization or the equipment and processes, the same weaknesses that, under other circumstances, could lead to a serious accident. These are the events that the process industry must use and learn from to avoid both minor incidents and major accidents. There is also a high potential in the process industry for traditional occupational health accidents/incidents that could have serious consequences for individual employees.

The reporting and further handling of deviations from normal operation has been a standard procedure in the process industries for many decades. Numerous administrative systems are in use for reporting and dealing with incidents, many of them on a commercial basis. Nowadays, most of these systems are computer-based, and can be used to track incidents from reporting to final closure of the case, and for various analyses, including statistical analyses on aggregated events.

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Related to the efforts of reporting and learning from incidents, is the issue of evaluating the effectiveness of such efforts. In an ongoing research project 'Learning from incidents for improving safety within dangerous operations', funded by the Swedish Civil Contingencies Agency, the aim is to develop tools for evaluating the effectiveness of learning from incident learning systems. In these evaluations the term incident learning system includes all activities, from reporting an incident, to implementation and follow-up of measures designed to prevent such incidents in the future. In the research project several ways to approach the issue of the effectiveness of learning from incidents are used. One approach is to focus on the measures that are taken as a result of the incident – the lessons learned, asking e.g.

- What are the measures actually implemented?
- What measures could be taken if the organization would use the full potential for learning?
- How does the actual learning compare with the potential learning?

In this paper we will focus on the above bullets, i.e. the product of the learning – the lesson learned. The paper presents the development of a method for evaluation of the lessons learned expressed in "level of learning". If such levels of learning can be evaluated and possible weaknesses can be identified, the organization can direct its efforts to those areas in need of improvement. Furthermore, it would be valuable to obtain measures of the learning that could be used in work directed at finding possible correlations between the learning from incidents and other safety issues, such as for instance results from safety audits and safety climate evaluations.

1.2. The aim of this paper

Good organizational learning is not always easy to achieve, and it is therefore vital to know how effective the learning from incidents is in an organization. The aim of this paper is to present a method for the evaluation of the effectiveness of learning from incidents in an organization, based on the idea of level of learning.

1.2.1. Study objectives

The objectives of the work presented in this paper were:

- To develop a method for the evaluation of the effectiveness of learning from incidents in the process industry, based on an evaluation of the level of learning.
- To test the method by applying it in six organizations in the Swedish process industry for the evaluation of actual learning compared with potential learning.

The intention is that the method should be used primarily by companies in a self-assessment to find opportunities for improvement in the learning from incidents. It is also the intention that the method could be used in research work aimed at finding correlations between learning from incidents and other safety parameters.

The collection of data in the six process industry companies could also be a first step in establishing reference data concerning levels of learning in the Swedish process industry.

1.3. Theoretical foundations

The theoretical foundations of the method developed and used in this study are described below.

1.3.1. Organizational learning

Most learning starts as *individual learning* before it can become *organizational learning*. In the development of the method the primary interest is in organizational learning. Learning from incidents means gathering information from the individual(s) involved in an incident and from the incident itself, and converting it into general knowledge for the whole organization, or at least for those people for whom the knowledge is important. Argyris and Schön (1996) talk about learning as both a *product* and a *process*. Here, the focus is on treating learning from incidents mainly as a product.

Organizational learning regarding safety normally takes place via many activities and instruments. Besides incident learning, these include safety audits, training, safety rounds, safety committees, risk analysis, inspections, and behavior-based-safety activities.

Organizational learning can be any type of learning where the organization increases its ability to perform its activities better, which in this context means performing them safely or at least safer. The organizational learning can include technical matters (e.g. exchanging a piece of equipment to another of better material), procedural matters (e.g. modifying an operating instruction), and personnel matters (e.g. increase the competence of operators through more training).

Classical terms used to describe the actual learning process are *single-loop* and *double-loop learning* (Argyris & Schön, 1996). In the definition of double-loop learning there is a requirement that the organization changes its guiding principles and/or values regarding how an industrial activity should be performed, e.g. as a result of an incident. Our interpretation of this definition is that this means change of fundamental and profound guiding principles and values. From this follows that the vast majority of incidents reported in the normal broad range incident learning systems of process industries will only have a potential for single-loop learning and that only very few will lend themselves to true double-loop learning.

1.3.2. Accident model

For the purpose of this work, the view of the traditional sequential accident model was chosen. Although regarded in the scientific community as somewhat old-fashioned, this accident model appeared to be the most practical, considering the material obtained from the field objects of this study. The sequential model talks about *causes* and *effects* (*consequences*) and *barriers*. Normally, there are a number of barriers that should stop an initiating event from developing into a serious accident. However, there are sometimes defects in these barriers, and if all the barriers have defects or weaknesses at the same time, the initiating event can propagate through the barriers and result in a major accident – as illustrated in the Swiss Cheese model by Reason (1997). We consider that in the current context accident models could also be used as incident models. Koornneef (2000) also found that the adoption of a causal model was the most feasible in settings similar to those in this study.

Apart from the *direct cause(s)*, there are normally additional aspects in every incident that influence the probability of the event happening and the course it takes. The term causes thus embraces both the *direct* causes, which trigger the event, and *underlying causes*. Typical examples of direct causes are an error by an operator or failure of a piece of equipment, while underlying causes may be inadequate training, which leads to mistakes, or inadequate maintenance, which leads to equipment failure. The *root cause* is defined by Hollnagel (2004) as "the combinations of conditions and factors that underlie accidents or incidents, or even as the absolute beginning of the causal chain", and by Kjellén (2000) as "most basic cause of an accident/ incident, i.e. a lack of adequate management control resulting in deviations and contributing factors", which are both similar to underlying causes or the most deeply lying underlying cause.

Other contributing factors and circumstances can also be regarded as causes. There are often *latent conditions* and *situational factors* in play. Latent conditions (Reason, 1997), usually refer to less obvious conditions, which can often be dormant for a long time, but which can contribute to the course of events, once a triggering direct cause occurs. Typical examples of latent conditions are deficiencies in the design/engineering of the equipment, insufficient training, deficiencies in procedures and instructions, deficiencies in preventive maintenance, all originating from decisions at a higher organizational level. *Situational factors* are those that are not constantly present, but turn up occasionally and can make it more difficult to perform a certain task correctly and safely, thereby contributing to triggering an incident.

A very important point in learning from incidents is the analysis of the cause(s) of the incident. This must be detailed enough to reveal not only the direct causes but also underlying causes, latent conditions, root causes, and situational factors, if relevant. The latter (underlying causes, etc.) reveal more about the general weaknesses in an organization and its process and equipment than the direct causes.

1.3.3. Incident learning system

A prerequisite for effective learning from incidents is that there is some structured way of handling the information concerning an incident and of converting the experiences resulting from the incident into individual and organizational learning, as a lesson learned for everyone concerned. In other words, a formal incident learning system is needed. At most companies this system is normally part of a larger information system for safety (S), health (H) and often environment (E). Kjellén (2000) describes a SHE information system, providing four basic functions for accident prevention: (i) reporting and collection of data, (ii) storing of data, (iii) information processing and (iv) distribution of information to decision-makers inside the organization. For effective learning this requires a formal procedure covering the steps in the *learning cycle* – the incident learning system. Many steps are involved in the learning cycle, typically:

1. Data collection and reporting
2. Analysis and evaluation
3. Decisions
4. Implementation
5. Follow-up

These five steps form a first loop, after which a second loop is normally carried out based on aggregated material from many incidents to allow deeper evaluation of the underlying causes and possible lessons learned. In order to learn from incidents, the different steps must be based on good information, in terms of both quality and detail, and including aspects concerned with the incident, such as work situation, competence and level of support, procedures, stress level, technical status of equipment, and knowledge of the process.

Obviously, the incident must be identified as something worth reporting. This is a crucial point, and is connected with the question of the threshold for reporting in an organization. This is discussed by Phimister, Kleindorfer, and Kuhnreuther (2003).

1.3.4. Lesson learned

Gordon (2008) defined the *lesson learned* as “information that has a real or assumed impact on operations; valid in that it is factually correct; and applicable in that it identifies a process or decision that reduces or eliminates the potential for the recurrence of an incident or reinforces a positive result”. Gordon also says, “Another way of defining a lesson learned is an effective work practice or innovative approach that is captured and shared to promote repeat application, or an adverse work practice or process that is captured and shared to avoid recurrence”. This latter definition is used in this study.

1.3.5. Organizational memory

Once the useful information from an incident has been defined and extracted, the knowledge must be implemented throughout the organization. This could mean one single measure but many measures are often required to integrate this knowledge into the *organizational memory*. When the knowledge has been converted into activities which have had effects in different parts of the organizational system we can call it a “lesson learned”. To exemplify the content of an organizational memory, the structure of Nertney (1987) for *organizational readiness* can be applied: Personnel system, Plant/Equipment system and Procedural system. The Personnel system normally includes accountability/authority and training programmes, Plant/Equipment systems may include engineering standards/specifications and risk analysis, while Procedural systems include management systems, operating instructions and maintenance programmes.

The lesson learned can remain in the organizational memory for shorter or longer times. For instance, when an incident leads to a new way of performing a task, and this is manifested by new instructions, thorough training and follow-up of the results, the lesson learned will probably remain in the organizational memory for a longer time than if only a more casual, verbal information is given to somebody of the workforce.

1.3.6. Level of learning and type of learning

When analyzing incidents in the process industries one will from a practical view normally find that many of the lessons learned concern only the most immediate vicinity within a plant where the incident occurred (Jacobsson, Sales, & Mushtaq, 2010). Occasionally, the lesson learned will be applied on a much broader geographical scale. The organizational learning after an incident often contains limited technical measures and/or changes of working procedures and/or some training (Hale, 2008). Sometimes, measures are taken to ensure deeper organizational learning, sometimes even extending into the safety culture of the organization. Some measures will only be effective for a short period of time others for longer (Kjellén, 2000). From a practical point of view, these three aspects – geographical application, degree of organizational learning, and the time aspect – can be used to classify the lessons learned in terms of *level of learning*.

The aspects of single-loop learning and double-loop learning are very important and relevant when dealing with major accidents and complex causation. However, the question of single-loop or double-loop learning is less relevant in a classification system for classifying the typical broad range of incidents that take place in the process industry, because only very few of the incidents would really lend themselves to double-loop learning.

1.3.7. Number of incidents reported and threshold for reporting

Ideally, all incidents with a potential for learning should be reported, i.e. the *threshold for reporting* should be low. Whether to report an incident or not is normally decided by the employee closest to the incident. However, once the incident has been reported, it is important that the report is dealt with properly otherwise people will stop reporting incidents. As Cooke and Rohleder (2006) say, “the reporting of incidents is driven by individuals’ willingness to report incidents and management’s willingness to investigate them”. There will always be incidents with a learning potential that are not reported in an enterprise. This “hidden number” should be as low as possible. In reality, it is necessary to strike a balance, and it is probably better for the total learning to have fewer reports properly handled, than many reports poorly handled (Rogers, Dillion, & Tinsley, 2007), or said in another way to obtain "a compromise between the generation of enough events to learn from and avoiding swamping the analysis system with too much work which will cost more than its added value for improving management" (Freitag & Hale, 2008).

However, it is important to try to report and handle as many as possible of the incidents which occur, because there will always be specific lessons to learn at least on a detailed level. If incidents are picked out only on the basis of the general lessons they can generate, valuable lessons on a detailed technical and procedural level can be lost.

1.3.8. Learning agents

Koornneef (2000, p. 70) talks of the importance of the *learning agency* in a learning organization. According to Koornneef, the main function of the learning agency is to learn the lessons and retain both the experiences regarding implemented lessons, and the lessons themselves on behalf of the organization. For the incident learning system to generate good lessons we need actors in each step of the learning cycle who have sufficient competence and understanding of the aspects relevant to learning. The chain starts with the reporting of the facts from the incident, continues via analysis of the causes and other circumstances concerning the incident, into converting the information into knowledge, and finally to modifications of the artefacts of the company, e.g. operating instructions and the design of equipment, but sometimes also changes in behavior and attitudes, and the values of the company. Especially in steps 2–5, from analysis to follow-up in the learning cycle, we need *learning agents* (functions, persons) in the organization through which the causes and other circumstances concerning an incident can be analyzed and transformed into a lesson learned and stored in the organizational memory.

1.3.9. The company as a socio-technical system

Most incidents involve more than one person or one organizational level, and the reasons and causes behind accidents are distributed among different employees and organizational levels. This is expressed, for example in the model of a socio-technical system by Rasmussen (1997). This view has also been used in the present work. This also implies that there must be learning agents on several levels in the organization.

1.3.10. Some fundamental prerequisites for learning from incidents

Many things influence the learning from incidents, but some aspects are fundamental to good learning. Firstly, there must be a willingness in the organization to learn. The basic prerequisite for good learning from incidents is probably that there is a learning culture in the organization based on openness, non-punishment and management commitment (Reason, 1997). Secondly, there must be a driving force for reporting and learning from the top management, generated by the commitment of management, and requirements on the organization to report and learn (Reason, 1997). Thirdly, as Koornneef (2000) points out, the role of the learning agent(s) is vital for driving the learning process, for extracting the lessons learned and disseminating them. Fourthly, as Kjellén (2000) has shown, there must be a structured way of dealing with the incidents reported in some kind of safety information system.

2. Methods and material

2.1. Development of a method for evaluation of the level of learning

The aim was to obtain a method with high objectivity for evaluation of the learning from incidents that takes place in an organization. When developing the method, elements and notions normally used in incident learning systems of companies in the process industry, were used. However, during the course of the work it was found that other sources of information also had to be taken into consideration in learning from incidents. The focus of the method is on the learning at the site.

The following steps were included in the method:

1. Evaluation of the *actual* learning levels of reported incidents
2. Evaluation of the *potential* learning levels of reported incidents
3. *Comparison* of actual and potential learning levels
4. *Adjusting* the results obtained in steps 1–3 for incidents not reported (*this step will be addressed in another paper*)
5. Consideration of possible learning from incidents on an aggregated basis – here called *the second loop*.
6. Consideration of *other learning mechanisms* for learning from incidents

Where possible, the results from the method should be expressed in numerical terms to provide for correlation with other safety parameters such as safety audits and safety climate inquiries using statistical methods.

2.1.1. Step 1: Actual learning

The method of evaluating the actual level of learning from incidents is based on a previously presented model used to evaluate learning from accidents reported to the MARS (Major Accident Reporting System) database for major accidents under the Seveso legislation (Jacobsson et al., 2010). This method is in turn based on a system originally developed by Van Court Hare (1967) and refined by Kjellén (2000). A model with 6 possible levels of learning was developed, as illustrated in Table 1. The model focuses

- Primarily on how broadly the lesson learned is applied geographically at the specific site (from very locally at the specific place or piece of equipment involved to over the whole site with similar conditions, depending on relevance),
- Secondly on how much organizational learning is involved, regarding
  - Technical measures (from fixing the specific problem to modifying broader technical procedures and specifications or even re-evaluation of basis for design in general)
  - Procedural measures (from fixing the specific instruction to broader administrative procedures or even changing basic safety management system procedures)
  - Personnel measures (from information to extensive training or similar, and to re-organization), and
- Thirdly on how long the lesson learned stays in the organizational memory.

Admittedly, there are no exact boundaries between the three aspects; some overlap between the geographical aspect and the other two aspects will occur.

The method is adapted to the nomenclature normally used in the process industry.

The actual level of learning could be evaluated, using the model in Table 1, for each incident report during a specified period of time based on the information given in the reports. The most important information in the incident reports is that on which measures have been implemented or, at least have been decided for implementation. With the results from the evaluated reports, it is possible to see the typical distribution of incidents among the levels of learning at a specific site or company. There is no given answer to what would be a reasonable or an acceptable distribution among the levels of learning. The distribution will depend on many things

Table 1
A model for levels of learning from incidents.

Level	Main characteristics	Description	Examples
0	No learning.	Essentially no learning.	Only repair of failed equipment or plain acceptance of "human error".
I	Primary: Limited local level learning. Additional: Almost no organizational learning; Short-term memory.	Learning only at a very local level, only at the specific place in the plant where the incident occurred. At most, limited documentation. Limited organizational learning. Mostly only short-term organizational memory involved.	Discussions within a shift and possibly notes in a logbook.
II	Primary: Local level learning. Additional: Limited organizational learning; Mostly long-term memory.	Learning at a local level, somewhat broader than for I, but still limited to the specific place in the plant where the incident occurred. Normally documented. Some organizational learning. Normally long-term organizational memory.	Changes in a specific procedure with documentation, and providing some info/training, or changing the material in a specific piece of equipment.
III	Primary: Process unit level learning. Additional: Substantial organizational learning; Long-term memory.	Learning at a process unit level (occasionally site level). Applying the lessons to other, similar places/systems or procedures in a process unit. Documented. Organizational learning. Long-term organizational memory involved.	Changing of all pumps of a specific type, or changing the procedures and training for sampling generally within a process unit.
IV	Primary: Site level learning. Additional: Substantial organizational learning; Long-term memory.	Learning at a typical site level. Applying the lessons to other, similar places/systems over the site, including generic lessons to be included in general and SHE management systems and norms (policy, goals, specifications, etc.). Documented. Long-term organizational memory involved.	Major changes in engineering specifications, working procedures, training programme requirements for the site.
V	Primary: Higher learning. Additional: Corporate learning; Long-term memory.	Higher level learning (on a corporate level). Lessons are brought to the attention of the corporate top management and fundamental re-evaluation of SHE activities takes place. Long-term organizational memory involved.	Fundamental changes in corporate SHE policies.

and will be up to the judgment of the individual company. However, already the result from this first step could certainly be used as a base for discussion in the company on its effectiveness concerning the learning from incidents.

2.1.2. Step 2: Potential learning

To assess the effectiveness of learning better than just considering the actual level of learning in step 1, the actual learning result can be compared with the learning that would have been possible, had the full learning potential been exploited.

It is obvious that not all incidents lend themselves to learning on higher levels. Some only justify actions on a lower level – local technical action and/or limited procedural or organizational action – or even no action at all. However, most incidents could have a potential for learning on higher levels of learning. It is here postulated that it is possible to determine the potential lessons to be learned and the appropriate actions to be taken if one had the full causation picture of an incident. Therefore, the next step in the method is to evaluate the potential learning that could reasonably be achieved from each incident. In order to do this a root cause analysis needs to be made for every incident reported. However, this is rather laborious and could normally only be done for a small number of the incidents reported. Therefore, a tool for a less time-consuming evaluation of the most likely underlying causes, given the direct causes in the incident reports, was developed. The tool refers to the different socio-technical levels in a typical process industry. The following levels were chosen:

- Top level, company management (typically site management)
- Other influencing levels (typically staff/support functions)
- Supervision at higher levels (typically plant/middle management)
- Supervision at execution (typically first line supervisors)
- Direct executing level (typically sharp-end operators)
- Process/Equipment.

This approach is similar to that in the Rasmussen (1997) model. A number of typical direct causes and the most plausible underlying causes are identified on each level. The tool includes latent conditions, and lack of or inadequate barriers. Some situational factors have also been included at the direct execution level. The tool, which is presented in Table 2, is largely based on a similar tool developed for deep causation analysis of the accidents in the MARS database (Jacobsson Sales, & Mushtaq, 2009). The major difference is that the direct causes (under "direct executing level") in the present work have been modified to reflect the most frequent direct causes in the reports from the companies in which the tool has been applied, whereas in the MARS project the direct causes given in the MARS system had to be used. The tool in the MARS work was validated by an expert group (Jacobsson et al., 2009).

In Table 2 it can be seen that many (but not all) of the underlying causes at one level show up as direct causes at the next higher organizational level. By applying this tool to the incident reports the probable underlying causes can be established, and thus the type of learning and potential learning that could reasonably have been made from each incident can be assessed. One would be able to assess whether the incident concerns only a local aspect regarding a piece of equipment or a specific procedure or training, or whether it concerns a wider area, or a general procedure or organizational aspects. The model used for evaluating the actual level of learning (i.e. Table 1) will also be used for evaluating the potential level of learning. We claim that this tool can be used for all types of incidents, both minor and major. For minor incidents the ultimate underlying cause will often be found on rather low levels in the hierarchy, whereas for major, normally more complex, incidents the underlying causes would be found higher up in the hierarchy.

2.1.3. Step 3: Comparison of actual and potential learning levels

When the potential learning levels have been evaluated in step 2, these are compared with the actual learning levels providing a measure of the effectiveness of learning from incidents. Firstly,

Table 2
Tool for causation analysis of accidents and incidents, examples of causes.

Analysis level	Department/organization	Direct causes	Underlying causes (latent conditions)
5. Top level	Company management	Inadequate review of systems and safety performance of organization; Need for training/competence not appreciated; Incompatible goals and wrong priorities given to lower organizational levels; Poor communication of priorities related to safety; Inadequate allocation of responsibility/accountability; Poor selection of managers; Inadequate risk assessment procedures; Inadequate systems for designing and installing to good engineering standards etc.	Inadequate or weaknesses in Safety Management System, (SMS); Inadequate or weaknesses in safety culture, (SC). Sub-standard thinking in terms of safety. Poor commitment to safety. Poor leadership. (The above statements refer mainly to a thought corporate or board level.)
4. Other influencing levels (support functions, etc.)	Technical department	Design inadequate; Poor risk assessments.	Inadequate systems for designing and installing to good engineering standards, for applying inherent-safety thinking etc.; Inadequate risk assessment procedures; Inadequate resources/competence.
	Purchasing department	Inspection inadequate; Purchasing procedures inadequate.	Inadequate review of systems and safety performance of organization.
	Other (if applicable)[a]	(To be developed by the user)	(To be developed by the user)
3. Supervision at higher levels (often line managers)	Operations	Supervision/review/control of systems and organization inadequate; Operation procedures inadequate; Inadequate competence and training given; Resources inadequate; Risk assessment inadequate; Managers "don't care" or do not show they actually care.	Risk awareness inadequate; No systematic procedures for risk assessment; Poor resources and competence; Inadequate commitment (from higher levels of management); Inadequate review and control by higher management; Need for training/competence not appreciated; No time for relevant training.
	Maintenance	Supervision/review/control of system inadequate; Maintenance/inspection programmes inadequate; Inadequate competence and training given; Resources inadequate; Managers "don't care" or do not show they actually care.	Inadequate awareness of the need for a maintenance programme or deliberate negligence; Inadequate commitment (from higher levels of management); Inadequate review and control by higher management; Inadequate risk assessment; Procedures only for satisfaction of system; Need for training/competence not appreciated.
2. Supervision at execution	Operations	Supervision/control of execution inadequate; Training of operator personnel inadequate; Staffing inadequate; Supervisors "don't care" or do not show they actually care; Other priorities higher than safety; Attitudes of individuals inappropriate.	Inadequate commitment (from higher levels of management); Resources inadequate; Need for training/competence not appreciated; No time for relevant training; Inadequate review of system and safety performance.
	Maintenance	Maintenance/inspection programmes not followed; Supervision/control of execution inadequate; Training of maintenance personnel inadequate; Inadequate maintenance procedure; Supervisors "don't care" or do not show they actually care; Other priorities higher than safety; Attitudes of individuals inappropriate.	Inadequate review of system and safety performance; Resources inadequate; Need for training/competence not appreciated; No time for relevant training; Inadequate commitment (from higher levels of management).
1. Direct executing level ("Sharp-end operators")	Operations (operator)	Operation outside design conditions; Procedures not followed; Direct operator error; Shortcomings of individuals; Inadequate competence; Attitudes of individuals inappropriate.	Procedures inadequate; Training inadequate; Inadequate supervision and control; Staffing inadequate; Other priorities than safety; Situational factors: High workload, stress or other aggravating factors.
	Maintenance (technician)	Procedures not followed; Direct technician error; Shortcomings of persons; Inadequate competence; Attitudes of individuals inappropriate.	Procedures inadequate; Training inadequate; Inadequate supervision and control; Staffing inadequate; Other priorities than safety; Situational factors: High workload, stress or other aggravating factors.
	Contractor (technician)	Procedures not followed; Direct technician error; Shortcomings of individuals; Inadequate competence; Attitudes of individuals inappropriate.	Procedures inadequate; Training inadequate; Inadequate supervision and control; Staffing inadequate; Other priorities than safety; Situational factors: High workload, stress or other aggravating factors.
0. Process/Equipment		Vessel/container/containment/equipment failure; Component/machinery failure/malfunction; Loss of process control; Instrument/control/monitoring device failure.	Fabrication failure; Corrosion/erosion/fatigue; Technical failures; Maintenance/inspection programmes inadequate or not followed; Operation outside design conditions.

[a] Additional categories of employees may be relevant at all levels, for which the model has to be amended when relevant.

the pattern of the distribution among the levels of learning for actual learning and potential learning is compared. A second comparison is made by calculating the ratio between the "mean value" of the actual level of learning and the "mean value" of the potential level of learning. The scale used to evaluate the level of learning is an ordinal scale from 0 to V, and the mean values, calculated as arithmetical mean values, are mathematically strictly not true mean values. However, we consider this method of calculating representative averages of the level of learning acceptable for the purpose of the study. The ratio between the mean values of actual and potential level of learning could be a suitable measure when trying to correlate the learning from incidents with other safety parameters that are expressed as numbers (e.g. from safety audit results).

2.1.4. Step 4: Adjusting for incidents not reported (the "hidden number")

The above picture is not the whole story. As the next step in the method an adjustment of the results is applied, because there are always a number of non-reported incidents. However, this step will be considered and discussed in another paper and will here be mentioned only in general terms.

The "hidden number" depends on the openness, alertness and willingness in the organization to report all incidents with a learning potential. It also depends on the threshold the company has defined for reportable incidents, or rather the incidents worth reporting. There is not a given number for how many incidents that would be reportable in an organization. However, the total number of reportable incidents can be assumed to be proportional to the size of the company, and therefore at least reasonably proportional to the number of employees. The number of reportable incidents will also depend on the type of industry and its activities. However, in this first version of the method only the number of employees is used as a base, as a first approximation.

2.1.5. Step 5: Consideration of possible learning from incidents on an aggregated level – the second loop

So far we have only discussed the learning from each separate incident. Efforts are sometimes made to re-analyze incidents, normally on an aggregated basis, to gain more information about underlying causes and possibly to learn more lessons than when analyzing the incident in the first loop of the learning cycle. The next step was therefore to try to take into consideration learning from the second loop. The method employed in this second loop of learning from a number of incidents should take into consideration:

- The regularity of examination of the incidents reported,
- The analysis of the incidents (type, scope, quality),
- The actions and programmes/measures resulting from this analysis, and
- The type of lessons learned.

A good second-loop analysis could compensate for poor first-loop analyses, if thorough analyses of the underlying causes are performed, and the appropriate actions are taken in the second loop. So far in this work, no specific method has been developed for second-loop analysis. When applying the method in the six organizations in the study, a general judgment of the impact of this step was made, based on information obtained from interviews with the employees responsible for the incident learning systems.

2.1.6. Step 6: Consideration of other mechanisms for learning from incidents

As a final step in the method a consideration was made concerning other possible ways of learning from incidents than through the formal incident learning system. It is not uncommon for other functions, besides the normal handling agents of the incident learning system, to deal with incidents, especially in terms of deciding which actions should be taken. The safety committee, or an equivalent group, sometimes takes on this role, especially in the case of more significant incidents. Such activities will sometimes not be documented in the incident learning system. When evaluating the lessons learned such activities must also be taken into account. There may also be ways of learning from incidents, besides the official systems. For instance, some incidents, especially those of more technical nature, are not reported but actions are taken directly in the form of a work order to repair or modify the equipment that failed. These other ways of learning should be identified and given credit when they play a relevant role in learning. However, in the companies included in this study, the normal case was that incidents were reported in the official system, and the lessons learned were documented in that system.

2.2. Expert judgments of the method

The tool for causation analysis of accident and incidents (Table 2) was assessed by an expert panel using a short questionnaire, in which the items were answered using a six-point scale (0 = disagree completely, 5 = agree completely). The expert panel consisted of the safety committee of the Swedish Plastics and Chemicals Federation, the members of which are typically safety managers at Swedish chemical companies.

2.3. Material

The method presented above was tested for usability by applying it at six sites in the Swedish process industry. Key data concerning the companies (sites) are presented in Table 3. All the organizations had a formal incident learning system, all of which were computer-based. The risk potential for the six plants has been judged by the authors.

Concerning the analyses of incidents, two years of reports (2007 and 2008) were obtained directly from the incident learning systems for the companies A–E. In order to detect possible trends with time, the analysis was carried out separately for each year. For company F, which had comparatively few incident reports, a longer sampling period was selected (3½ years, from 2007 to mid 2010) to obtain sufficient data. A total of more than 1900 reports was analyzed. When other relevant material existed, e.g. root cause analysis, this was also obtained. By choosing a rather homogeneous group – six companies within the process industry – we believe that the results of the application of the method could also be used to compare the effectiveness in learning from incidents at the companies.

2.4. Safety audit for supporting information

In addition to the incident analysis study, a general safety audit, with some 90 dimensions, was also performed at all sites, in which a representative selection of 15–30% of the personnel was interviewed for 1 h per person. During the interviews the incident learning system was discussed, as well as the issue of other mechanisms for learning from incidents. Moreover, special interviews were conducted with those persons responsible for the incident learning system, to gain information about the performance of the second loop. Some of the results from the two types of interviews were used in this paper, mainly for steps 5 and 6 in the assessment of the companies.

Table 3
Key data for the six companies included in the study.

Company	Type of industry	Size of site (technical employees)	Incidents reported per year (2008)	Incidents reported per employee and year	Risk potential	Comments
A	Petrochemical	360	570	1.6	High	Part of a major multi-national corporation
B	Chemicals, general	115	270	2.3	High	Part of a major multi-national corporation
C	Food and drugs	45	30	.67	Medium	National, single-site company
D	Pulp and paper	650	220	.34	High	National, multi-site corporation
E	Energy production	100	10	.10	Medium	National, single-site company
F	Food and drugs	40	24	.60	Medium	Part of a major multi-national corporation

3. Results

3.1. The method

The main result of this study is the method itself, with the tools presented above in the Methods section, namely:

1. Evaluation of the *actual* learning levels
2. Evaluation of the *potential* learning levels
3. *Comparison* of actual and potential learning levels
4. *Adjusting* for incidents not reported – the "hidden number"
5. Consideration of a possible *second loop*
6. Consideration of *other learning mechanisms.*

The great value of the method is not the generated figures per se but the message they convey when they are related to the level of learning they stand for and when comparisons over time or between companies or departments are made. A very important outcome is the ratio between actual and potential level of learning. The method can give clear indications of areas for improvement.

3.2. Evaluation of the method

It was found by the authors that the method worked very well when applying the method's six steps in the six companies.

Step 1: Evaluation of the actual learning levels was in most cases fairly simple and unambiguous based on the information in the incident reports. About 7% of the reports was of low quality and could not be assessed.
Step 2: Evaluation of the potential learning levels was associated with greater uncertainty. However, with the help of the tool for assigning probable underlying causes, this was also reasonably straightforward.
Step 3: The comparison of actual and potential learning levels was straightforward, once steps 1 and 2 had been performed.
Step 4: The correction of the results for incidents not reported – the hidden number – was not applied on the results in this paper and will be reported on in another paper.
Step 5: Although we have not yet developed a specific method for the consideration of possible learning through a second loop, it was easy to check for the existence of some kind of second loop learning during the safety audits, and adjust the picture obtained from the analysis of the individual incidents only, when relevant. In our study, none of the companies showed any signs of significant second-loop activity, indicating that the level of learning was not significantly better than that given by the results of steps 1–4.
Step 6: Learning from incidents in other ways than via the formal incident learning system could be of major importance in some companies. However, based on the information obtained during the safety audits other learning mechanisms seemed to contribute little in the companies included in this study.

In summary, evaluating the level of learning from incidents, using the method developed here appears to be useful in practice. To be able to perform steps 5 and 6 additional information, apart from the data in the incident learning system, is needed, e.g. information from safety audits. The method appears to be stable based on the fact that it worked well in all six companies, despite, for example, six different incident learning systems. Additions and refinements, especially concerning steps 4–6, could make the method even more useful. It is thus concluded that the method could be used to evaluate the effectiveness of learning from incidents and to identify areas requiring improvement.

3.3. Results of the application in six companies in the process industry

The method of evaluating learning in terms of levels of learning was applied in the six companies, using incident reports from a period of two years (for company F, 3½ years).

3.3.1. Actual level of learning

In Table 4, the results of actual levels of learning for the six companies in the study are presented as distributions (percentages of incidents) among various levels of learning and as "mean levels", per 2007 and 2008 (except for company F).

The results show that for most companies, especially companies A–D, there were high percentages of low-level learning (levels 0 and I) (Table 4). Especially, the percentage of incidents with learning level 0 was very high in these four companies. A typical level 0 learning case is where failing equipment is repaired without further improvement, or an operator error is accepted without further notice. Level I learning, i.e. a very local and minor improvement, dominated at all the companies.

Company C had a relatively high average level of learning, which could be explained by the fact that it is a small company with a committed management (but also relatively few incident reports). Companies E and F also had a high mean level of learning, but with very few incident reports, which tends to give a rather high level of learning. In the case of company F, the additional safety audit result revealed a very strong safety culture, high management commitment and good systems for incident reporting, all of which probably contributed to the high level of learning from incidents.

Some interesting differences could be seen when comparing incident reports from 2007 to 2008. At company B an improvement was seen, which coincides with a change in the organization and the appointment of a specific safety coordinator. In company D there was a significant increase in reporting between 2007 and 2008 (almost a factor 3), which coincided with a very clear change in safety commitment from the site manager, with focus on incident reporting. However, the increased focus on reporting incidents seems to have resulted in somewhat poorer quality in terms of learning. The improvement seen for company E between 2007 and 2008 could not be easily explained by any changes in the organization, and could be due to random variations in the small sample.

Table 4
Distribution of levels of actual learning from incidents that occurred in 2007 and 2008 in six companies in the process industry (Company F: 2007-mid 2010).

	Company										
	A		B		C		D		E		F
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007–2010
Actual level of learning	% of incidents										
0	30	41	34	18	31	28	40	48	13	0	0
I	53	41	52	62	44	29	41	42	75	60	44
II	15	15	13	17	19	25	18	9	0	30	35
III	2	2.5	1	3	0	18	1	1	12	10	21
IV		0.5			6						
V											
"Mean" level	0.9	0.8	0.8	1.1	1.1	1.3	0.8	0.6	1.1	1.5	1.8

3.3.2. Actual vs. potential level of learning

The next step in applying the method was to use the tool in step 2 (Table 2) to evaluate the probable underlying causes for each incident and then to use the model in step 1 (Table 1) again to evaluate the potential level of learning. The values of the potential level of learning and corresponding values of the actual level of learning are presented in Table 5. To increase clarity, only figures for 2008 are included, except for company F, where all reports from 2007 to mid 2010 are included.

As seen in Table 5, there is a shift in the percentages of the levels of learning toward higher levels when applying the analysis for potential learning. The ratios between the mean values for actual and potential levels of learning show that the actual level of learning was approximately "half" the potential level of learning, except for company F, which has a considerably higher ratio of actual to potential level of learning than the others. Company D seems to have a lower actual/potential ratio of learning compared to the others.

3.3.3. Consideration of possible learning from incidents on an aggregated basis

None of the companies had a very structured way of dealing with their incident reports on an aggregated basis, although companies A, B, D and F all made some annual summary of the reported incidents. Most of these summaries presented only the number of incidents per department, the severity of the incidents, etc. None of the companies made any real effort to investigate the causes of the incidents on a regular basis, or tried to find any general pattern regarding more underlying causes or the lessons to be learned. Therefore, there seemed to be no reason to further correct the picture of the learning from incidents in any of the six companies in this study.

3.3.4. Consideration of other ways of learning from the incidents

In one company there was a tendency to hand over the handling of part of the reports to the safety committee. The protocols from these safety committee meetings were also studied, and the actions recommended by the committee were subjectively taken into account in our evaluation. Information about incidents was disseminated in all companies, and some degree of discussion took place in various meetings. However, the probable extra learning from this information was not taken into consideration in the evaluation of the learning level.

3.4. Results from the expert judgments

Five out of eight members of the safety committee of the Swedish Plastics and Chemicals Federation gave their expert judgments concerning the method used to evaluate the level of learning. The tool for causation analysis of accidents and incidents, as outlined in Table 2, was evaluated by the experts using a short questionnaire. All the experts agreed generally on the hierarchical model of relating underlying causes with management levels. They also agreed completely with the idea that there are a number of underlying causes in most accidents. Given the direct causes in Table 2, the experts also agreed that the proposed underlying causes are possible (average expert judgment of 5.0 = agreed completely); they are likely (average expert judgment of 4.2); and they are the most probable ones (average judgment of 3.6). Some experts suggested additional underlying causes that could be included in Table 2. At level 0, poor design (inadequate design), hardware deficiencies and failure of defenses (e.g. alarms, trip systems) were suggested. At level 1, error-inducing conditions (e.g. noise, distracting factors such as telephone calls) could be added. At levels 1–3 (maintenance), insufficient planning, control and coordination, as well as lack of technical documentation were suggested. At level 4 (inadequate purchasing procedure) underlying causes such as insufficient communication and lack of resources could be added. Other influencing or underlying causes mentioned by one expert were weaknesses in R&D and logistic provider. Another expert suggested incompatible goals (e.g. between production, economy and safety)

Table 5
Distribution of actual and potential levels of learning from incidents reports in 2008 in six companies in the process industry (Company F: 2007-mid 2010) (rounded values).

	Company											
	A		B		C		D		E		F	
	Act	Pot	Act	Pot	Act	Pot	Act	Pot	Act	Pot	Act	Pot
Level of learning	% of incidents											
0	41	0	18	0	28	0	48	0	0	0	0	0
I	41	35	62	10	29	18	42	40	60	0	44	21
II	15	52	17	61	25	36	9	44	30	40	35	52
III	3	13	3	27	18	43	1	14	10	60	21	27
IV	0.5	0.5		2		4		2				
V												
"Mean" level	0.8	1.8	1.1	2.2	1.3	2.3	0.6	1.8	1.5	2.6	1.8	2.1
Actual/potential, %	45		48		57		36		58		86	

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to be highlighted or expressed with more clarity than the existing other priorities apart from safety in Table 2.

4. Discussion

This paper presents the development of a method for evaluating the level of learning of incidents in a company and the application of the method in six process industry companies. We believe the uniqueness of the method to be the concept of comparing the actual level of learning with the potential level of learning.

4.1. Usefulness of the method

The method and its results can be very useful both in practical application in companies and in research work. The results from the method in the form of distribution of levels of learning can be used to judge whether the learning from incidents in general is satisfactory or if improvements are needed. The specific measures in terms of ratios between mean values of actual and potential level of learning (both without and with adjustment for the hidden number of incidents) can be used as safety performance indicators. These ratios could also be used in work aiming at finding possible correlations between learning from incidents and other safety parameters which can be expressed numerically, for instance results from safety audits and safety climate inquiries. The authors have already used the results in this way with promising results. The method is intended for use by safety professionals in both industry and academia. We anticipate the main use of the method to be in individual companies for evaluation of the effectiveness of learning from incidents. We also envisage the method being used for benchmarking purposes between departments at a particular site and between sites in the same company. Although the method has been developed with the process industry in mind, we believe that the method could be used in many other kinds of hazardous activities where learning from incidents is important.

4.2. Uncertainties in the results

Obviously, there are uncertainties in the results when applying the method. The results of the first step are largely dependent on how accurately the lessons learned are described in reports and on how much effort the assessor gives to securing that a full and correct picture is used as the basis. When the method is used internally in a company, one would have the possibility to have a very good basis for assessing the first step. Assessing the second step, potential level of learning, brings in more uncertainty in the results, as it involves a judgment of what would have been a reasonable lesson to be learned. There will certainly be single cases where two assessors, would have a differing opinion of one level of learning, after having applied the tools, first for assessing the potential lesson to be learned in Table 2 and then the potential level of learning from Table 1. However, with a larger sample of incidents we believe that the "mean values" will not differ significantly. Although not applied here, the introduction of the adjustment for the hidden number in step 4 also introduces an uncertainty in the figures produced. However, when the method is applied in a company, one will have a fair possibility to use an internal company value for the probable number of reportable incidents, which is rather close to a "correct" value. With each step in the method, uncertainties are introduced into the figures. However, we believe that the picture comes closer to reality with more steps, and the added value in usefulness in assessing the learning from incidents would outweigh the increased uncertainty in the values.

There is a risk of overestimating the potential level of learning for an incident when the assessor has access to a large number of incidents, letting the information from previous assessed incidents induce the requirement of a higher potential level of learning of following, similar incidents. However, the way the tools are meant to be used, is to assess each individual incident with no influence from the results from assessment of other incidents. The issue of an improved level of learning would be captured in step 5, the evaluation of the second loop.

4.3. Possible explanations of variations between results for different companies

Differences were found between the companies in terms of level of learning and the ratio actual/potential learning from the incidents. One could perhaps have expected a higher mean value of the level of learning for the two companies with the relatively good reporting frequency, i.e. company A and B. However, in organizations where the reporting frequency is high – which normally means that the threshold for reporting is low – it is reasonable to expect that the actual level of learning from many of these "minor incidents" (i.e. with no or small consequences) would be on average comparatively low. However, some of the reported incidents would lead to lessons to be learned on a high level of learning, so it is important that they are all reported. The minor incidents often have a single cause or at least a simple causation picture, whereas incidents with more serious consequences are often found to have a more complex causation picture, often with many underlying causes. This means that the relative level of learning for organizations with a high-reporting frequency would be lower than for organizations where only incidents with serious consequences are reported. This is probably not a major drawback if these high-reporting organizations regularly analyze all the incidents in more detail on an aggregated basis – the second loop – and then act according to the findings. However, this is often not the case, and therefore it could be a waste of resources just to report a lot but not to carry out the remaining part of the learning procedure to obtain the full potential for learning.

The importance of having a learning agent, or a prime mover for safety, in the organization is rather evident from our results. In company F, there were very clear focal points for learning from incidents in terms of personnel committed to administrating the incident learning system and for working with these questions on a departmental level. Company A also had good departmental resources and resources for administrating the system, but there seemed not to be the same support from the top management, which could explain the lower ratio of actual/potential learning. The reason for company C performing relatively well, despite the fact that the number of reports was rather low, we ascribe to the small size of the company, the commitment of top management and the departmental safety resources. The main reason for company F showing such a high level of learning from incidents we ascribe to the high commitment of the management and the very rigorous corporate systems which had to be followed in this company.

The importance of a formal system for learning from incidents is often stressed. The authors agree that it is important to have a good system for the reporting and further handling of incidents, which drives the process and the necessary activities in the learning cycle. However, our results present no evidence that a more elaborate system would result in a higher level of learning from incidents.

4.4. Further research

The method described in this paper is already a useful tool for evaluating the level of learning. However, there are opportunities to refine the method further. In particular, there is a need to develop a more specific method for taking the second loop into account. Also, the method for adjusting for the hidden number of incidents

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should be developed further. The risk level and the type of activities in the evaluated organization are aspects that could be used in that respect. There would also be a great value in evaluating the effectiveness of the various steps in the learning cycle, to determine where the strengths and weaknesses in the loop appear to be. The authors explore this issue in another paper. Another interesting subject would be to investigate how one can best select the incidents that are worth analyzing in detail to learn lessons, without having to study all the reported incidents in detail. Finally, it would be of great interest to see which general factors in a company that influence the learning from incidents, i.e. which factors are favorable and which are obstructive for good learning. One way of doing this could be to link the results from safety audits and safety culture measurements with those from the analysis of learning from incidents, as described above.

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A sequential method to identify underlying causes from industrial accidents reported to the MARS database

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A B S T R A C T

This paper presents a method designed to identify underlying causes leading to industrial accidents. The method developed intends to facilitate the learning process from accidents by identifying possible causes related to the accidents that were not directly stated in an accident report, but that can be deduced following the description of the event, in particular with regard to the quality of the safety management systems in place at the industrial establishment at the time of the accident. The method has been prepared following a sequential approach, although a combination of the philosophy behind other existing accident models has been taken into consideration. The starting point to develop the model is the causes for accidents included in the MARS database of the European Commission. These causes have been extended by considering typical operational or organisational failures that are normally related to the original reported cause. The extension of causes has been performed by adding three follow-on levels of possible underlying causes. The first level could be considered as a direct cause of the accident and, the last level being more applicable to the foundation of establishing safety: "Safety Management System or the Safety Culture".

In order to check the applicability of the method developed, it has been validated by a group of experts of the European Federation of Chemical Engineering, in order to reinforce the strategy adopted by the authors. Moreover, the method has been used to analyse the total set of accidents reported to the MARS database. The objective is to determine the efficiency of the method in identifying underlying causes, and to establish a link between the results obtained and the actual causes stated in the reports. In this way, it is possible to establish a system to go deeper into the analysis of past accidents, in order to obtain lessons learned, and to avoid recurrence of similar accidental scenarios in the future, as well as to give directions for a better reporting system of industrial accidents.

1. Introduction

1.1. General

This paper is a result of a joint project between the Major Accident Hazards Bureau of Joint Research Centre (JRC) of the European Commission and the National Centre for Learning from Accidents, a part of the Swedish Rescue Services Agency, on the MARS database.

MARS (Major Accident Reporting System) was established in 1984, and it is the system used by the European Commission to keep track and to handle the information of industrial accidents occurred in EU Member States, as stated in the requirements of the Seveso II Directive (EC, 1997). The reporting to the MARS database is done by what is known as Competent Authorities in the member states. Soon after an accident, a short report is issued which is then followed by a full report when the full details are available. Detailed information on MARS can be found in the JRC reference (Joint Research Centre, 2008).

One important use of the MARS database is to give a basis for legislative actions in the EU countries. For a correct prioritization of the actions, one would need a full picture of the underlying causes for the accidents.

The analysis of past accidents in process industries is a useful method for identifying common aspects regarding the causes that triggered or contributed to such events. The MARS system provides different possibilities for introducing the identified causes that led to an accident, e.g., insertion of free text or selection from predefined lists (Mushtaq & Christou, 2004).

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In the last years, different analyses have been performed on the information included in the MARS database. Previous studies on the MARS accidents have covered various aspects related to the causes of the accidents. Some of these analyses have been performed at a general level (Sales, Mushtaq, & Christou, 2007a), while others were aimed at obtaining lessons to be learned, focusing on specific issues such as handling of dangerous substances (Drogaris, 1993), efficiency of emergency systems (Kirchsteiger, 1999), management issues (Mushtaq, Christou, & Duffield, 2003) or chemical reactions (Sales, Mushtaq, Christou, & Nomen, 2007b). The analyses so far have been based mainly on the causes directly reported from the Competent Authorities, with little attempt to a deeper analysis of underlying causes.

There are several objectives of the joint project. General objectives are:

- to learn more about underlying causes, especially regarding organisational aspects, from the accidents reported in MARS;
- to link underlying causes to issues of safety management systems and safety culture;
- to identify weaknesses in the quality of reporting and analysing.

The primary objective of this paper is to determine whether it would be possible to go deeper into underlying causes of the reported accidents. Secondary objectives are – provided that the primary objective can be achieved:

- to compare the extent of underlying causes generated from a deeper analysis with those actually reported in the MARS accident reports,
- to compare the distribution of underlying causes with and without the deeper analysis, and
- to give a basis for evaluating whether the correct conclusions are drawn from the MARS reports or if, in the case of too shallow analyses of the causes, the wrong conclusions and non-optimum decisions in the legislative work of the European Commission can be the case.

In order to carry out the deeper analysis, a reasoned and systematic method had to be developed and its feasibility had to be validated.

1.2. Theoretical background

1.2.1. Accident models

There are several types of accident analysis models. Hollnagel (2004) distinguishes three types:

- sequential,
- epidemiological, and
- systemic models.

Sequential models are the oldest ones, originally developed by researchers such as Heinrich, Petersen, and Roos (1980) and further refined by others, e.g., Bird and Germain (1985) in the ILCI model. These were followed by epidemiological models developed in particular by Reason (1997). The most modern models are of the systemic type, developed among others by Dekker (2006) and Hollnagel (2004). Often new models criticise or even disqualify older ones. However, in reality these models can be complementary to each other, each one having its strengths and its weaknesses. Fig. 1 shows a schematic representation of a sequential model (Kjellén, 2000), which includes the idea of "root causes".

The root cause can be defined either as "the combinations of conditions and factors that underlie accidents or incidents, or even as the absolute beginning of the causal chain" (Hollnagel, 2004). This is illustrated in Fig. 2.

In every accident and near-miss, there are normally, apart from the direct cause(s), some additional aspects that have had influence on the probability for the event to happen and on the course it took. There are often latent conditions and situational factors in play. With *causes*, we understand both the direct causes which trigger the event, and underlying causes. Typical examples of causes can be a classical mistake or error by an operator or a direct failure of some equipment, but also inadequate training, which led to the mistake or inadequate maintenance, which led to the equipment failure.

Other contributing facts and circumstances can also be regarded as causes. These may be called explanations (Dekker, 2006) or *latent conditions* (Reason, 1997). These concepts usually refer to less obvious conditions, which can often be dormant for a long time, but which can contribute to the course of events, once a triggering direct cause occurred. Typical examples of latent conditions could be decisions at a higher organisational level leading to deficiencies of the design/engineering, inadequate training, deficiencies of procedures and instructions, deficiencies in preventive maintenance, and so on. Latent conditions could also be lack of or deficiencies in safety barriers of various kinds (Hollnagel, 2004).

With *situational factors*, we understand factors that are not constantly present but turn up occasionally and can make it more difficult to perform a certain task in a correct and safe manner, and thereby contribute to trigger an incident. Typical examples of situational factors can be the fact that a work place is occasionally very noisy, an unfavourable weather influence, or a particularly high stress level.

In most accidents, not only one person or one organisational level is involved, but the reasons and causes behind accidents are distributed among different persons and organisational levels. This is, for example, expressed by Rasmussen and Svedung (2000) in their model of a socio-technical system. This view has also been used in the present work.

In our opinion, there are almost always some sequential elements of causes (e.g., lack of resources resulted in poor

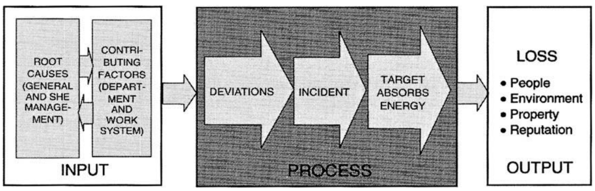

Fig. 1. Sequential model of accident after Kjellén (2000).

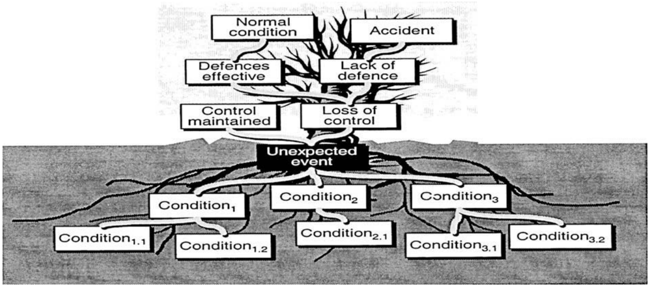

Fig. 2. Influence of different conditions in the event of an accident as described by Hollnagel (2004).

training of operators, not updated procedures and poor supervision which in turn contributed to a wrong decision by the operator). In many sequential models, there is the notion "*root cause*". However, very seldom is there only one root cause, but a combination of several root causes (the accident tree has several roots, not a single one).

In the epidemiological models, there are usually some performance deviations in combination with, and often influenced by, environmental conditions. Typical for these models is also the inclusion of various barriers and normally a number of latent conditions (Hollnagel, 2004). The latter are normally attributed to basic organisational processes such as design, construction, procedures, maintenance, training, communication, human-machine interfaces and so on. Latent conditions do not normally trigger accidents as such, but may be revealed by performance deviations. Similarly, latent conditions may also render ineffective the barriers in the system. Latent conditions can have several different causes, such as organisational or managerial decisions, design and/or maintenance failures and deficiencies, and the undetected, slow degradation of system functions or resources.

We also acknowledge the essence of the systemic models, where steps and stages on the way to an accident are seen as parts of a whole rather than as distinct events or causes, as being relevant. However, we have chosen to use a basically sequential model in this work, but including many features of the epidemiological and the systemic models as well.

1.2.2. Learning from accidents

One of the main objectives of the MARS system is to support learning from the reported accidents. Many steps are involved in the process of learning the full lessons from accidents. Typical steps would normally include:

1 data collection and reporting;
2 analysis;
3 decisions;
4 implementation;
5 control/check;
6 evaluation and act.

This sequence of steps borrows elements from a Safety Information Model by Kjellén (2000) and from Demingś circle of Plan, Do, Check, Act.

The steps form a loop, normally leading to improved learning. This "learning loop" could be applied to all levels: for the individual accident, at the individual enterprise and at a MARS system level. A similar stepwise description is expressed by Krausmann and Mushtaq (2006).

This paper deals primarily with the first and second step of the "learning loop" and with the emphasis on the analysis step. It is important that the analysis of the factors that caused (and contributed to) an accident occurring is thorough and deep enough to reveal the aspects that will best be tackled to avoid a repetition of similar accidents in the future.

2. Methods

2.1. Development of a causation model

In order to be able to make a deep analysis of the accidents reported regarding causes and to go beyond the causes that are given in the reports, a model was needed that described how direct causes as given in the reports could be linked to certain underlying causes in several steps in some kind of causal chain.

The starting point of the causation model was the definition of causes as given in the MARS system, which are shown in Table 1. These were then linked to plausible underlying causes in some steps, striving in the direction of root causes, the deepest lying causes. Underlying causes like "deficiencies in safety culture" are considered to be root causes, here also used as a stop rule in the analysis. The model was developed partly at the beginning of the project (based on experience of the authors) and partly during the analysis work (based on the support for certain connections of underlying causes from the data within the MARS reports).

The causation model is related to the model by Kjellén (2000) in Fig. 1. Especially the INPUT part of Fig. 1 was included in the model. In this paper the term "underlying causes" has been used for what is stated under INPUT, namely root causes (general and SHE management) and contributing factors (department and work systems). Information from Fig. 2 by Hollnagel (2004) was also used in the model, where "conditions" in Fig. 2 (in our terminology "direct causes" and "underlying causes") are included as possible, probable or even necessary prerequisites for the accident.

Tables 2 and 3 show parts of the new extended model for classification of causes and underlying causes of accidents, one part related to operational causes and another part to organisational causes. The causes as given in the existing MARS system were directly used as much as possible, and were also related to each other where appropriate. This was done especially for the causes under the heading Operation. Here, when setting up deduced, underlying causes following the "Direct causes" (Cause 1), links were determined between the direct cause as given in the present system and the causes under Organization (as underlying causes) with a reasonable logic. Three follow-on levels of possible

Table 1
List of predefined causes for accidents as included in MARS.

Operation
100 101 vessel/container/containment/equipment failure
100 102 component/machinery failure/malfunction
100 103 loss of process control
100 104 corrosion/fatigue
100 105 instrument/control/monitoring-device failure
100 106 run-away reaction
100 107 unexpected reaction/phase transition
100 108 blockage
100 109 electrostatic accumulation
Environment
110 201 natural event (weather, temperature, earthquake, etc)
100 202 domino-effect from other accident
100 203 transport accident
100 204 struck by object
100 205 utilities failure
100 206 establishment safeguarding/security deficiency
Organization
110 101 management organization inadequate
110 102 management attitude problem
110 103 organized procedures (none, inadequate, inappropriate, unclear)
110 104 training/instruction (none, inadequate, inappropriate). Resources and competence.
110 105 supervision (field supervision) (none, inadequate, inappropriate)
110 106 staffing (none, inadequate, inappropriate)
110 107 process analysis (inadequate, incorrect)[a]
110 108 design of plant (inadequate, inappropriate)
110 109 user-unfriendliness
110 110 manufacture/construction (inadequate)
110 111 installation (inadequate, inappropriate)
110 112 isolation of equipment (none, inadequate, inappropriate)
110 113 maintenance
110 114 inspection
110 201 operator error
110 202 operator health
110 203 wilful disobedience
110 204 malicious intervention

[a] Process analysis is often also called risk assessment or risk analysis.

underlying causes were used, where the last level normally represents "Inadequate Safety Management System or weaknesses in the Safety Culture", corresponding to root causes (general and SHE management) in Fig. 1.

Under the heading Organization, also three follow-on levels of possible underlying causes to the original cause were used. Cause 2 mostly relate to contributing factors, Cause 3 mostly to root causes and Cause 4 entirely to root causes in Fig. 1. Most of them are newly formulated causes. It is also not so evident which cause could be deduced from the previous one. It becomes more a mixture of simultaneously more or less related causes, closer to the thinking of the systemic models.

2.2. Validation of the causation model

In order to increase the credibility of the causation model developed to be used for the analysis it needed to be validated. "Expert judgement" was considered to be the best way to do this. A group that was considered to be highly qualified for the task was the "Loss Prevention Working Party" of the European Federation of Chemical Engineering. The group consists of prominent safety experts in Europe from academia, authorities and the process industries. The group was contacted and its members declared themselves willing to undertake the task. A questionnaire was constructed with questions on the causation model to determine to which degree it was supported by the experts. The questions, relevant to this paper, concerned the following items:

- the general idea that there are a number of underlying causes in most accidents;
- the extent to which the person supported the model with the proposed causes as *possible, likely or the most probable* underlying causes, given the basic causes of the MARS system.

The experts were asked to judge the system on the basis of individual relationships between specific causal factors.

Approximately half the members of the group responded with answers to the questionnaire (15 persons out of 26). The support received for the developed model can be considered as being very high. The average rating given to the questionnaire can be found in Table 4. The support given for the most important questions (question number 2, 3 and 4 in Table 4) was 4.6, 4.2 and 3.6, respectively, on a 0 (disagree completely) to 5 (agree completely) scale.

2.3. Data sources and analysis

The data used in the research was the information as included in the MARS database per mid 2007, totally 653 accidents. Only the information in the reports in the database itself was used.

Both in the short reports and the full reports there are possibilities to insert the causes of the accident, in the short reports as free text and in the full reports as specific causes selected from a predefined list (Table 1).

As a base for the work, a work sheet was developed with accident code, country, industry type, official causes, possible underlying causes, lessons learned plus possible comments.

The first step was to list the relevant information as given in the official report for every accident. This was based only on what was reported in the accident reports.

In the second step, the causation model was applied and each accident was analysed for potential additional underlying causes. As

Table 2
Part of of the classification system for direct and underlying causes related to operation.

Direct cause	Possible underlying causes		
From existing MARS	From existing MARS (coded); new proposals (non-coded)		
Cause 1- - ->	Cause 2- - ->	Cause 3- - ->	Cause 4
Operation			
100106 run-away reaction	"Technical failures"	Failure of components/instruments etc. (110101) and (110102); risk assessment inadequate (110107) etc.; design inadequate (110108)	Design inadequate (110108); maintenance/inspection programs inadequate (110113/110114); or programs not followed;
	"Direct operator error" (110201)	Procedures inadequate (110103); procedures not followed; training inadequate (110104); Staffing inadequate (110106); shortcomings of persons; environmental factors (stress etc)	Supervision/review/control of system inadequate (110105); need for training not appreciated; Safety management system (SMS) inadequate or weaknesses in safety culture (SC)

Table 3
Part of the classification system for direct and underlying causes related to organization.

Direct cause	Possible underlying causes		
From existing MARS	New proposals (non-coded)		
Cause 1--->	Cause 2--->	Cause 3--->	Cause 4
Organization			
110103 organized procedures (none, inadequate, inappropriate, unclear)	Procedures inadequate	Inadequate review of system. Resources inadequate.	Safety management system (SMS) inadequate or weaknesses in safety culture (SC)
	Procedures not followed. Procedures only for satisfaction of system.	Inadequate supervision and control. Stress, negligence.	SMS inadequate or weaknesses in SC
110107 process analysis (inadequate, incorrect)	Low risk awareness. No systematic procedures for this. Poor resources and competence.	Inadequate review of system or inadequate commitment (from higher level of management).	SMS inadequate or weaknesses in SC
	Inefficient risk assessment; not given high priority.	Inadequate review and control by higher management.	SMS inadequate or weaknesses in SC
110113 maintenance	Inadequate preventive maintenance program (or not carried out maintenance)	Inadequate awareness of need for program or deliberate negligence. Inadequate risk assessment.	SMS inadequate or weaknesses in SC
	Inadequate maintenance procedure.	Inadequate review of system. Resources inadequate.	SMS inadequate or weaknesses in SC
	Not followed procedure. Procedures only for satisfaction of system.	Inadequate supervision and control. Stress, negligence.	SMS inadequate or weaknesses in SC
110201 operator error	Inadequate competence. Inferior training. Inadequate or inferior procedures.	Need for training/competence not appreciated. No time for relevant training. Inadequate review of system. Resources inadequate.	SMS inadequate or weaknesses in SC
	Incorrect action (despite competence and relevant procedures)	High work-load, stress or other aggravating circumstances.	SMS inadequate or weaknesses in SC

a prerequisite for adding underlying causes, some support for this was normally found in the accident report either in the free text or from the actions taken afterwards. By this combined use of the causation model with actual evidence in the reports, we argue that there should be a high likelihood that the most probable causes have been selected.

Approximately 15% of the cases had to be rejected because of lack of information to base any opinion on.

The analyses were carried out independently by two of the authors. Their respective results were then compared and only where the results from the two persons agreed the results were used in the preparation of the final results.

The underlying causes of interest to the authors have been those causes included in the MARS system under Organization in Table 1.

Therefore, the number of reports with these causes were counted – first based on what was reported in the official report, then after application of the model. The results are shown in Table 5.

Taken directly from the official reports, the organisational causes as defined in MARS, appeared 631 times, with the distribution as shown in Table 5. After application of the model, the same causes appeared 2044 times.

3. Results and discussion

One of the primary objectives of this study was to investigate whether it would be possible to go deeper into identifying underlying causes of the reported accidents. This has been done by applying the developed causation model to the MARS reports.

The results of the study which are presented in this paper are:

- the causation model used and the validation of it;
- the basic results of applying this causation model to the MARS accident reports.

More detailed findings in terms of linking underlying causes to specific parameters related to the accidents will be given in further publications.

Table 4
Questionnaire and average results obtained from the validation exercise by EFCE Loss Prevention Working Party.

Question	Rating (0–5)	Comment
1 Do you support the general idea that we have a number of underlying causes in most cases of accidents?	4.9	
2 Given the basic/direct causes (Cause 1) by the MARS system, to what extent do you agree that the proposed causes (Cause 2, Cause 3 and Cause 4) are *possible* underlying causes?	4.6	
3 Given the basic causes (Cause 1) by the MARS system, to what extent do you agree that the proposed causes (Cause 2, Cause 3 and Cause 4) are *likely* underlying causes?	4.2	
4 Given the basic causes (Cause 1) by the MARS system, to what extent do you agree that the proposed causes (Cause 2, Cause 3 and Cause 4) are the *most probable* underlying causes?	3.6	
5a For Operation-causes (first part of system), do you generally agree that we arrive in one or two steps at causes that should be controlled by "middle management"…?	4.1	
5b …and in two or three steps at causes that should be controlled by higher management or are parts of the "safety culture"?	4.1	
6a For Organization-causes (latter part of system), do you generally agree that we start at causes that should be controlled by "middle management"…?	3.7	
6b …and in one or two steps arrive at causes that should be controlled by higher management or are parts of the "safety culture"?	3.7	

Use a scale 0–5, where 0 = disagree completely; 5 = agree completely.

Table 5
Total number and percentages of accidents reporting specific organizational causes, as stated in the MARS reports and after application of the causation model.

Category of causes	From reports			With application of model		
	Number of reports	% Of reports	Ranking	Number of reports	% Of reports	Ranking
Management organization and attitude	51	9	6	83	15	
Procedures	121	22	1	331	60	2
Training	58	10	5	233	42	4
Supervision	25	4	7	160	29	6
Staffing	6	1		6	1	
Process analysis	78	14	4	438	79	1
Design	107	19	2	244	44	3
User un-friendliness	8	1		8	1	
Manufacture/construction	6	1		6	1	
Installation	4	1		4	1	
Isolation	14	2		14	2	
Maintenance, preventive program	13	2		170	31	5
Maintenance, operations	9	2		60	11	
Inspection	23	4		152	27	7
Operator error	98	18	3	100	18	
Operator health	0			0		
Wilful disobedience	1			1		
Malicious intervention	9	2		9	2	
Housekeeping	0			25	4	
Total number of causes	631			2044		

We argue that the causation model that was developed has proven to be suitable for its purpose, i.e., to deepen the causation analysis of accidents into more underlying causes, as can be seen below. The model has also received considerable support from an expert group during the validation step.

The result of the analysis, when applying the causation model to all the accident reports, is presented in Table 5. Totally 556 accident reports were used. The table gives a comparison of the number and the percentages of accidents which were caused by weaknesses in the organisational categories – first as stated directly in the reports and then after application of the causation model.

The results presented in the table show that many more contributing factors are at play in reality than are actually reported. The total increase of causes under the headline of organization is a factor of 3.2, with the biggest increase in "Maintenance" (16×), "Inspection" (7×), "Supervision" (6×), "Process analysis" (6×) and "Training" (4×). With application of the deeper analysis, also the ranking of the various underlying causes change. With the information from the original reports, "Procedures" is the most common underlying cause, followed by "Design", "Operator error", "Process analysis", "Training", "Management organisation" and "Supervision". After application of the model, "Process analysis" becomes the most common underlying cause, followed by "Procedures", "Design", "Training", "Maintenance", "Supervision" and "Inspection". Weaknesses in safety management systems and in safety culture were treated separately (as will be discussed in future publications) and were not included in the "Management organization" category. If that had been done this category would have ranked as the highest.

The additional information that comes from applying the model is information associated with higher levels of management in the companies, especially when it could be shown that weaknesses exist in the safety management system and/or in the safety culture. This will be of significant value to know and to act upon for increased safety performance.

It is also an important finding in itself that accident reports from the Competent Authorities to the EC accident data base are not deeply enough analysed. It is obvious that if some of the relevant underlying causes are not identified non-optimum decisions could be taken.

4. Conclusions

The application of the developed causation model to the accidents reported to the MARS database clearly reveals that the analyses of causes of the accidents in the original reports are often poor and there is a need for a deeper analysis of the circumstances that lead to industrial accidents. The use of this model revealed three times as many causes than were actually reported. Even though they were not considered as direct causes to the accidents, these underlying causes refer to deficiencies in safety management systems, which can generally be grouped in two or three levels of causes, linked to the direct ones. If these underlying deficiencies had been properly identified, evaluated and corrected, they could have eventually helped to avoid other accidents with the same underlying causes.

The model developed proves to be efficient in identifying additional causes on top of those included in the MARS reports. Even though the model does not give a 100% certain result of the underlying causes in each individual case, it should give a reliable result seen over the large number of accidents analysed. The use of a systematic model validated by experts can be an efficient tool in order to improve the degree of learning from accidents in the process industries. Furthermore, this model can help to improve the quality of the reporting of accidents by EU Member States to MARS, by helping the person reporting to establish the causes of an accident in a more accurate and precise manner.

The EC Joint Research Centre is already working on improving the reporting to the MARS database as a result of this research.

The versatility of the information included in the MARS reports gives the possibility to perform analysis of the accidents from different points of view. The causation model for identifying underlying causes presented in this paper has been used to study the MARS accidents taking different aspects into consideration, e.g., type of industry, countries or periods of reporting. The results of these analyses will be given in future publications.

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Underlying causes and level of learning from accidents reported to the MARS database

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A B S T R A C T

MARS is the system established and maintained by the European Commission in order to collect information related to major industrial accidents in EU Member States in the context of the Seveso II Directive. One of the main purposes of the MARS database is to provide information for learning from the accidents to avoid similar events. Probably, the most important issue for the learning is the determination of the causes, particularly the underlying causes, of the accidents. One objective was to find possible patterns of underlying causes per industry type and per country. Another objective was to determine the occurrence of weaknesses in safety management systems and in safety culture as underlying causes. A further objective was to determine the level of learning from the accidents, as it appears from the reports, per industry type and per country. A sequential method, presented by us in a previous paper in this publication, was used to make it possible to go beyond the causes given in the original reports and to find more underlying causes. To determine the level of learning from the accidents, using the actions/lessons learned given in the reports, a classification method was developed. This method establishes the level of learning of the lessons learned from each case description, essentially from the organisational point of view. This paper presents the results of an analysis regarding underlying causes of all the accidents of the MARS database reported up to mid 2007. The results are expressed per industry type and per country. The main results are that as much as three times as many underlying causes can be found when applying the method developed compared with what is given in the original reports. The most important underlying causes are found in weaknesses in process analysis (risk assessment) and in procedures, regardless of industry type. Weaknesses in safety management systems and in safety culture contribute as underlying causes in a very high percentage of the accidents. The quality of reporting, measured in terms of analysis of underlying causes, vary considerably between various countries. The level of learning, as determined from the information in the reports, is found to be in general rather low, especially from some of the countries. This study has given rise to ideas of improvement of the MARS system. It has also raised many questions, some of which would be suitable for further research.

1. Introduction

The main objective of the analysis of past accidents in process industries is to avoid recurrence of such events. In order to achieve this, it is necessary to ensure that as much information as possible is extracted from the available description of an accident. The Seveso II Directive of the European Commission, in its article 15 (EC, 1997) states that Member States must report to the MARS database following a major industrial accident. Since Seveso is a goal oriented and not a prescriptive Directive, which is transposed independently in each country of the EU, the degree of detail provided to MARS is quite heterogeneous among Member States.

This paper is a result of a joint project between the Major Accident Hazards Bureau of Joint Research Centre of the European Commission and the National Centre for Learning from Accidents, a part of the Swedish Rescue Services Agency, on the MARS database.

General objectives of the project are:

- to learn more about underlying causes, especially regarding organisational aspects, from the accidents reported in MARS;

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- to link underlying causes to issues of safety management systems and safety culture;
- to identify weaknesses in the quality of reporting and analysing.

One of the results of the project is a sequential method to identify underlying causes from industrial accidents. This method has been presented previously in this journal (Jacobsson, Sales, & Mushtaq, 2009). The method intends to identify possible causes that could have played a significant role in the occurrence of an accident, but that may not have been directly indicated in the accident reports. It was shown in this previous paper that it was actually possible to go deeper into underlying causes of the reported accidents and to compare the degree of underlying causes generated from a deeper analysis with those actually reported in the MARS database.

In addition to looking for deeper lying causes of the accidents, it is also considered important to determine the level of learning from the accidents while analysing the MARS database material. A specific tool for this, based on the lessons learned, has been developed.

Specific objectives of this paper are to determine:

- possible specific characteristic patterns in the underlying causes per industry type
- possible specific national characteristic patterns in the underlying causes
- any impact of the requirement of the Seveso II legislation of safety management system on the causes of accidents
- quality of analysis of underlying causes
- the level of learning for reported accidents
- possible industry specific characteristic patterns in the level of learning
- possible specific national characteristic patterns in the level of learning

2. Background

2.1. Learning from accidents in the MARS system

MARS is the system established and maintained by the European Commission in order to collect information related to major industrial accidents in EU Member States in the context of the Seveso II Directive (Mushtaq & Christou, 2004). MARS reports consist of the "Short report" and the "Full report" sections. The short report gives essential information concerning the accident, in a free-text format completed within a short period after the accident. The full report is much more systematic, and normally completed some time later after an investigation. While there are always free-text fields available to describe facts connected with an accident, a great deal of effort has been put into the definition of descriptive codes, for the accident itself and for associated information, to enable the data to be inputted in a very structured way, and thereby allowing the MARS database to be interrogated effectively.

The main objective of the MARS system is the learning aspect from accidents. Many steps are involved in the process of learning the full lessons from accidents. Typical steps would normally include:

1. data collection and reporting;
2. analysis;
3. decisions;
4. implementation;
5. control/check;
6. evaluation and act

This sequence of steps borrows elements from a Safety Information Model by Kjellén (2000) and from Deming's circle of Plan, Do, Check, Act.

The steps form a loop, normally leading to improved learning. This "learning loop" could be applied to several levels; for the individual accident, at the individual enterprise and at a MARS system level. A similar stepwise description is expressed by Krausmann and Mushtaq (2006).

This paper deals primarily with the second and third step of the learning loop, the analysis and decisions steps. Since the MARS database does not include any information on how the lessons learned, as stated in the reports, are implemented in practice, it is not possible to go any further in the analysis.

The degree of learning from accidents can be categorised in various ways. The most well-known is probably the principle of single-loop and double-loop learning by Argyris (1992). The definition of double-loop learning requires that the organization changes its guiding principles and/or values for how to perform the industrial activity as a result of the accident. Based on the analyses of the authors (presented under Results) double-loop learning occurs in few cases. Accordingly, most accidents only lead to single-loop learning. A second aspect to look at is whether the learning is primarily learning in technical or in organisational respect or both. A third aspect is to look at how broad in terms of both geographical and organisational implementation the learning is.

Kjellén (2000) has developed a classification system based on Van Court Hare (1967). The basis of this system is the duration of the lessons learned – short-term or long-term storing of experience – in combination with the level of organisational and geographical learning. This has been used as a starting point for this present work.

It is widely recognised that safety management systems play an important role in the safety of enterprises in general and in high-risk industries such as the process industries in particular. Therefore, in order to increase the safety level in enterprises covered by the Seveso II Directive, the European Commission included in the legislation (EC, 1997) the requirement for enterprises to have safety management systems implemented. The Directive was implemented at a national level by EU Member States in 1998. Therefore it would be expected that after this year the causes of the accidents reported in MARS should have changed in character. It is expected that there should be less accidents with causes related to weaknesses in safety management systems after 1998 and onwards. Assuming that there is some connection between "safety culture" and safety management system one would also expect less accidents with causes related to "safety culture" aspects after 1998 and onwards.

3. Methods

3.1. Method to identify underlying causes from accidents

In order to analyse the accidents reported to the MARS database deeper for underlying causes than what was stated in the accident reports a special method was developed. The starting point for this was the causes as stated in the MARS system, from which additional levels of possible underlying causes were developed. The method was validated successfully by an expert group. The method has been described in a previous paper in this journal by the authors (Jacobsson et al., 2009).

In short, the method can be explained as follows. The MARS system has three categories of causes: Operation, Environment and Organization, each with a number of defined causes (totally 33), which are used by the reporters of the accidents. Our system starts with these causes and develops another three levels of possible underlying causes. Two examples will be given. From the MARS cause "run-away-reaction" (under Operation) and from the MARS cause "organized procedure" (under Organization) our system proposes the possible underlying causes given in Table 1. These are then the underlying causes looked for in our analyses.

The method was applied to all the accidents included in the MARS database per mid 2007, totally 653 accidents. Previous analyses on the whole of the database have aimed at establishing general patterns of accident history in Europe, related for instance to the number of accidents per year, number of fatalities, type of physical consequences involved and so on (Sales, Mushtaq, & Christou, 2007). A focus of the present analysis has been the identification of underlying causes from different points of view in order to find both general patterns and any possible patterns per industry type and per country, in accordance with the objectives set up for the study.

As a measure of the quality of the analysis of underlying causes in the reports the ratios between the number of underlying causes taken directly from the reports and the total number of underlying causes including causes identified by the causation model was used.

3.2. Possible impact of Seveso II requirements of safety management systems

The Seveso II Directive was issued in 1996, replacing the previous Directive from 1982, to include, among others, the requirement for implementation of safety management systems for industries affected by the legislation. This new Directive came into force in EU Member States in 1998. To check whether the requirement of safety management system has had any impact on the underlying causes of the accidents the aforementioned method was applied to the MARS database. In order to make the comparison as representative as possible the same length of time (7 years) was chosen before and after the requirement was introduced.

3.3. Development of a classification system to determine the level of learning

In order to complement the method for identification of underlying causes, a new classification system to determine the level of learning from accidents has been generated, based on the work of Kjellén (2000). However, this new system focuses on how broad the learning is rather than on the duration of the learning (lessons learned) – primarily in a geographical respect, secondly in an organisational respect and only thirdly taking the duration of learning into consideration. The method focuses primarily on organisational issues.

The developed system contains 6 possible levels of learning from accidents, as shown in Table 2.

In our system we use the word "place" to mean a very specific location, the place where the accident occurred (e.g. the pipe, the pump, the sampling point and so on that failed or was the object of the "human failure"). "Other places" will then correspond to more generic locations relating to a process unit or maybe the whole site. When comparing our system with the original Kjellén system the interpretation of "workplace", as used by Kjellén, is important. Assuming that "workplace" could be interpreted as being similar to our "place", then the classes presented in this paper by us will correspond closely with those developed by Kjellén.

For each accident report the information supplied under the "Lessons Learned" section in the full reports or the "Immediate Lessons Learned" in the short reports was taken into consideration for classifying it into one of the categories in the proposed classification system.

Approximately 15% of the cases had to be rejected because of lack of information to base any opinion on for both types of analysis above.

4. Results and discussion

A description of the general results from the analysis of underlying causes can be found in the previous paper from the authors, published in this journal (Jacobsson et al., 2009). The general finding was that by applying the causation model for underlying causes more than three times as many underlying causes could be deduced than stated in the accident reports in the MARS database.

In this paper, further analysis of these underlying causes has been performed in an attempt to establish correlations between different parameters of the accidents, such as weaknesses in various aspects (underlying causes) identified per industry type, country, time frame and so on.

The results are considered to be reliable when considering the overall picture generated from the vast number of reports, but not necessarily for each individual report.

4.1. Weaknesses in various aspects, per industry type

Table 3 presents a summary of weaknesses in certain aspects (underlying causes) per industry type as it appears after application of the model developed by the authors (Jacobsson et al., 2009). Only the results for the most relevant industry types in MARS and most common identified aspects are shown, along with the ranking, for each industry type considered. Only industry types with more than twenty reports have been included.

Table 3 shows that there is a similar pattern regardless of the industry type for the most common underlying causes. All

Table 1
Examples from the method of analysis of underlying causes.

CAUSE 1 (MARS)→	CAUSE 2→	CAUSE 3→	CAUSE 4
Run–away reaction	"Technical failures"	Failure of components/instruments etc → Risk assessment inadequate etc.	Design inadequate; maintenance/inspection programs inadequate; or programs not followed;
	"Direct operator error"	Procedures inadequate; procedures not followed; training inadequate; staffing inadequate; shortcomings of persons; or environmental factors (stress etc)	Supervision/review/control of system inadequate; need for training not appreciated; Safety Management System inadequate or weaknesses in Safety Culture.
Organized procedures (none, inadequate, inappropriate, unclear)	Procedures inadequate	Inadequate review of system; or resources inadequate.	Safety Management System inadequate or weaknesses in Safety Culture.
	Procedures not followed; or procedures only for satisfaction of system.	Inadequate supervision and control. Stress, negligence.	Safety Management System inadequate or weaknesses in Safety Culture.

Table 2
Levels of learning from accidents according to the new system developed.

Class	Main characteristics	Description	Kjellén
0	No learning	Essentially no learning	
I	Primary Limited local level learning Additional Almost no organisational learning; Short-term memory	Learning only at very local level, only at the specific place in the plant where the incident occurred. At the most some limited documentation. Limited organisational learning. Mostly only short-term organisational memory involved (e.g. discussions within a shift and maybe notes in a logbook)	I. Correction of deviations, i.e. only the 'short-term memory' is employed. The deviation may reoccur
II	Primary Local level learning Additional Limited organisational learning; Mostly long-term memory	Learning at a local level, somewhat broader than I, but still limited to the specific place in the plant where the incident occurred. Normally documented. Some organisational learning. Normally long-term organisational memory (e.g. changes in a specific procedure with documentation and giving some info/training, or changing the material in a specific equipment)	II. Long-term storing of experience by means of changes of design, work procedures, etc. at the workplace of the accident. The conclusions drawn from the experience will have lasting effects and may prevent a recurrence, but will be of limited scope and will not affect accident risks at other workplaces
III	Primary Process unit level learning Additional Substantial organisational learning; Long-term memory	Learning at a process unit level (occasionally site level). Applying the lessons to similar other places/systems or procedures in a process unit. Documented. Organisational learning. Long-term organisational memory involved (e.g. changing of all pumps of a specific type, or changing the procedures and training for sampling generally)	III. Long-term storage of experience by means of changes in supervision of the personnel and in technical and administrative systems for production control at the functional department. These types of change will also have lasting effects and will affect other workplaces as well.
IV	Primary Site level learning Additional Substantial organisational learning; Long-term memory	Learning at a typical site level. Applying the lessons to similar other places/systems over the site, including generic lessons to be included in general and SHE management systems and norms (policy, goals, specifications, and so on). Documented. Long-term organisational memory involved (e.g. major changes of engineering specifications, work procedures, training program requirements)	IV. Long-term storing of experience by means of changes in the general and SHE management systems and norms (policy, goals, specifications, and so on). The changes will not only have lasting effects but will also have a wide scope and affect many workplaces all over the company
V	Primary Higher learning Additional Corporate/national learning; Long-term memory	Higher level learning (on a corporate and/or national level). Lessons are brought to the attention of the corporate top management (and/or national authorities) and fundamental re-evaluation of SHE work takes place. Long-term organisational memory involved (e.g. fundamental changes of corporate SHE policies or new legislation)	

industry types have weaknesses in "Process analysis" and "Procedure" as the two most common underlying causes. The third most common underlying cause is found in either "Training" or "Design". Notable is also the high percentage of weaknesses in "Maintenance" and "Inspection" for many industry types.

4.2. Weaknesses in various aspects, per country

Table 4 shows a summary of weaknesses in certain aspects (underlying causes) per country as it appears after application of the model. A similar pattern as in the analysis per industry type is at hand, although not quite as unambiguous. All countries (except one) have weaknesses in "Process analysis" as the most common. The second most common weakness is found in either "Procedure", "Training" or "Design". Only countries with more than twenty reports have been included.

Some figures stand out somewhat, both in Tables 3 and 4, but as of now we have no good theories of explanations. This could be an area for further research.

4.3. Weaknesses in safety management system (SMS), before and after Seveso II-implementation, per industry type

Table 5 presents the number and percentages of the accidents where weaknesses in the safety management system are given as underlying causes (with application of the causation model) – before and after 1998. Results are given for those five industry types with the highest number of reports (more than ten reports in each time span).

Table 3
Percentages of reports with weaknesses in various aspects (and ranking within brackets) – per industry type.

Industry type	Number of reports	Weaknesses in						
		Procedure	Training	Supervision	Process analysis	Design	Maintenance program	Inspection
General chemicals	185	65 **(2)**	48 **(4)**	32 **(5)**	80 **(1)**	57 **(3)**	30	26
Petrochemicals	97	49 **(2)**	34 **(5)**	30	67 **(1)**	47 **(3)**	43 **(4)**	33
Plastics	23	65 **(2)**	57 **(3)**	30 **(5)**	74 **(1)**	43 **(4)**	26	22
Fine chemicals	42	67 **(2)**	43 **(3)**	36 **(4)**	93 **(1)**	31 **(5)**	17	12
Wholesale/retail	49	41 **(2)**	31 **(4)**	22	69 **(1)**	35 **(5)**	24	31 **(4)**
Metal refining	36	61 **(2)**	44 **(3)**	22	81 **(1)**	44 **(3)**	25 **(5)**	22
Food and drink	26	46 **(2)**	46 **(2)**	38 **(4)**	69 **(1)**	35	38 **(4)**	38 **(4)**
Other	91							
Total	549	60 **(2)**	42 **(4)**	29	79 **(1)**	44 **(3)**	31 **(5)**	27

Table 4
Percentages of reports with weaknesses in various aspects (and ranking within brackets) – for different countries.[a]

Country	Number of reports	Weaknesses in						
		Procedure	Training	Supervision	Process analysis	Design	Maintenance program	Inspection
A	26	69 **(1)**	35 **(4)**	31 **(5)**	50 **(3)**	54 **(2)**	31 **(5)**	12
B	142	46 **(2)**	31 **(5)**	25	73 **(1)**	44 **(3)**	37 **(4)**	28
C	28	75 **(2)**	39 **(4)**	11	82 **(1)**	39 **(4)**	50 **(3)**	4
D	130	65 **(2)**	48 **(3)**	33 **(5)**	82 **(1)**	41 **(4)**	17	24
E	90	62 **(2)**	41 **(4)**	29	74 **(1)**	51 **(3)**	32	39 **(5)**
F	24	54 **(3)**	54 **(2)**	42 **(4)**	75 **(1)**	38 **(5)**	38 **(5)**	21
G	40	53 **(3)**	55 **(2)**	43 **(5)**	88 **(1)**	50 **(4)**	18	25

[a] Due to confidentiality issues, the names of the countries involved in this analysis cannot be given.

According to the analysis a very high percentage of the accidents have their underlying causes related to weaknesses in the safety management systems.

One would expect a decrease in the percentages of the accidents with weaknesses in safety management systems in the period after implementation of the Seveso II requirements. However, from the accidents analysed there seem to be approximately the same or even a higher percentage of those cases that have weaknesses in safety management systems as underlying cause after implementation of Seveso II. This would be a suitable area for further research.

4.4. Weaknesses in safety culture, before and after Seveso II-implementation, per industry type

Similar to the previous point, it is possible to consider that also the safety culture in the enterprises could have changed with time, possibly linked with the increased use of safety management systems. Table 6 shows number and percentages of the accidents where weaknesses in the safety culture are given as underlying causes (with application of the causation model) – before and after 1998. Results are given for those five industry types with the highest number of reports.

The analysis shows that a very high percentage of the accidents have their underlying causes linked to weaknesses in the safety culture. Besides, from the accidents analysed there seem to be approximately the same percentage of those that have weaknesses in safety culture as underlying cause both before and after implementation of the Seveso II requirements.

4.5. Weaknesses in safety management systems and safety culture, per country

In order to complement the previous results, Table 7 presents the number and percentages of the accidents where weaknesses in the safety management system and the safety culture are identified as underlying causes (with application of the causation model) per country. As it can be seen from this table, all countries show a high percentage of weakness in both factors. The spread between the various countries ranges from approximately 50%–80%. This would be an interesting area to investigate further.

4.6. Quality of analysis of underlying causes, per country

Table 8 shows the ratios between the number of underlying causes taken directly from the reports and the total number of underlying causes including causes identified by the causation model for different countries. This ratio can be considered to be a measure of the quality of the analysis for underlying causes. As can be seen from Table 8, the results vary from approximately 20% (for two countries) to between 40 and 50% (for three countries).

Table 5
Comparison of frequency (percentage) of accidents found to have weaknesses in the safety management system as an underlying cause before and after the implementation of the Seveso II Directive at national level – per industry type.

Industry type	1992–1998			1999–2005		
	Number of reports	Reports with weaknesses in SMS	% with weaknesses in SMS	Number of reports	Reports with weakness	% with weaknesses in SMS
General chemicals	60	39	**59**	71	51	**72**
Petrochemicals	31	17	**55**	34	21	**62**
Fine chemicals	10	10	**100**	12	12	**100**
Wholesale/retail	25	15	**60**	12	9	**75**
Metal refining	15	10	**67**	15	13	**87**

Table 6
Comparison of frequency (percentage) of accidents found to have weaknesses in the safety culture as an underlying cause before and after the implementation of the Seveso II Directive at national level – per industry type.

Industry type	1992–1998			1999–2005		
	Number of Reports	Reports with weaknesses	% with weaknesses	Number of reports	Reports with weaknesses	% with weaknesses
General chemicals	60	37	**62**	71	45	**63**
Petrochemicals	31	20	**65**	34	19	**56**
Fine chemicals	10	7	**70**	12	9	**75**
Wholesale/retail	25	20	**80**	12	7	**58**
Metal refining	15	14	**93**	15	12	**80**

Table 7
Total number and percentages of accidents found to have weaknesses in the safety management systems and in the safety culture as an underlying cause – for different countries.

Country	Number of reports	Safety management system		Safety culture	
		Reports with weaknesses	% with weaknesses	Reports with weaknesses	% with weaknesses
A	26	14	**54**	12	**46**
B	142	73	**51**	82	**58**
C	28	20	**71**	17	**61**
D	130	105	**81**	98	**75**
E	90	65	**72**	58	**64**
F	24	20	**83**	19	**79**
G	40	26	**65**	24	**60**
Other	60				
Total	540	370	**69**	353	**65**

Only those countries with more than twenty reports (i.e. seven countries) are included in the results.

This must be regarded as a poor result.

4.7. Distribution of level of learning, for all accidents and per industry type

Table 9 shows the percentages of the accidents distributed among the classes of level of learning – as a total for all the accidents and per industry type.

From the data given in Table 9 it can be seen that around one third of the accidents provide a very poor level of learning (no learning or limited local learning). For approximately another third, the learning that is obtained is only at a local level, while in the remaining one third, the learning is at least on a process unit or site level. Higher degree of learning – on a corporate or national level – is very rare; it can only be found in around 2% of the accidents analysed.

The pattern for the total of the accidents does not change very much when looking at the various industry types. Nevertheless, it appears that for petrochemical industries there is a higher percentage of learning on higher levels (III, IV and V) than in most other industry types.

4.8. Distribution of level of learning, per country

Table 10 presents the percentages of the accidents distributed among the classes of level of learning per country.

Table 8
Ratios between the number of underlying causes taken directly from the reports and the total number of underlying causes including causes identified by the causation model for different countries.

Causes	Country						
	A	B	C	D	E	F	G
Management	3/8	3/12	6/6	5/13	13/18	1/2	8/11
Procedures	9/22	18/68	6/20	23/86	31/56	8/13	12/21
Training	6/9	5/45	4/11	9/64	13/37	7/13	9/22
Supervision	2/8	1/36	0/3	8/43	6/28	1/9	5/17
Process analysis	4/13	13/105	2/22	11/108	25/67	8/19	4/36
Design	14/17	16/61	4/11	13/53	31/47	5/9	15/22
Maintenance program	0/8	2/54	1/14	0/22	4/29	2/9	0/9
Maintenance operations	1/2	2/13	0/0	1/16	3/12	0/1	0/3
Inspection	3/3	4/42	0/1	0/31	14/34	0/7	3/12
Operator error	6/6	24/24	4/4	18/18	21/21	6/6	9/11
Housekeeping	0/1	0/3	0/0	0/8	0/8	0/0	0/4
Total number of reports	26	142	28	130	90	24	40
Total	48/97	88/463	27/92	88/462	161/357	38/88	65/168
Total, in %	49	19	29	19	45	43	39

Table 9
Percentages of accidents grouped in the specific levels of learning established – per industry type.

Industry type	Number of reports	Level of learning, class (in %)					
		0	I	II	III	IV	V
Total	535	29	5	31	18	15	2
General chemicals	190	20.5	5	34	20.5	18.5	1.5
Petrochemical	87	18.5	3.5	20.5	28.5	26.5	2.5
Plastics	20	20	5	30	25	20	–
Fine chemicals	40	25	–	30	25	20	–
Wholesale and retail	50	30	6	36	14	6	8
Metal refining	33	27.5	9	33.5	12	18	–
Food and drink	26	31	11.5	46	7.5	4	–
Power generation	12	8.5	8	41.5	25	8.5	8.5
Waste treatment	13	23	–	23	38.5	7.5	8
Handling and transport	7	57	–	–	29	14	–
Ceramics	3	33	–	33	–	34	–
Electronics	1		100				
General engineering	2	50				50	
Agriculture	7	43	–	14	14	29	–
Textiles	2	50	–	50	–	–	–
Paper	11	36.5	–	45.5	9	9	–
Timber/building	5	20	–	80	–	–	–
Fairgrounds	5	20	–	60	20	–	–
Other	21	24	5	19	14	38	–

Two countries (E and G) stand out positively with a high percentage of learning on higher levels (III, IV and V), whereas one country (C) stands out negatively with a low percentage of learning on levels III, IV and V and a very high percentage on level 0 learning. For the rest of the countries the percentages are more or less equally distributed, with higher percentages on the 0, II and III levels of learning.

5. Conclusions

The results of the analysis performed show that the overall level of learning from the accidents reported to the MARS database can certainly be enhanced. The fact that only one third of the cases studied are considered to provide learning on a broader basis than that related to the specific place involved, shows that there is a need to improve this issue. Besides, the specific results related to the identification of underlying causes by means of the sequential method developed by the authors prove that there is a general failure in linking the direct causes of the accidents to managerial weaknesses. These conclusions seem to be generally valid regardless of industry type and country.

The fact that it is up to the Competent National Authorities to decide the extent of the information provided to MARS could be an explanation as to the "heterogeneity" between various countries of the results obtained from the analysis. Furthermore, it has to be considered that the Seveso Directive allows Member States not to

Table 10
Percentages of accidents grouped in the specific levels of learning established – for different countries.

Country	Number of reports	Level of learning, class (in %)					
		0	I	II	III	IV	V
A	26	34.5	–	23	31	11.5	–
B	142	20.5	4	42	22.5	11	–
C	28	64.5	3.5	25	3.5		3.5
D	130	28	9	33	16	11	3
E	90	10	2	23.5	22	34.5	8
F	24	25	–	33	25	17	–
G	40	17.5	2.5	22.5	25	30	2.5
Other	60						
Total	540	29	5	31	18	15	2

report relevant information concerning the accidents, when these are subject to juridical procedures until these have been settled. Unfortunately this is often the case when considering major industrial accidents, and these procedures are usually very time consuming, making the information unavailable for a long time. Nevertheless, the fact that some countries clearly present poorer reports compared to others suggests that some Member States should revise their systems for investigating/reporting accidents. On the other hand it has to be considered that the analysis has been based to a high degree on the expertise of the authors, by extrapolating information directly from the information included in the MARS reports which, as has been stated before, is in many occasions quite scarce.

The issue of analysing for weaknesses in safety management systems and in safety culture is very important – though admittedly difficult. Changes in those aspects are probably rather slow and the time intervals that could be used in the current study may not have been long enough to see any trends. Therefore it would be important to follow the development of this closely in the next years.

This study has revealed a number of interesting results. However, due to the limited information in the MARS database, it has not been possible to present plausible explanations to most of the interesting findings, such as e.g. the lack of deepness in analysis of underlying causes, the generally poor level of learning and the national differences in certain aspects.

Based on our study we would suggest further research of the MARS system in order to investigate the reasons for

- the poor analysis of underlying causes in general
- the weaknesses in various aspects, both per industry type and per country
- the weaknesses in safety management systems and safety culture, especially in some countries
- the poor level of learning (as defined in our study) from the accidents, especially in some countries and some industry types

The Major Accident Hazards Bureau is currently developing a new version of the MARS database. The objective of this revision is to facilitate the extraction of lessons learned from the accidents reported. A primary and essential goal of this revision is to simplify the use of the database, and to guide Member States when reporting accidents by specifying key issues that are considered of primary importance to analyse the accidents. Special emphasis will be placed in the reporting of underlying causes linked to the obvious direct events triggering the accidents. The results obtained from the analysis presented in this paper, both from the identification of non-reported underlying causes as well as from the classification of the level of learning from accidents, provide a clear picture as to what are the areas that can be improved in the lesson learning cycle from past accidents The objective (and next steps to be taken in this context) is therefore to disseminate these results to the personnel involved in the reporting process.

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