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WORM Metamorphosis Consortium

The quantification of occupational risk

The development of a risk assessment model and software

RIVM Report 620801001/2008

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Abstract

The quantification of occupational risk
The development of a risk assessment model and software

The Dutch Ministry of Social Affairs and Employment commissioned the RIVM to develop a model for calculating occupational risk in the Netherlands. This model is to provide employers with a choice of measures – or combination of measures – aimed at reducing the risk of employees suffering injury or death as a consequence of job-related incidents. The model can also be used to calculate the cost of these measures and the extent to which the risk has been reduced. As such, the model can be used to work out an optimal balance between the cost and the benefits of implementing risk-reducing measures.

The model is based on extensive research that involved the analysis of a large number of job-related incidents documented in incident reports of the Labour Inspectorate. The results of the analysis were stored in a database, and the job-related incidents were subsequently classified into 36 different incident scenarios, such as ‘falling from heights’. The incident scenarios were used to construct so-called bow ties, which describe the causes of an incident (which event led to its occurrence?) and its consequences (injury or fatality?). Possible measures that may help prevent an incident or mitigate its consequences are also mentioned in the bow ties. The bow ties also set a value that indicates the failure rate of these measures.

Job-related activities and workplace conditions of the average Dutch employee were then analysed in terms of the extent to which employees are exposed to potentially risky situations/activities. The quality of the risk-reducing measures implemented at the workplace was also assessed. Given the large amount of data used to develop the model, it can be applied to calculate the risk of incidents on an activity, job, company or whole industry basis.

Key words:
quantified risk assessment, occupational safety, safety management, risk model, occupational incidents.

Rapport in het kort

Kwantificering van arbeidsveiligheidsrisico's
De ontwikkeling van een risicomodel en software

Op verzoek van het ministerie van Sociale Zaken en Werkgelegenheid (SZW) is een model ontwikkeld om arbeidsrisico's in Nederland te berekenen. Werknemers kunnen tijdens hun werk gewond raken of overlijden als gevolg van ongevallen. Met het model kunnen werkgevers combinaties van maatregelen kiezen die het risico reduceren. Ook kunnen de kosten van deze maatregelen en de behaalde risicoreductie worden berekend. Hiermee is een optimale afweging mogelijk van de kosten en de baten van risicoreducerende maatregelen.

Voor het onderzoek is een groot aantal arbeidsongevallen geanalyseerd, op basis van de ongevalrapporten van de Arbeidsinspectie. Deze gegevens zijn in een database gezet, waarbij de arbeidsongevallen werden verdeeld naar 36 typen ongevalscenario's, zoals 'vallen van hoogte'. De ongevalscenario's werden gebruikt om zogenoemde vlinderdasmodellen te construeren. Hierin staan de oorzaken van een ongeval vermeld (welke gebeurtenissen leiden tot het optreden van het ongeval?) en de gevolgen ervan (gewond raken of dodelijk letsel?). In een vlinderdasmodel worden tevens de maatregelen genoemd die een ongeval helpen voorkomen, dan wel helpen om de gevolgen te beperken. De vlinderdasmodellen geven eveneens getalsmatig aan hoe vaak dergelijke maatregelen kunnen falen.

Vervolgens is een analyse gemaakt van de activiteiten en werkplaatsomstandigheden van de gemiddelde werknemer. Daarmee is bepaald in welke mate werknemers aan risicovolle activiteiten blootstaan en van welke kwaliteit de risicobeperkende maatregelen op de werkplaats zijn. Met deze gegevens kan per activiteit, baan, bedrijf of industrietak het risico op ongevallen worden berekend.

Trefwoorden :
kwantitatieve risicoanalyse, arbeidsveiligheid, veiligheidsbeheer, risicomodel, arbeidsongevallen

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Summary

Developments in Dutch occupational safety policy led to the initiative to build a quantified Occupational Risk Model. A quantified risk model could support companies and workers in carrying out their responsibilities to reduce occupational risk. The model supports risk reduction that is tailored to the specific needs of a company or a job.

The Occupational Risk Model is built on detailed analysis of 9000 accident reports made by the Dutch Labour Inspectorate. The consequences of interest were recoverable injury, permanent injury and death from activities at work. 36 types of accident scenarios for all types of occupational hazards were structured from these accidents, which occurred between 1998 and 2004, through a newly developed software tool, ‘Storybuilder’. These 9000 accidents are a subset of the total of 12000 incidents which were investigated in that period. The scenarios or ‘storybuilds’ then formed the basis of logical models or ‘bow ties’ of which there are 64 built and quantified from accident and exposure data using the software tool ‘Bowtiebuilder’. Exposure data on activities and specific working conditions were collected in 2006 and 2007 from the Dutch working population which totals around 7 million workers. These exposure data provide the Dutch National Average for thousands of risk related workplace conditions that affect the quality of safety barriers. In addition, nearly half a million Danish occupational accidents provided a basis for identifying hazards associated with jobs.

Together these bow ties and data enabled the building of a computerised Occupational Risk Model for assessment of the risk of an activity, a job, a company, or an industry. Data were collected on a large number of measures that influence the factors affecting safety barrier quality. Measure effectiveness was estimated and the associated costs calculated. The measures and costs information, together with the results of the risk calculations are put together to calculate the most cost effective risk reducing groups of measures. The results are shown in a graphical form.

This report gives the headlines of the project. It describes the model, the software for the user, and the data as well as the most important insights on occupational risk.

The Ministry of SZW acknowledges the participation of the Danish Working Authority, Dr K Jørgensen and the UK Health and Safety Executive, Dr T Madisson and the important contribution of these organisations to this project with the UK and Danish occupational accident databases.

1 Introduction

1.1 Program for improving occupational safety

In 2002 about 103,000 accidents took place resulting in injuries and absence from work. 3,500 accidents led to hospitalization and 91 people died because of occupational accidents (Venema et al., 2004). In 2003, the Ministry of Social Affairs and Employment in the Netherlands launched the policy program ‘improving occupational safety’ which had two strands:

1. Sector-related improvement programs aimed at behaviour change of workers were carried out by companies.

2. A project to provide a way of prioritising occupational accident hazards and to provide individuals and organisations with a way to identify the most cost-effective set of measures to improve their safety performance.

With regards to the latter, a quantitative occupational accident risk model was required to provide probabilities of accident occurrence and consequences, given a particular activity and working conditions. The research project to develop such a model, the Occupational Risk Model (ORM), was started. This project aimed to produce a software tool for policy makers, companies and workers to assess occupational accident risk and to reduce it by being able to choose the most cost-effective set of measures.

This risk-oriented approach could also provide an opportunity to contribute to a consistent occupational safety policy which ties in with the quantitative risk policies of the Ministry of Housing, Spatial Planning and the Environment and the Ministry of Transport, Public Works and Water Management in the Netherlands.

The research team ‘Workgroup Occupational Risk Model’, WORM, developed the initial risk model and a mock-up of the software tool ORM in June 2006 (Ale, 2006). The WORM Metamorphosis team, WORM-M, which was formed in the latter half of 2006, undertook the quantification process to fill the model with data and to develop the software tool as a working model.

The Occupational Risk Model is described in this report.

1.2 Target groups Occupational Risk Model

The target groups of the occupational accident risk model are:

- policy makers, to enable them to prioritise and evaluate occupational safety issues and to answer questions of parliament and society
- the Labour Inspectorate, to focus inspection strategies
- companies, workers, works councils, unions, branch organisations to carry out risk assessment and cost benefit analysis to optimise risk reduction
- insurance companies, to enable them to influence the taking of prevention measures by their clients

- safety consultants and other safety support service organisations (e.g. ‘arbodiensten’), to train and assist companies in undertaking risk assessments
- educational institutions to raise awareness on occupational risk among young workers

1.3 Scope

The data in the Occupational Risk Model relate to the Dutch working population. Data on accidents and exposure to hazards were from the working population in workplaces in The Netherlands. The accidents used were occupational accidents investigated by the Dutch Labour Inspectorate (DLI) of the Ministry Of Social Affairs and Employment. Only serious accidents, reportable under Dutch law, are covered.

Some sectors or activities are not covered by the DLI:
- self-employed and employers are not covered although self-employed are covered when they work under someone’s authority;
- cabin crew in aviation;
- ships’ crew in the shipping industry (sea and inland waterways);
- workers involved in exploration drilling and exploitation of minerals;
- Dutch companies which operate abroad are not covered but foreign employees who work on Dutch territory are covered; the Dutch Labour Inspectorate only works on Dutch territory;
- travelling to and from work is not covered. Travel by employees during their work is theoretically covered (e.g. involving drivers), but in practice traffic accidents are investigated by the police.

Accident investigation data were obtained for the period January 1998 to February 2004 inclusive (a period of 6.17 years). Surveys on *exposure* to activities associated with accident *hazards* and conditions of identified *safety barriers*[1] to the realisation of those hazards were collected in 2006 and 2007.

The model was based on events derived from acute exposures leading to accidents with injury or death as a consequence. These are one time exposures resulting in harm. The model excludes chronic exposures leading to illness and/or disease. So long term or repeated exposures leading to certain health effects such as lung disease are not part of this model. Although accidents in the home may well have similar scenarios, this risk model does not include them, nor risks to the public. It deals solely with accident prevention at work.

1.4 Process and reading guide

The WORM Metamorphosis project team was made up from experts of the Netherlands, Greece, Denmark, and the UK. The organisation is described in more detail in Technical Report 1, together with the methodology for producing the quantitative risk analysis tool in Technical Report 2.

Figure 1 shows the components of the development of the quantified risk model. Throughout the report the different components of the model are described. Annex 1 provides a glossary of some of the important terms used in this report.

[1] Terms such as exposure, hazard and safety barrier are defined in the Glossary

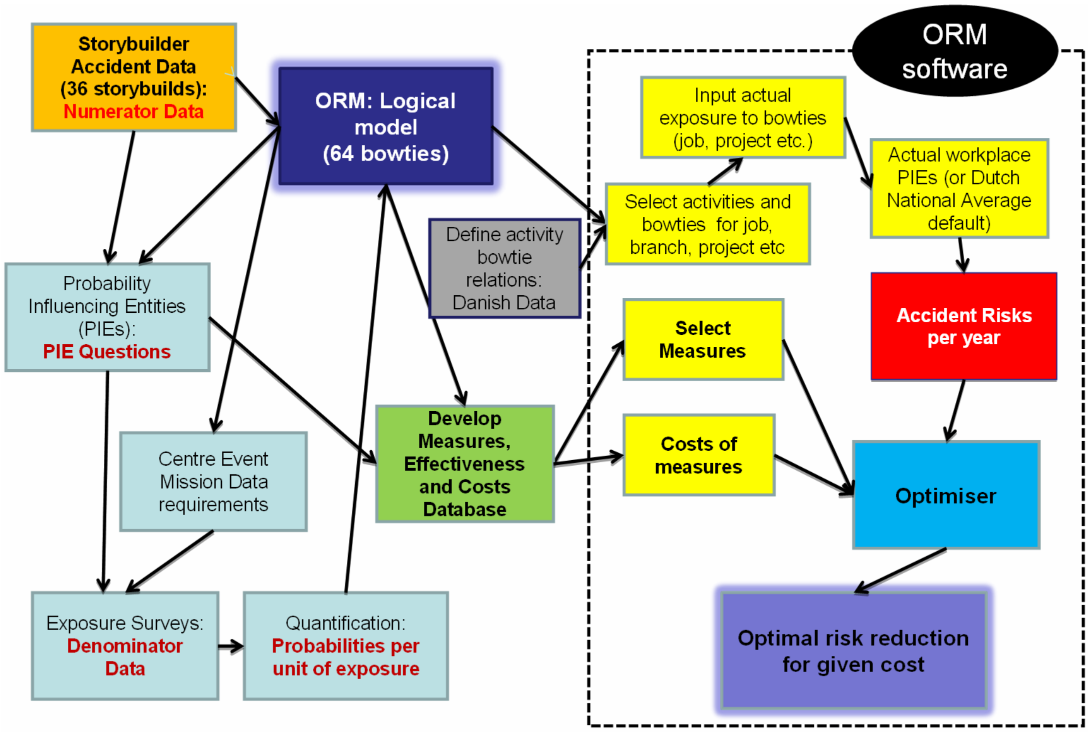

Figure 1 Components of the development of the quantified Occupational Risk Model

The ORM logical bow tie model is the central component. The logical model is equivalent to an event tree, a well established model in safety science, and provides the framework for quantification. The model contains both the causes that can lead to an accident, and the factors mitigating the consequences of the events once an accident (loss of control) has occurred, giving the model a bow tie shape. This model is described in chapter 2.

The data collection started with the analysis of accidents using a software tool called 'Storybuilder'. This is described in chapter 3, section 3.1. In Figure 1 the arrow between the Storybuilder accident data and the ORM logical model indicates the translation of 36 storybuild structures into 64 logical bow ties which are the core of the model. These storybuild and bow tie hazards lists are given in Annex 2.

Once the bow ties were produced, data on exposure were needed. These exposures concern two things:

1. the activities associated with the bow tie hazards listed in Annex 2, such as going up a ladder or working with a machine, and
2. exposure to work conditions relating to the safety barriers, like whether a machine is guarded or not, whether a ladder is long enough for the job, or whether the person is fit to do the job.

These two types of exposure survey are:

1. *mission* data survey, and
2. safety barrier or *'PIE'* questions survey - the Probability Influencing Entities that affect the chance that a barrier will fail.

The PIEs are described in chapter 2 section 2.6. The surveys for missions and PIEs are described in chapter 3 sections 3.2.1 and 3.2.2.

The combination of the numerator data (accidents) and the denominator data (exposures) provided the basis for quantifying the bow ties, giving probabilities of events and outcomes for a given exposure – the *risk*.

In addition, for the advice on follow-up strategies to the risk analysis, the model also needed data on *measures* to reduce the risk. These are measures that improve the PIEs by a given amount for a given cost. A database of measures, effectiveness and costs (MEC) was developed for this purpose. Measures are explained in chapter 2, section 2.7 and described in Chapter 3, section 3.3. Finally, a means was needed to identify which bow tie hazards are associated with which industries, jobs and activities for any given user. For this purpose nearly half a million Danish occupational accidents provided a basis for automating the identification of bow tie hazards associated with jobs. The accidents in this database, 'RAW', were each associated with an ORM bow tie (see Annex 2) which could then be associated with the accident information on the activity, job, industry, and agent of harm of the victim - all defined in association with European classifications. This use of the job-activity-bow tie scheme is explained in chapter 2, section 2.8 and described in chapter 3, section 3.4

Together these components are used in the ORM software for making a risk assessment and cost benefit optimisation for risk reduction. This software part is shown within the dotted lines in Figure 1. The software is described in chapter 2, section 2.11 and its application shown in chapter 4, section 4.2.

Results derived from the ORM software and from the individual components shown in Figure 1 are given in chapter 4.

During the project, spin-offs, both in terms of datasets and tools for analysis were realised as each component in the model development was made. These useful additional products are described in chapter 5.

Finally, in chapter 6 conclusions are drawn and recommendations given for future use and development.

Further more detailed information of the components of the Occupational Risk Model is contained in separate technical reports as follows:

1. Description of the project organisation
2. Overview of methodology, production steps and quality control
3. Occupational accidents in the Netherlands, Storybuilder & Storyfilter - The 36 Storybuilds
4. ORM logical model and Bowtiebuilder
5. Probability Influencing Entities and the PIE questions
6. Centre Event Mission Data
7. Exposure surveys
8. Bow tie models and quantification
9. Measures, effectiveness and costs
10. Activities, agents, jobs and bow tie links
11. Storybuilder software user manual
12. Bow tiebuilder software user manual
13. ORM software user manual

2 Logic and development of an Occupational Risk Model

This section outlines the basic principles and characteristics of the Occupational Risk Model (ORM).

2.1 The concept of quantified occupational risk

Occupational accidents can result in various degrees of harm to a worker. In this model harm to a worker has three possible values:

- recoverable injury
- permanent injury
- death

This distinction is related to the Dutch occupational accident reporting requirements for serious accidents addressing fatal, permanent injury and hospital treatment outcomes. The Netherlands does not require reporting on the basis of lost time. In addition it is important to have categories of harm that can be related to the dose-response modelling of the ORM model.

Occupational risk from accidents is quantified when the level of severity of the potential health damage can be measured together with the relative likelihood that each level of damage severity is expected to occur. Every time a worker performs a work-related activity and faces one or more particular hazards he or she faces the possibility of an accident that will result in one of the above consequences. Such a consequence does not happen with certainty but rather occasionally in the working population and during the lifetime of the workers. The associated risk is quantified when it is known what the probability is with which each of these possible consequences can occur during a specified period of time.

2.2 Single hazard model

The basis of ORM is the model for a single hazard. For a specific accident type (e.g. fall from height) the model provides the framework for making a quantified link between exposure to the various cause and effect factors and their relation to the outcomes.

In essence the single hazard model provides a number of event combinations. Each combination represents a collection of events such that, when all occur, an accident with a specific accident consequence occurs. These combinations of events can be considered as ‘sequences’ of events. The sequence can have either a chronological meaning or a cause-consequence meaning. Historically, this concept of events occurring in an order dictated either by the time at which they take place or by their causal link has helped both the determination of such sequences as well as the communication of this information.

2.3 Bow tie

Following this tradition, the single-hazard model of ORM has been called a 'bow tie[2]' (see Figure 2). This name derives from the schematic form of the diagrams used to depict the logical interrelations of the various events. The concept of the 'bow tie' is based on the definition of an important event that describes the main characteristic of an accident. Such events are for example a 'fall from a height' or a 'contact of part of the body with a moving part of a machine'. Appropriately, this event is called 'Centre Event' (CE). Then the model can be distinguished in two parts:

- left of the 'centre event' called the left hand side (LHS)
- right of the 'centre event' called the right hand Side (RHS)

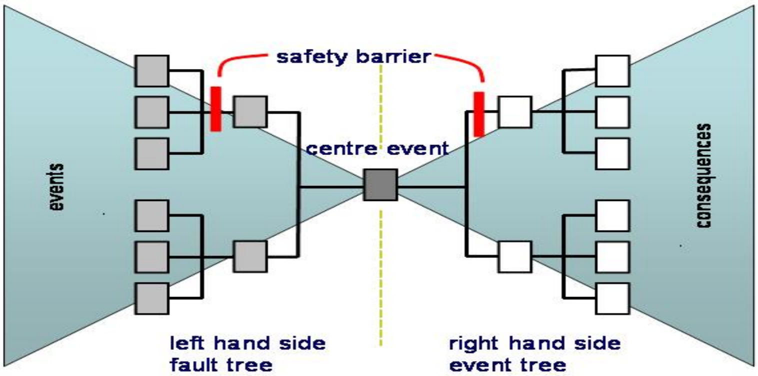

Figure 2 The bow tie model

The LHS of the model depicts the part of the model that includes the causes that led to the centre event. In this 'fault tree'-like part of the model, the accident evolves in time going from left to right.
In this direction two or more events at one level combine into one composite event at the next level.

Once the centre event has occurred, the bow tie model develops on the right-hand-side. Here all the possible and consecutive events, leading to the final consequence, are depicted[3]. In principle, the LHS of a bow tie includes all the elements of the accident sequences that correspond to '*prevention*' measures: whatever means exist that aim at preventing the centre event from occurring. Similarly the RHS of a bow tie includes all the elements that influence the final consequence given that the centre event has occurred and hence it models all the '*mitigation*' aspects of an accident.

A fundamental concept of the 'bow tie' model is the concept of a 'safety barrier'. A safety barrier is a physical entity, a technical, hardware, procedural or organisational element in the working environment that aims either at preventing something from happening (e.g. the CE) or at mitigating the consequences of something that has happened. Some of these events or barriers have a deterministic logical relationship with the event that follows them or the event that they cause. For example, 'loss of a worker's stability while on a high platform' coupled with the 'absence or failure of an edge protection-rail' result in a fall from height (see Annex 1 Glossary: Primary safety barrier).

[2] Important terms that determine the Occupational Risk Model are described in the Glossary in Annex 1.

[3] A suitable model for such sequences of events is the 'consequence tree' or the 'event tree'.

On the other hand, a second class of events in the model do not determine the outcome of more complex events but rather influence the relative likelihood of other events occurring. Thus working ‘outdoors’ in a ‘windy environment’ does not necessarily imply ‘loss of worker stability’ but it rather increases the likelihood that such an event might happen (see Annex 1 Glossary: Support safety barrier).

In conclusion, the ‘bow tie model’ for a single hazard provides a way for organising various events from a root cause via the centre event, ending up with a reportable damage to the health of the worker. Pictorially, an ‘accident sequence’ can be visualized as a path in the ‘bow tie’ that starts from the left, goes through various events of the LHS, passes through the CE and then through various events of the RHS and ends with a final consequence at the outmost right of the bow tie (see Figure 2).

The use of such a model is twofold. On the one hand it provides the accident sequences, the sequences of events that lead from a fundamental or root cause to the final consequence. On the other hand, it provides a way for quantifying the risk.

2.4 Building the bow tie model for a single-hazard

Building a logical model (or bow tie) for a single hazard is based on the existing characteristics of the working environment, the fundamental laws of physics and engineering, as well as the characteristics of human behaviour. The model and its quantification are based on the observed, historical accident data. These are in the accident reports of the Dutch Labour Inspectorate in their management database GISAI. This information has been analysed and organised in a systematic way consistent with the adopted logic of the ORM. In particular, a method and associated computer tool named ‘Storybuilder’ has been developed (Bellamy et al., 2006, 2007, 2008). This method and model are described in section 3.1 and in more detail in Technical Report 3 ‘Occupational accidents in the Netherlands, Storybuilder & Storyfilter - The 36 Storybuilds’.

In essence, the Storybuilder model develops the accident sequences or scenarios of occurred accidents through a set of rules that help in defining the safety barriers, their failure modes and factors that influence these failure modes. This information refers to both preventing as well as mitigating aspects of the accident scenarios and is organized in the form of the bow tie. The fact that there are 36 storybuilds (see Annex 2) reflects an initial decision on the way to group the data. The choice was influenced by the list of hazards in an internal document produced by the Dutch Labour Inspectorate in 2002 on a risk analysis model (AIRA) for working conditions. These hazards included e.g. collision danger, moving parts, flying parts, falling parts, cold and/or hot surfaces, and trapping/crushing/cutting danger. This list was taken on board and formed a starting point for categorizing accidents into groups. As the analysis progressed the bigger categories of accidents were split into smaller groups resulting ultimately in 36 storybuilds (Annex 2).

All the ‘structural’ information i.e. safety barriers, their failure modes (all the different ways in which barriers fail), combinations of failures leading to more general events and eventually to the Centre Event and through this and other potentially mitigating events to the final consequence, were contained in the storybuilds developed from the accidents involving the particular hazard (e.g. struck by moving vehicle). On the basis of this information a ‘bow tie’ or logical model was developed. In some cases the logic of the model demanded that the storybuilds be split into smaller groups e.g. fall from a ladder was split into different types of ladder and contact with moving parts of machines into different

activities like operating a machine or clearing a blockage. Given these further splits, 64 single hazards have been developed as bow ties (see Annex 2).
The bow tie or logical model for a single-hazard is a model exhibiting the general characteristics of the 'bow tie' concept described in the previous chapter but allowing for more sophisticated characteristics like multistate events (events having more than two outcomes, like death and recoverable injury) and probabilistic influences. The details of this model are provided in Technical Report 4: ORM Logical Model and Bowtiebuilder. A tool called Bowtiebuilder has been developed to facilitate the development of these models that are similar to influence diagrams. This tool is further described in section 5.3 and in Technical Report 12 Bowtiebuilder software and user manual

2.5 Quantification of the logical model

The Occupational Risk Model needs quantified data to make risk calculations possible. Needed are:

1. the probabilities of the (basic) events, and
2. the exposure of the workers to the single hazard and information about the working conditions.

The probabilities have been quantified as ratios of numerator to denominator where:

1. the numerator is equal to the number of observed instances of occurrence of a particular outcome of an event, and
2. the denominator is the total number of instances the event has been observed or the total duration over which the occurrences have been observed. In general the denominator of the equation is referred to as the 'exposure'.

For example, in the use of scaffolds the numerator is the number of accidents (with different outcomes of permanent or recoverable injury, death) and the denominator is the total time workers have been working on a scaffold over the period within which the accidents have been recorded. The number of occurrences is extracted from the GISAI database, using the Storybuilder tool. The total time the working population spent on the corresponding activities over the period during which the accidents have been observed was determined through surveys of the Dutch working population. Details are given in subsection 3.2.1 'mission survey'. Additional information about the prevailing workplace conditions where the accidents have taken place (e.g. whether scaffolds are equipped with 'edge protection') have been obtained through additional surveys of the Dutch working population as described in subsection 3.2.2 'working conditions'. This latter information has been incorporated into the logical model using the concept of PIE presented in the following subsection.

2.6 Probability Influencing Entities (PIEs)

Surveys of the Dutch workplace conditions concerning the quality of safety barriers were based on questions about PIEs.

In several instances the basic events of the bow tie models are simple enough to link directly to easily understood working conditions as in the event 'Protection of scaffold from being hit by passing vehicles'. Assessing the frequency with which scaffolds protected from passing vehicles are met in the working environment is straightforward since the meaning of protection is easily understood.
In other instances, however, this is not possible. For example, the event 'Condition of the scaffold floor' has to be analysed into other more detailed and more concrete factors that affect the quality of the floor. Such factors are: (i) presence of debris on the scaffold floor; (ii) presence of gaps wider than 3cm; (iii)

presence of plank over plank condition. This decomposition at a deeper level, however, would result in large models with computational difficulties. To get around this difficulty the concept of the 'barrier quality' has been adopted. According to this concept the quality of a barrier depends on the quality of the influencing factors. Each influencing factor is assumed to have two possible levels, 'adequate' and inadequate'. The quality of an influencing factor is then set equal to the frequency with which this factor is at the adequate level in the working places. The quality of the barrier is given by a weighted sum of the influencing factor qualities. The weights reflect the relative importance of each factor and are assessed by the analyst on the basis of expert judgement.[4] This way the probability of a basic event to be in one of its possible states is given by the weighted sum of the frequencies of the influencing factors.

These factors have been given the name of 'Probability Influencing Entity' or PIE. For each of the 63 hazards[5] and their associated logical models (bow ties) a set of PIEs has been established corresponding to concrete specific detailed factors concerning specific hardware presence, hardware conditions, behavioural patterns, procedural and organisational factors. These PIEs were identified from the details of the storybuild models.

Each of the basic events of the logical model has been associated with a subset of the PIEs, the working environment-shaping factors. Knowledge of the relative frequency with which the various PIEs are met in the workplace determines the frequency of the associated basic events of the bow tie, or in other words determines the input of the logical model. This model in turn provides the quantified risk associated with the particular hazard. The relation of the PIEs, safety barriers (or blocks) and bow ties is schematically shown in Figure 3.

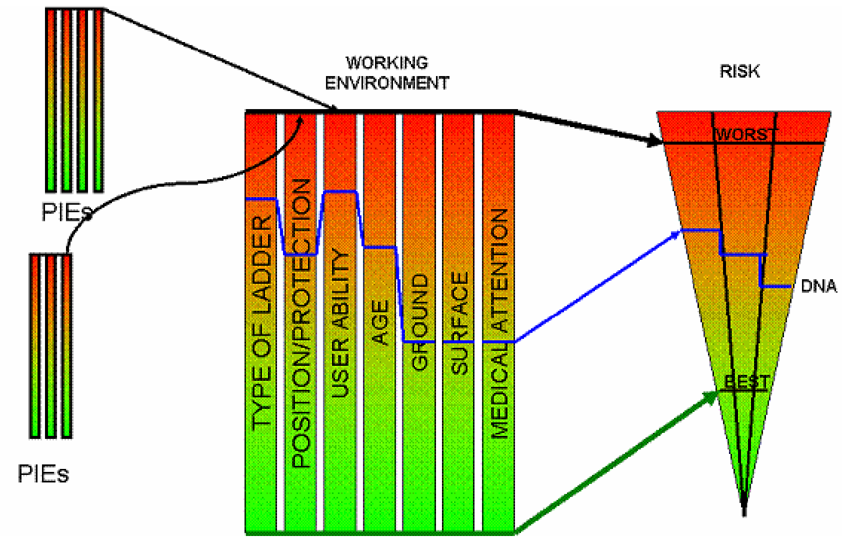

Figure 3 Relationship between Probability Influencing Entities (PIEs), safety barriers and bow ties. The PIEs are the factors which influence the probability that the safety barrier is in a good state. The frequencies with which PIEs are encountered in the workplace go into the bow tie model

In this picture the Working Environment is described in terms of the 'Type of Ladder', 'Age', 'User Ability' etc. The quality of each of these blocks is measured by the probability of being in the bad

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[4] Currently equal weights are given when the relative importance is not known.

[5] There are 64 bow ties (Annex 2) but rope ladder was excluded due to lack of data.

condition. This is indicated by a bar where the upper part (the red colour) is the worst, and at the bottom (the green colour) is the best. When all blocks are red this gives the worst value of risk (higher). When everything has the best green value the organisation gets the best (minimum) risk. Somewhere in the middle is the average that results in the DNA value of the risk (Dutch National Average). The same concepts are extended to the PIE concept. The prevailing frequencies of these conditioning factors in Dutch workplaces have been established through surveys as described in chapter 3 section 3.2.2. More details about the concept of PIEs are given in Technical Report 4.

2.7 Risk reducing measures

We now have the basic tools for risk management:
- The logical model contains the sequences of events that form an accident scenario.
- Knowledge of the probabilities of the basic events allows for the calculation of the probabilities of the accident's consequences (recoverable or permanent injury and death).
- The probabilities of the basic events are calculated in terms of the probabilities of the PIEs (as described above).

To influence the risk, measures can be introduced to affect the state of the PIEs. A measure is now defined as a collection of specific actions that result in a change of the probabilities of PIEs. These changes are then transferred into a corresponding change in the quality of the safety barrier and this in turn to the probabilities of basic events. This results in a change in the probabilities of the consequences and hence in a measurable change in the risk. This process is shown schematically in Figure 4. Looking at the example in the previous section, the measures are (1) cleaning the scaffold floor, (2) putting the planks of the scaffold floor together and (3) taking care that no planks are overlapping each other. This influences the conditions of the PIEs (i) presence of debris on the scaffold floor, (ii) presence of gaps wider than 3cm, (iii) presence of plank over plank condition. In turn this finally influences the quality of the barrier ('Condition of the scaffold floor').

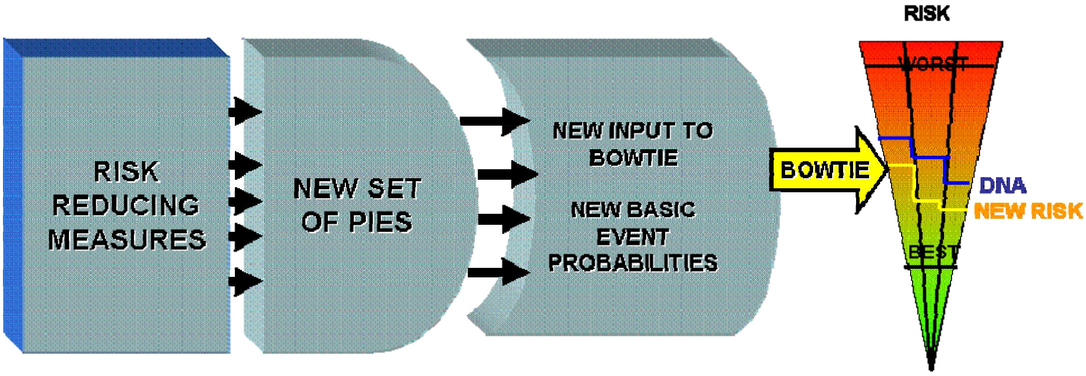

Figure 4 The influence of measures on risk. This is through the effect that the measures have on the PIEs for the safety barriers (bow tie blocks), that influence the risk per bow tie and thus the risk for the organisation

Details about the definition of risk reducing measures and their characteristics are given in chapter 3, section 3.3. This section also contains information about the cost and effectiveness of a particular measure.

2.8 Model for multiple hazards – company model

In real life, a worker is not exposed to a single hazard. Instead during the performance of his ordinary work composite tasks and complex environments expose a worker to a multitude of hazards. For this reason ORM includes a composite model that allows for the exposure to multiple hazards simultaneously or consequently during different phases of the work or during different time intervals of the work. Furthermore, the composite model allows for the consideration of more than one person. Risk is then quantified at different levels of composition. The composite model is thus suitable to a single person performing a variety of tasks, to a small enterprise with only a few employees or to a larger organisation. A tree-like structure is used to develop the composite model of ORM as depicted in Figure 5.

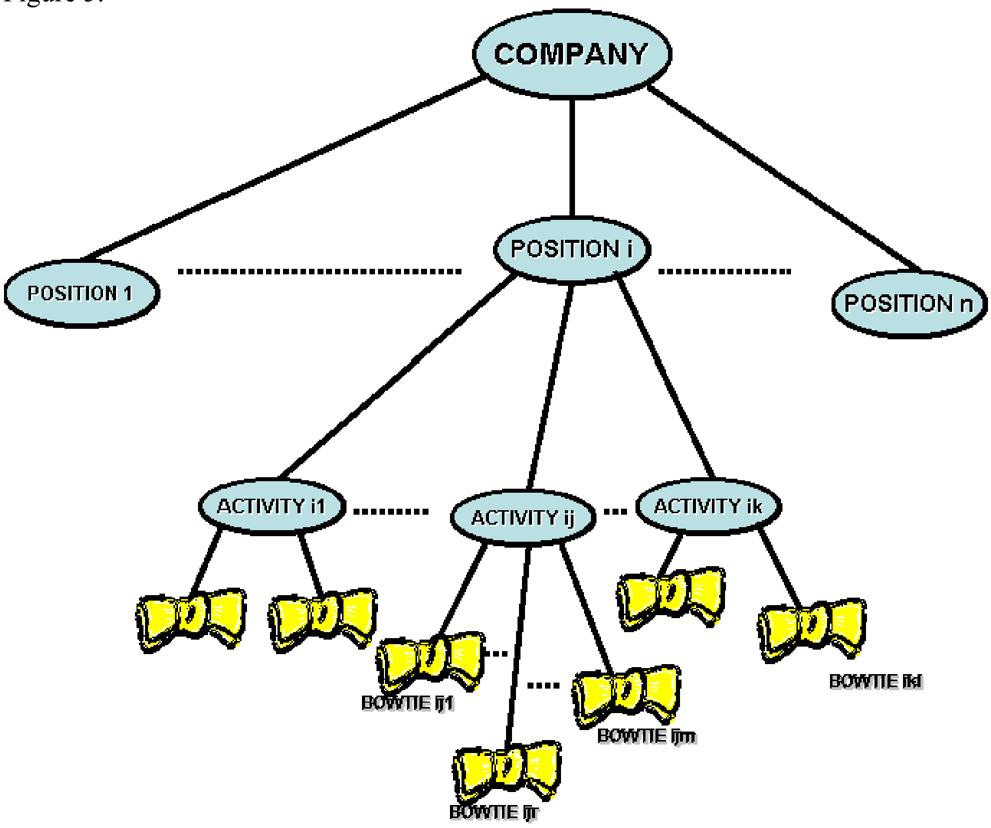

Figure 5 Composite ORM model structure for multiple hazards

The levels are as follows:
– The top level of the tree corresponds to the entity under analysis.
– The second level provides the type of 'company-position' corresponding to a specific type of job along with the number of people in each position type.
– The third level of the tree describes for each position-type the number of activities required to perform the corresponding job along with the respective frequencies.

This means that a particular job is described in terms of a number of activities each one of which is performed a specific number of times over a given period e.g. four times a month. Finally, performance of a specific activity is associated with a number of single hazards (out of the 64 single hazards) and a corresponding duration of exposure to each and every hazard.

Contrary to the single hazard model the structure of the composite model is not fixed. Only the architecture of the model is determined and has the tree-type form described above. Using this format and the basic library of the 64 single hazards an extremely large variety of composite models can be built to suit almost any conceivable practical case.

2.9 Comparing different levels of risk – efficient frontier

Once a model for quantifying the risk has been developed (as described in section 2.8) a particular set of measures can be evaluated in terms of their impact on the risk as indicated in Figure 6. Alternative sets of measures result in a different quantified assessment of the occupational accident risk.

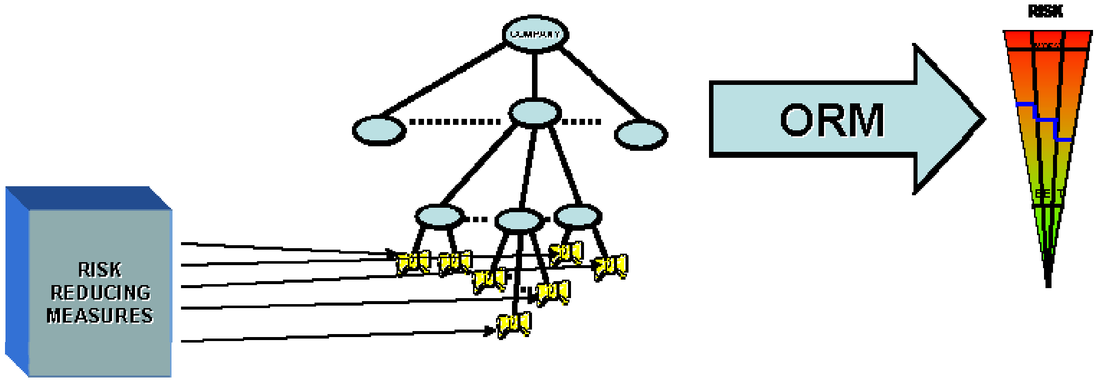

Figure 6 The calculation flow in ORM visualised

Furthermore, each set of measures might be associated with a different level of cost and related risk, as shown Figure 7 with points c_1 and c_2. Comparison of these two alternatives is easy because c_1 is better for both criteria (lower risk and lower cost). Actually c_1 is better than all alternatives corresponding to points in the shaded area in Figure 7. Comparison of points in the lower left rim of this area, the red line, however, is not straightforward. Taking any two points in this set, one will have higher cost but lower risk than the other. Going from right to left over this line the risk decreases. Going from left to right, the cost decreases. The points on this line are the most efficient risk-cost combinations, and are collectively called the efficient frontier. Deciding which point out of any two on the efficient frontier is more preferred requires a value judgment.

This concept can be used in more than one dimension. ORM evaluates alternative risk reducing strategies in four criteria:

1. monetary cost
2. risk of a recoverable reportable injury
3. risk of a permanent reportable injury
4. risk of fatality

Knowledge of the efficient set of alternative risk reducing strategies constitutes very powerful information and it can guide decision making in a variety of situations including the existence of specific risk threshold values that must be met or budget constraints.

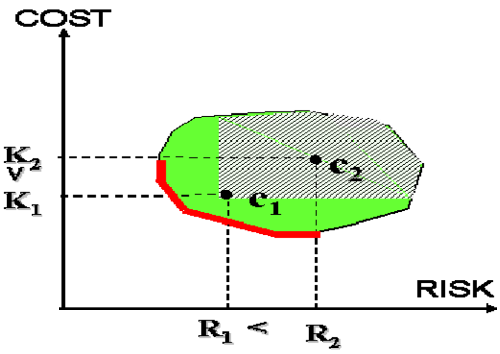

Figure 7 Comparison in multiple dimensions - the concept of the efficient frontier. Measures strategy C1 costs less and produces a lower risk than C2 which costs more. The points on the red line are the most efficient risk-cost combinations

2.10 Risk management – optimisation

In the context of ORM, risk management is equivalent to generating the set of efficient risk reducing strategies out of a set of possible strategies. In practice the set of possible strategies is extremely large. Direct evaluation of all possible solutions and determination of the most efficient risk-cost combination through straightforward comparison is no longer practical if possible at all. In situations like that, techniques of mathematical programming can be used to facilitate and expedite the determination of the best combination. ORM employs a multi criteria optimisation technique called ‘Genetic Algorithm’ that determines the set of efficient strategies out of a number of available risk reducing measures acting upon and affecting specific working-environment-shaping factors. The results are given both in pictorial as well as in analytic form at any degree of user-defined resolution. More information on the type of results is given in section 4.2.

2.11 Software development for the model

Sixty three logical model bow ties, the PIEs, measures and the optimisation tool have been translated into a software tool using ‘Dutch National Average (DNA)’ data. Specific models can be built interactively by the user for calculating the risk:

1. A large database of types of job-industry-activities-hazards combinations observed in actual accidents helps the user determine the hazards that are associated with a job (more details are given in section 3.4).
2. The user can change the PIE values to reflect the case specific working conditions.

3. A library of potential risk reducing measures is provided along with the capability of defining additional user-defined measures (more details are given in section 3.3). The user can choose a strategy from the efficient frontier

The software effectively contains two parts, the engine performing the calculations and the user-interface. Stakeholders were involved to a limited extent in the collection of requirements for inputs and outputs of the software. Policymakers, large corporations, researchers and consultants provided information for further development from different points of view. ORM software is further described in section 4.2

3 Data collected and analysed

There are four different data sets:

- accident data with causes and underlying causes, effects and mitigation
- data on exposure to hazards and working conditions
- measures, effectiveness and costs
- sector, jobs, activities and hazards relations

3.1 Accident data: inventory of hazards, causes, effects and mitigation

The systematic analysis of accidents through modelling of scenarios laid the foundation for structuring the logical model. The accident analysis was made possible through provision of detailed investigation reports from GISAI (Geïntegreerd InformatieSysteem ArbeidsInspectie) the database of the Dutch Labour Inspectorate together with the software tool Storybuilder developed specially for the accident analysis.

In 2004-2006 a team was formed for the sole purpose of analysing these occupational accident investigation reports. In this period the software Storybuilder was developed in an evolutionary manner to support the team of Storybuilders (Bellamy et al., 2006, 2007, 2008). Accident investigations of reportable accidents were analysed and bow tie structures or 'storybuilds' produced according to strict building rules[6]. The groundwork was done to get from individual accidents or 'horrible stories' to scenarios, sequences of events leading to paths through a bow tie-shaped structure. Dominant pathways could then be identified.

It was essential to find data with detailed enough descriptions of events causing the loss of control that results in an accident, the release of the hazard agent that leads to harm and the events which might mitigate or escalate the resulting effects and consequences for the victims. The important events are the failures of safety barriers for prevention of the release of a hazard agent and for mitigating the effect on victims. In the pathway of an accident scenario, not only the direct but also the underlying causes of accidents were of interest, the latter being the management factors also called 'delivery systems' which contribute to putting a barrier in place and keeping it used and intact.

An example of a storybuild is shown in Figure 8. It shows accident pathways passing through the structure. The number of pathways were counted for the events in the scenarios and laid the foundation for quantification in the logical bow tie models. Each line in the diagram represents one single accident, going from left to right through the event boxes. In the middle is the centre event. On the left hand side are the basic causes, the failures of safety barriers against hazard release. On the right hand side are the consequences and mitigating barriers such as emergency response.

[6] The storybuilding rules include how to capture the event sequence, which must always pass through a centre event (the release of the hazard agent), creation of safety barriers and their failure modes, and loss of control events.
See Technical report 3.

Until now, 9142 reported investigated accidents have been analysed in Storybuilder[7]. These accidents are distributed across 36 storybuilds, graphical structures in the software Storybuilder each representing a type of occupational accident hazard, characterised and named in each case by the release of the hazard agent or centre event of a bow tie of causes and effects.

These 36 storybuilds cover every type of occupational hazard encountered in the GISAI database. The 36 storybuilds were later further subdivided into 64 logic models, the bow ties. The list of 36 storybuilds and how they relate to the 64 bow ties is given in Annex 2. The process is described in more detail in Technical Report 3.

Coded boxes in the storybuild diagram have been used to represent different factors. Box codes help the user distinguish different types of events. Boxes with the same codes have other attributes in common like colour and shape which makes them visually easier to spot when 'reading' a storybuild. Considerations in the event sequence of an accident, which preserves a temporal causality from left to right in the storybuild diagram, include:

- Starting conditions
    - A - activity at time of accident
    - ET - equipment type
- Failures and successes:
    - DS - management delivery system failure
    - T - barrier task failure
    - BFM - barrier failure mode
    - IF - incidental or influencing factor
    - LCE - loss of control event
    - REG - compliance with regulations
- CE - Centre event
- Effects:
    - DDF - dose determining factor
    - INJP - part of body injured
    - INJT- type of injury
    - HOSP - whether hospitalised
- Consequences
    - FOD - final outcome death
    - FOI - final outcome probably not permanently injured
    - FOP - final outcome probably permanently injured
    - ABS - absence from work

European classifications were used to capture fine details of things such as equipment types, injured body parts and injury types.

[7] It has to be kept in mind that not all accidents are reported. Underreporting could be as high as 50%. However, it is considered that all deaths are accounted for. It is also always the case that a description of an accident is one or more steps away from the accident itself and has already been interpreted by the witness or the inspector.

rivm

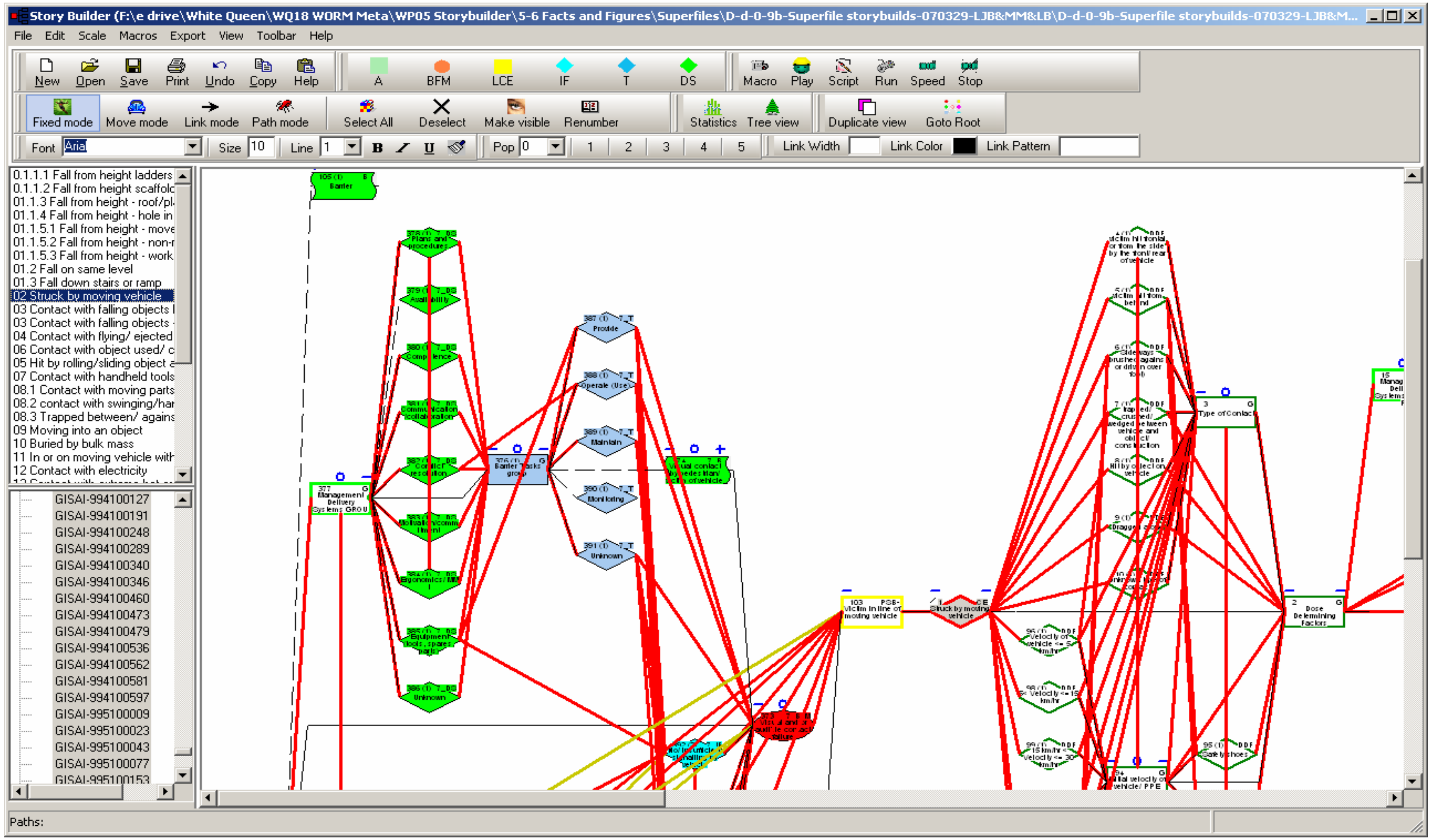

Figure 8 The Storybuild interface showing an example of one of the storybuilds. The lines passing through the structure are the accident paths. The diamond at the centre is the centre event. To the right are dose determining factors. To the left is a loss of control event and to the left of that an oval box, one of the barrier failures. This in turn is attached left above to four barrier tasks (plus a box for unknown) preceded by a block of the eight management delivery systems (and a box for unknown)

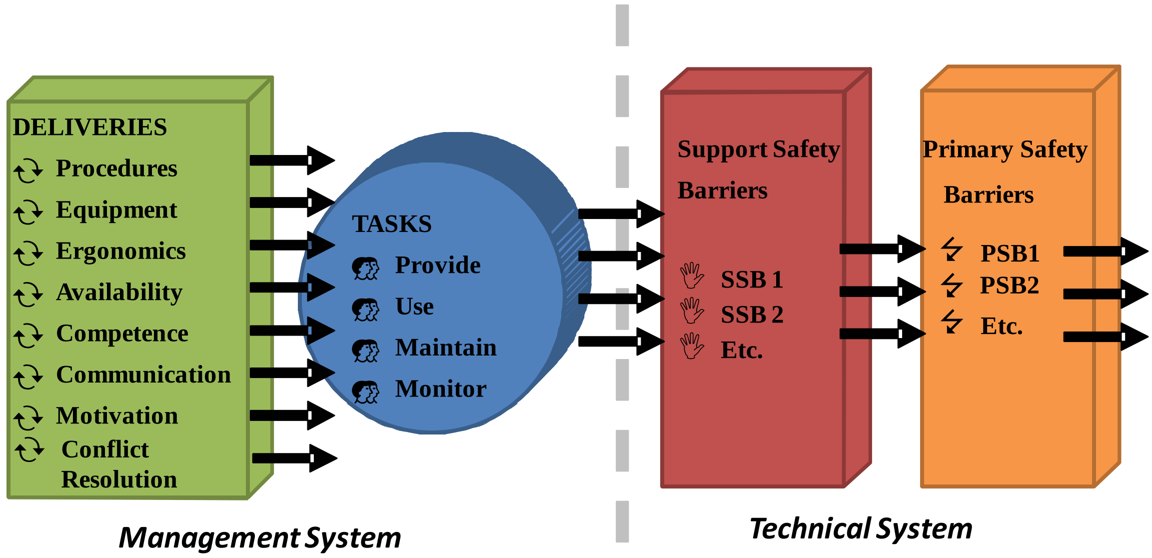

Figure 9 Delivery system and barrier task structure linked to safety barriers.

The barrier failures are important for the development of the logical bow tie models. In the Storybuilds every barrier failure mode is connected to a management system and also to influencing factors which together are used to determine the PIEs (see section 2.6). Figure 9 shows the eight management delivery systems connected to the tasks which preserve the support safety barriers which in turn affect the primary safety barriers.

For example, one support safety barrier is the loading of a vehicle which affects the primary safety barrier of vehicle stability in the bow tie 'In or on a vehicle with loss of control'. The delivery systems provide the controls, criteria and resources for carrying out the barrier tasks, in this example the safe loading of the vehicle. The modelling principles follow the I-RISK study for integrating management and technical systems (Bellamy et al., 1999; Oh et al., 1998; Papazoglou et al., 2003). The barrier tasks are Provide, Use, Maintain, and Monitor. For example, provide a load limit, keep to (use) the load limit. A barrier cannot be used if it is not provided and it has to be maintained in a good quality state and monitored to ensure that is being achieved.

In another example a barrier failure might be failure to use the correct tool for the job. The way the scheme works is that if that failure occurred because the worker did not use the guidelines for which tool to use for the job, the delivery system 'Procedures' and the task 'Use' would be selected in the link to the barrier failure. If however the correct tool was not provided then the failure would be identified as a failure in 'Equipment' and the task 'Provide' for the same barrier failure mode. Many combinations of delivery-task failures are possible, but usually a barrier has dominant underlying combinations of causes. So, the Storybuild models provide the basis for quantifying the frequency of management and barrier failures together, a first in accident analysis history. The deliveries-tasks data related to the management delivery systems are more detailed than the logical risk model currently models in ORM.

The use of Storybuilder allows the user to interactively explore the structures and data as described in section 5.1. Many options for data analysis are available and incorporation of further data from GISAI allows industry sector specific perspectives which can assist in determining inspection strategies. The tool for filtering sector specific perspectives, Storyfilter, is described in section 5.2. A standardized set of facts and figures data are further described in section 4.3.1 and in Technical Report 3. User manuals for Storybuilder and Storyfilter are to be found in Technical report 11.

3.2 Assessment of exposure to hazards and working conditions

Exposure data needed to make risk calculations possible were collected in internet surveys. First, a large internet survey, the 'mission survey', was carried out to obtain data showing how long workers are exposed to the 64 occupational hazards (Annex 2). Then, for each hazard, a separate internet survey was conducted to assess data on the working conditions of workers exposed to the hazards.

The internet surveys were run by TNS NIPO (Dutch Institute for Public Opinion and Market Research) because they offered a large representative panel with a useful source population. Figure 10 shows the coherence between the two types of surveys that were conducted to assess exposure data for ORM. The Figure shows that exposure to working conditions were calculated for 63 of the 64 bow ties. For five of the bow ties exposure data were assessed in pilot studies in the WORM-1 project. One bow tie (rope ladder) was excluded.

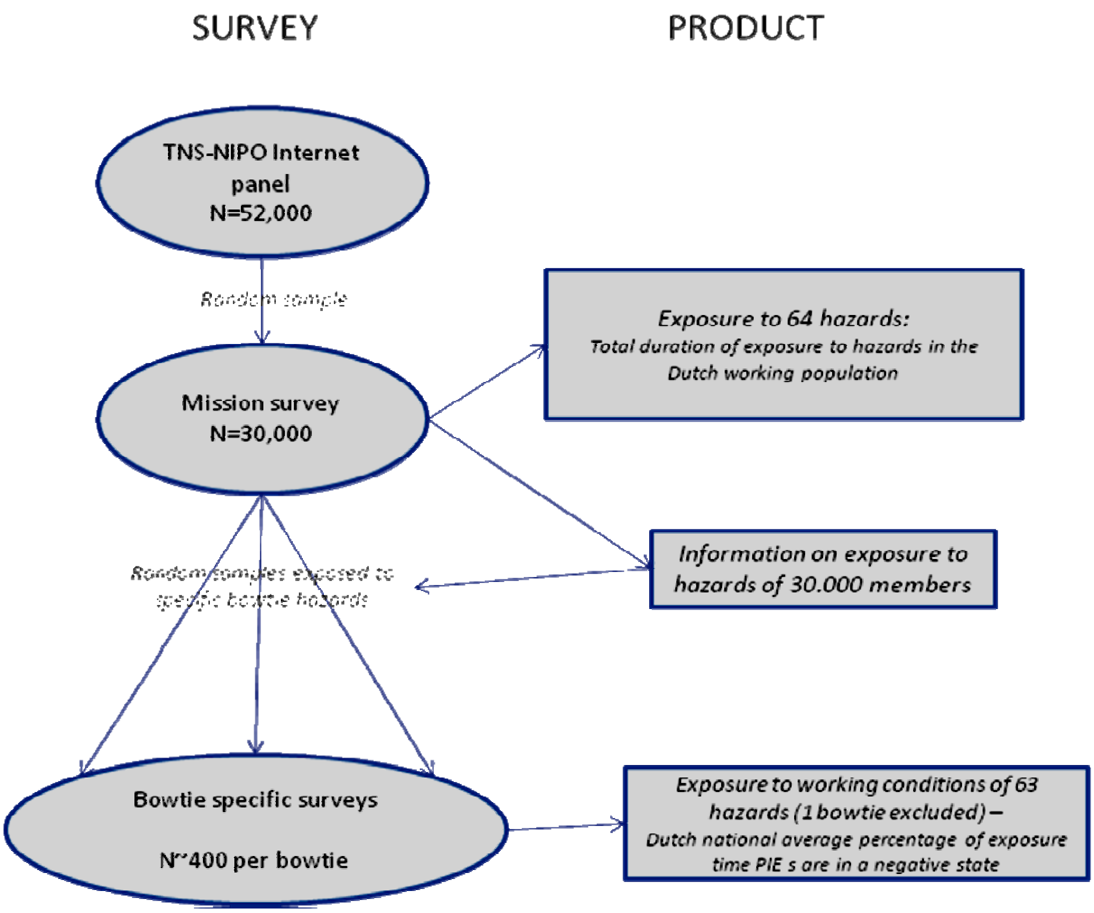

Figure 10 Approach used for the exposure surveys

3.2.1 Exposure to hazards: the mission survey

In the Occupational Risk Model, exposure relates to those activities or situations during which the worker is at risk of having the accident as described by the centre event of the bow tie. These activities/situations are called 'missions'. For quantification of the risks, ORM requires the total duration (number of hours) of exposure to each of these missions in the Dutch working population. An example definition of a mission is shown in Table 1.

Table 1 Example definition of a mission

Example of the definition of the hazard (mission) related to Bow tie 2 *'struck by moving vehicle'* *Number of hours workers are a pedestrian at locations with moving vehicles during work. This includes working on industrial premises, in warehouses or at loading/unloading bays, or along the public highway in the role of (for example) road construction worker, garbage collector, roadside vehicle repair mechanic/pick-up service or police officer. Normal traffic activity as a user of the public highway (including commuting and business travel) is not included.*

With a view to time, budget and whether the results would be adequate, it was decided that conducting a nationwide internet survey would be the best method when compared to others like on site observations or expert judgement.

In the spring of 2006, a pilot mission survey was carried out among 2000 members of the internet panel of TNS-NIPO to test the approach for the mission survey. The findings of the pilot were evaluated in a technical committee meeting with the quality advisor. As a result, procedures and weighting factors were adjusted, the questionnaire was refined and the formulation of missions was sharpened. For the model this was an important step as it gave focus by distinguishing and freezing the definitions of missions for which exposure was measured. This had an impact on the bow tie surveys too. The methodological implications of the survey procedures were also relevant to the model and the software.

In November 2006 the final mission survey was carried out among a random net sample of 30,000 members of the internet panel of TNS-NIPO. For each hazard the respondents filled out how many hours they were exposed in the week preceding the survey. Afterwards, this weekly exposure was extrapolated to yearly exposure, effectively based on 42 working weeks a year.

To obtain representative exposure data for the Dutch working population, major deviations from the survey sample with known population distributions (CBS, 2006; Bossche et al., 2006) were corrected by applying a weighting factor. Aspects of the population distribution that were considered in this weighting procedure were: sector, job type, type of employment, education level, age and sex[8]. A multiplication procedure was used to obtain the numbers for the total sum of exposure time to specific hazards for all workers in the Netherlands. Table 2 gives an example.

In the end, for all (sub) bow ties, the sum of exposure duration (hours) - extrapolated to the same period as the accident period analysed - was used for the quantification of the risks in the model.

[8] Since the accident population, derived from the GISAI-database, does not include some specified occupational groups, these occupational groups were excluded from the exposure data. The same holds for self employed people when not working under the authority of others.

Table 2 Example of exposure characteristics resulting from the mission survey: exposure in the Dutch working population to the hazard (mission) related to Bow tie 2 *'struck by moving vehicle'*

Total exposure (sum of exposure hours)	648,000,000	hours per year
Number of exposed (in survey week)	1,280,000	workers in NL*
Median of exposure (exposed only)	250	hours per year
Total exposure in accident-period**	4,000,000,000	hours

* For comparison: the total number of workers in NL was 7.815.009 (= average population size in 2000-2003, which was the basis for extrapolation of the survey results to the level of the Dutch working population).
****** For the quantification of ORM, the exposure was extrapolated to the period in which accident data (from GISAI) have been included in the bow tie model (6 years and two months).

The constraints of time and costs have an impact on the validity and reliability of the data. However, since a relatively large sample size was used, the panel was representative, and checks on the quality of the questionnaire and the survey were built in, the surveys deliver a fair estimate of exposure to hazards in the Dutch workforce. The exposure data are representative for the characteristics considered in the weighting procedure. Differences may remain for other characteristics of the working population (e.g. ethnicity). The period of exposure measured (2006) was not the same as the period covered for by the accident data (1998-2004). Ideally, data on accidents and exposure would cover the same period, which should be kept in mind for future updating of accident data and exposure data for the model.

3.2.2 Working conditions

For each of the hazards in ORM a set of PIEs (Probability Influencing Entities) was established per barrier or basic event corresponding to concrete, specific and detailed factors concerning behavioural patterns, hardware presence, and rules etc. which affect the quality of safety barriers. Data on the frequency with which these PIEs are met in the workplace were assessed in the bow tie specific internet surveys.

Table 3 Example of PIEs for one barrier in bow tie 2 'struck by moving vehicle'

* Barrier = Location / position of pedestrian

* PIEs: 1) measures for separating pedestrians and other traffic
2) use of these measures
3) passing close, in front or behind vehicle

Pilots were carried out for the data collection for the bow ties 1.1.1.1 fall from placement ladder and 1.1.2 fall from scaffolds[9]. On the basis of the findings from the pilot surveys, the approach for the entire quantification process was laid down, including a standard protocol and procedures and resources. The data on working conditions were assessed in internet surveys in cooperation with TNS-NIPO. For each of the bow ties, questions to assess the occurrence of the negative state of PIEs were

[9] For bow tie 1.1.1.1 exposure data were assessed in a written survey among workers and through expert judgements. For bow tie 1.1.2 (including the sub-bow ties 1.1.2.1, 1.1.2.2 and 1.1.2.3) a pilot internet survey was carried out by MWM2/Panelclix.

developed in cooperation with the storybuild-analysts, the Bowtiebuilders for the logical model, and the survey specialists, and were monitored by the quality advisor.

Respondents for each of the bow tie surveys were randomly selected from those members of the internet panel of TNS-NIPO that were - according to their answers in the mission survey - exposed to the hazard associated with this bow tie. The aim was to have a representative net sample of 300-400 respondents in order to present results within acceptable limits of precision and reliability.
Respondents were asked to indicate on a scale from 0-100% the percentage of exposure time a certain condition (failing PIE) exists; the higher the percentage the more negative the PIE condition. This continuous scale was chosen in order to obtain precise figures, which is to be preferred especially when conditional probabilities have to be calculated. Exposure period referred to the past 12 months in order to rule out seasonal variations.

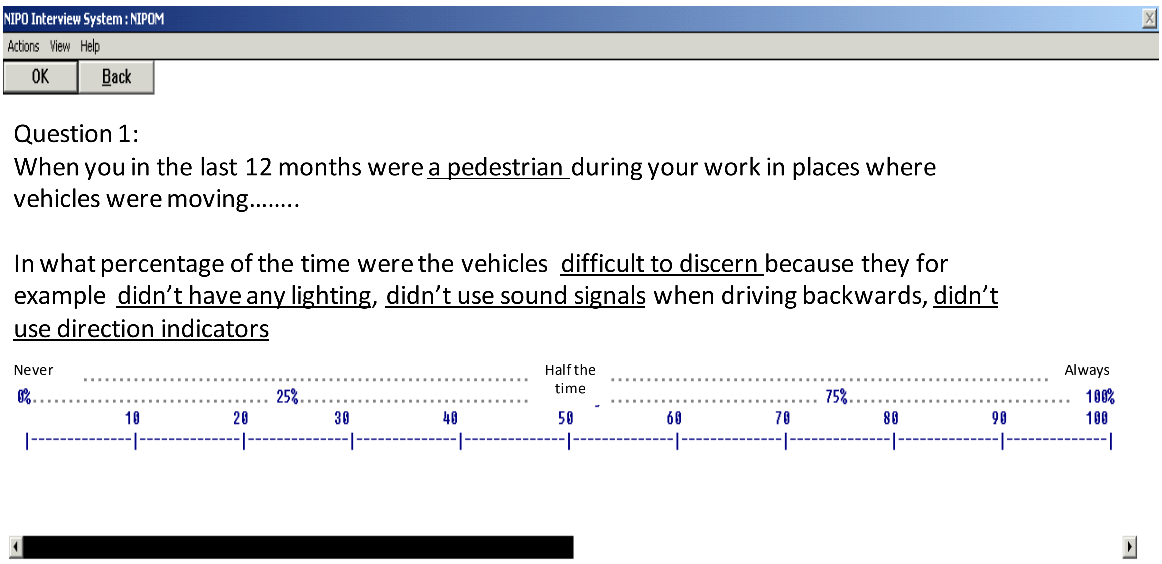

Figure 11 Example survey question interface: respondents had to move the time-bar to give the desired % of exposure time.

After a quality check on the survey data, the average percentage was calculated for each PIE, weighted for the mission exposure. These average percentages were used for quantification of the bow tie models.
Altogether, it was possible to collect data on working conditions at a very detailed level.

These surveys deliver a wealth of detailed information on exposure to specific working conditions in the Dutch workforce. As with the mission survey, the constraints of time and costs have an impact on the validity and reliability of data resulting from the bow tie surveys. The original plan to consult experts to validate the contents of the PIE questions could not be executed. Early in the process, some questionnaires were tested among respondents, and consequently improved. It was not possible to perform such pilot tests for all questionnaires. It should also be kept in mind that the exposure data resulting from the internet surveys are based on self-reports of workers; it is known that it is difficult to accurately estimate exposure. Furthermore, the period of exposure measured (2006-2007) was not the same as the period covered for by the accident data (1998-2004), working conditions may have changed due to legislation or new technologies.

3.3 Measures

3.3.1 Data needed to influence the risk

Measures give the ORM user the possibility to interact with the program. Here the user can intervene and see by how much the risk can be reduced as a result of introducing measures. The following data have been collected or produced for this purpose:

- A library of measures which can change the values of the Probability Influencing Entities (PIEs) of the model
- Detailed descriptions of measures including references to norms and standards
- Costs of measures calculated using a selection of relevant items, item cost estimation based on common implementation and combined in a generic function;
- A list of actions that a measure performs when applied - this is the link between measures and model;
- An estimate of the effectiveness of a measure that is the ability of a measure to reduce the risk given the actions it will perform/induce.

The model needs costs and effectiveness of measures and the relations between measures and PIEs to calculate the best solutions for risk reduction per consequence. A solution is actually a set of measures for a given cost (see section 2.9 on the efficient frontier).

The user needs the description of the measures as a guideline for implementation. The relation with the PIEs, in the form of so called *PIE actions*, tells the user what changes he should look for in the real world. This also helps the user if they want to make their own estimation of the cost of a measure in the ORM software.

3.3.2 Definition and collection of measures

The measure collection was last in a sequence of steps to develop the components for ORM. The basis for measure collection is the PIEs in the model as described in chapter 2 section 2.6. The measures need to be relevant to these PIEs. Only where PIEs were quantified by surveys are there measures available.

The collection consisted of a mix of generic and circumstance specific measures aimed at strengthening organisational, human (behavioural) and technical aspects of barriers. Generic measures include training, inspection, physical barriers, detection, signs and warnings. The collection was aimed at well established, proven concepts. There are no new solutions. Important sources for the collected set of measures are well established checklists, safety manuals, procedures, training schemes, mandatory levels of education and European and Dutch norms and standards. More details can be found in Technical Report 9 of the sources and the descriptive fields.

3.3.3 Impact of measures: influencing risk from PIE to barrier

The types of data needed are defined by the model and choices that were made during the modelling process.

A measure influences working conditions in the direction of decreasing risk.

Table 4 Example of how measures relates to a barrier – type or condition of stepladder

Bow tie:	1.1.1.3 Fall from height – stepladder or steps
Barrier:	Type or condition of stepladder or steps
PIE:	Surface condition of steps
PIE question:	What percentage of the time that you were working on a stepladder were the steps slippery e.g. slippery by itself or due to paint, mud, snow or other slippery material
PIE action:	Ensure that the rungs of the stepladder have sufficient grip
Measures:	Use anti-slip treads on ladder/steps/stairs Preventive maintenance system Visual inspection before starting work Periodic inspection and repair

One PIE-action can be carried out by more than one measure. The PIE-action 'awareness of the risk on a roof, when walking backwards' can be carried out by executing one or more of the following measures:

– toolbox meeting
– training
– safety harness
– fall protection around holes

The other way around a PIE-action specifies the measure. The measure 'toolbox meeting' can be found in the database in combination with several PIE-actions:
– awareness of the risk on a roof, when walking backwards
– do not load a crane with more than the maximum load
– awareness of the risks of working on a vehicle

3.3.4 Effectiveness

The effectiveness of a measure says something about its ability to affect the negative state of a PIE, notably the ability of the measure to close the gap between the current PIE value and a PIE being in a negative state 0% of the time. It proved to be a difficult concept to quantify using existing sources. Literature study, assessment of public sources and consulting of experts showed that there were not enough data available to base the effectiveness on.

As an alternative, an effectiveness prediction system was developed. The system assigns effectiveness to a measure based on measure characteristics. In the current system there are two dimensions:

– the type of measure (the source)
– what it influences (the application)

In both cases there are three possible values:
– technical - technical measure, hardware application
– organisational - procedural measure, organisational application
– behavioural - behavioural measure, human application

These are defined in the Annex 1 Glossary (see Measure).

How these dimensions relate to one another can be shown as follows in Figure 12

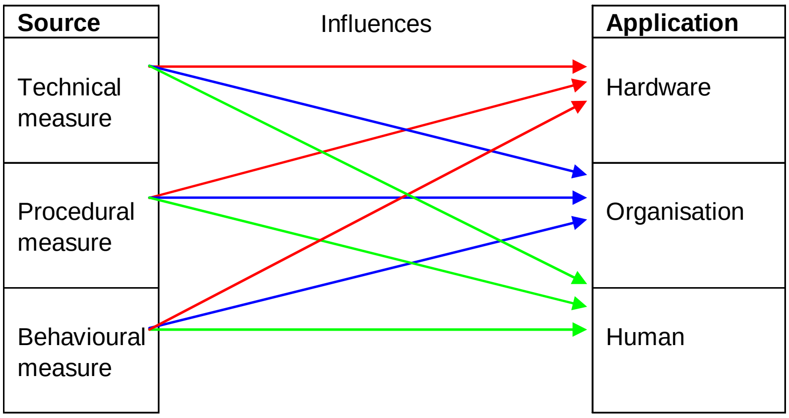

Figure 12 Categorisation of measures

The effectiveness is determined for every category. Table 5 shows the percentages used as a basis for the effectiveness. The user may change this for his or her situation.

Table 5 Percentage effectiveness per category of measures

Application: / **Source**	Hardware	Organisation	Human
Technical measure	80%	70%	50%
Procedural measure	60%	60%	50%
Behavioural measure	50%	50%	40%

Each measure can affect more than one PIE and each PIE can be affected by more than one measure. The PIEs determine the quality of the barrier, so via the PIEs the measures influence the state of the barrier. Each measure has an ability to reduce the gap to perfection. This is its *effectiveness*. So, for example, if a PIE is in a negative state 40% of the time and the effectiveness of a measure to reduce the gap to zero is 75% then it reduces it by (40% x 0.75) = 30%. The new negative PIE value is then (40% - 30%) = 10%. Suppose the PIE were ‘Detection of hazardous atmosphere’. The value of 40% would mean that 40% of the time that people can be exposed to a hazardous atmosphere a detection system is not in place. The gap to reduce is 40% and measures have to be found to reduce that gap. It is this gap the measure is targeting. If the effectiveness of a measure in combination with the action ‘detect hazardous atmosphere’ is estimated as being 75% e.g. an estimate of applying hardware to measure the atmosphere, then the gap will be reduced to 10% and the next measure will target the remaining gap of 10% and so on (so it can never be totally closed by the measure). This is shown in Figure 13.

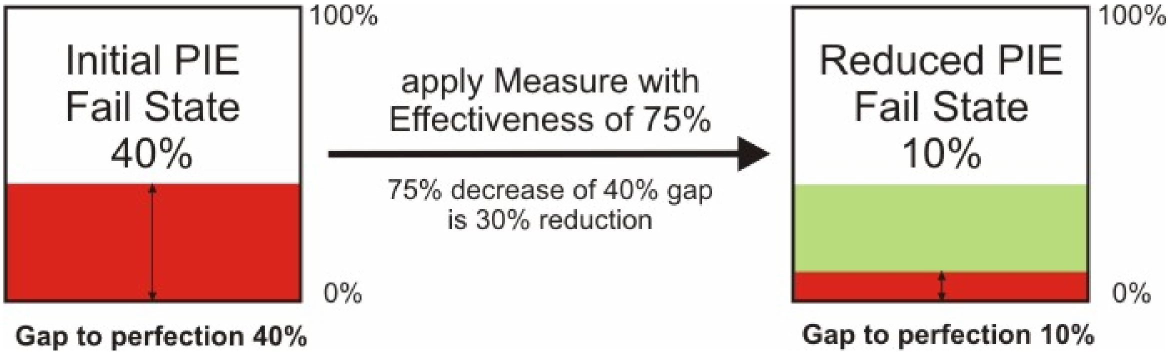

Figure 13 The effect in the model of applying a measure on a PIE in a negative state 40% of the time (e.g. 40% of the time that people could be exposed to a hazardous atmosphere there is no detection system for a hazardous atmosphere). When applying a measure with an estimated 75% effectiveness on the PIE state, the measure closes the gap to perfection by 75% and leads to a negative state 10% of the time

3.3.5 Costs

The main challenge to collecting costs of measures is the face value validity. The range of possible implementations and differences in (size of) companies and company strategies makes it almost impossible to present cost figures that will be considered valid by every ORM user. That is why:

- the most common implementation and the most common company characteristics (in a certain industry) are presented as default;
- only the most relevant direct costs have been considered.

The cost of a measure has a fixed component (a one time payment at purchase) and a variable component. The variable component is based on the expected lifetime of a measure. Both components can be changed by the user. Human labour is available in three levels of wages/tariffs. All kinds of indirect potential benefits (like production increase) or less injury time and potential costs (more staff needed, extra storage) are not taken into account.

The costs are checked against multiple sources using desk research of price catalogues. Furthermore, bids were asked for, and comparison of offers on websites of large suppliers took place. For certain areas, like construction, data on costs were checked by consulting experts in the field.

3.4 Jobs, activities and hazards

Many people are not aware of all the hazards that they could be exposed to when they do their job. Sometimes workers undertake tasks which are not part of their normal work. There were no available schemes linking jobs and hazards or activities and hazards so such a scheme had to be made. For that purpose a rich source of data, the Danish occupational accident database RAW, was used

The Danish database had the advantage of a) being sufficiently large to cover the activities and jobs that might be encountered amongst users, b) having a coding of accidents that enabled systematic and bulk classification of accidents as bow ties without having to read details of the accidents other than as spot checks and c) having international classification schemes on the dimensions of interest like job and industry and d) a European classification of activities and of material agents involved. The Danish data originate from the Register of Accidents at Work and consist of over 480,000 reported accidents resulting in at least one day of absence from work, starting the day after the accident, registered in the period 1993-2002. The data are quantitative, include all hazards defined in the risk model and all possible types of industry and job, activities and agents. Most of the data in the Danish database have been classified according to the classifications used for the European Statistics on Accidents at Work, ESAW (European Commission, 2001). Comparability of the Danish and the Dutch situation is not known exactly, so it had to be assumed that in general the Danish and Dutch labour force undertake comparable activities relating to comparable hazards. Based on a comparison of data sources and the assumptions made, it was decided to construct a database with information on the link between jobs, industries, activities, agents and hazard all based on Danish data.

Job

Job is defined as the occupation of the victim of the accident. The job list incorporated in the model is based on the international standard classification ISCO-88-COM (Elias and Birch, 1994). For the model some small modifications have been made to the official classifications. As there is no official Dutch translation of the ISCO-88-COM classification, a translation was made for use in the risk model.

Industry

The industry is defined as the economic activity of the employer. The industry list, incorporated in the model, is the international standard classification NACE (European Commission, 2002).

Activities and Agents

Activity is defined as the specific physical activity of the worker at risk. By performing this activity workers are exposed to one or more hazards that may lead to an occupational accident. Agent is defined as the principal material agent associated or linked with the specific physical activity performed by the worker at risk. The activity list and agent list incorporated in ORM are based on the ESAW classifications. The activities of workers and agents they work with were paired and structured hierarchically using the ESAW coding.

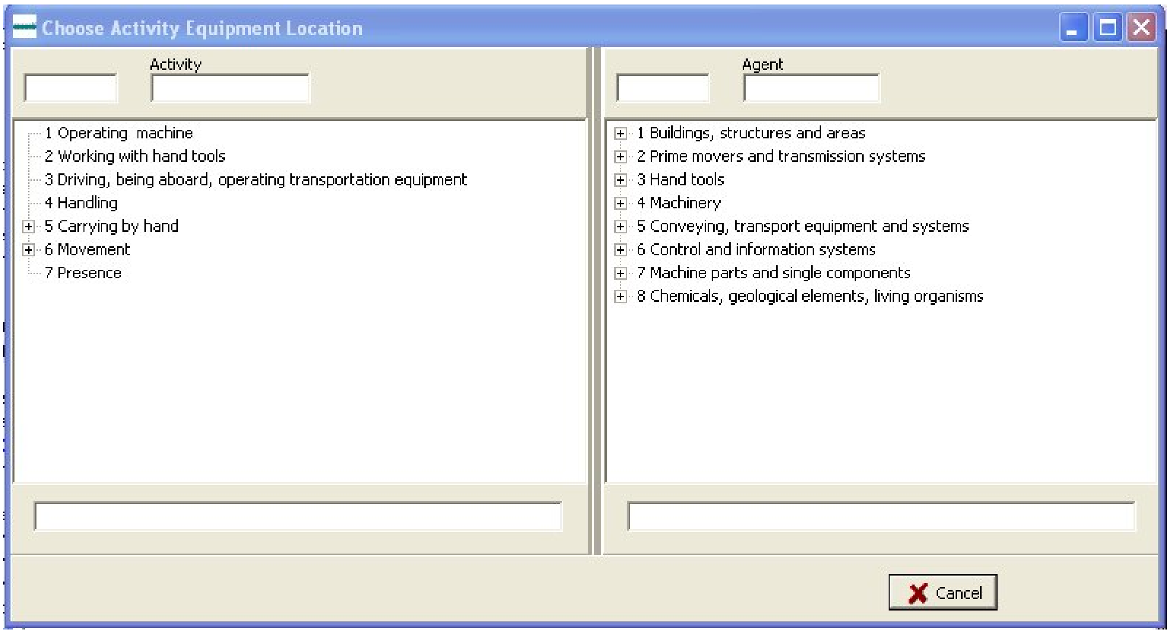

Figure 14 Screenshot of the combination of activities and agents a user can select to find the associated hazards based on previous accidents

Hazards

Based on all information available in the Danish dataset, all accidents were classified using the list of 64 bow ties, relating the accident data to the level of detail that could be reached.

Database with the link between job, industry, activity, agent and bow tie

On the basis of the classifications the risk model can present a list of activity-agent-bow tie groupings which occurred with a particular Job and Industry combination in the RAW data. This list is ranked, based on frequency and the consequence severity of the observed activity/agent/hazard groups for that particular job in the industry. The user can then select the members from the list that apply to their situation. An example is shown in Figure 15 for nursing professionals in hospitals. This is only meant as an advisory for selecting activity-bow tie combinations but can give insight into what has hitherto received virtually no attention in accident classification schemes.

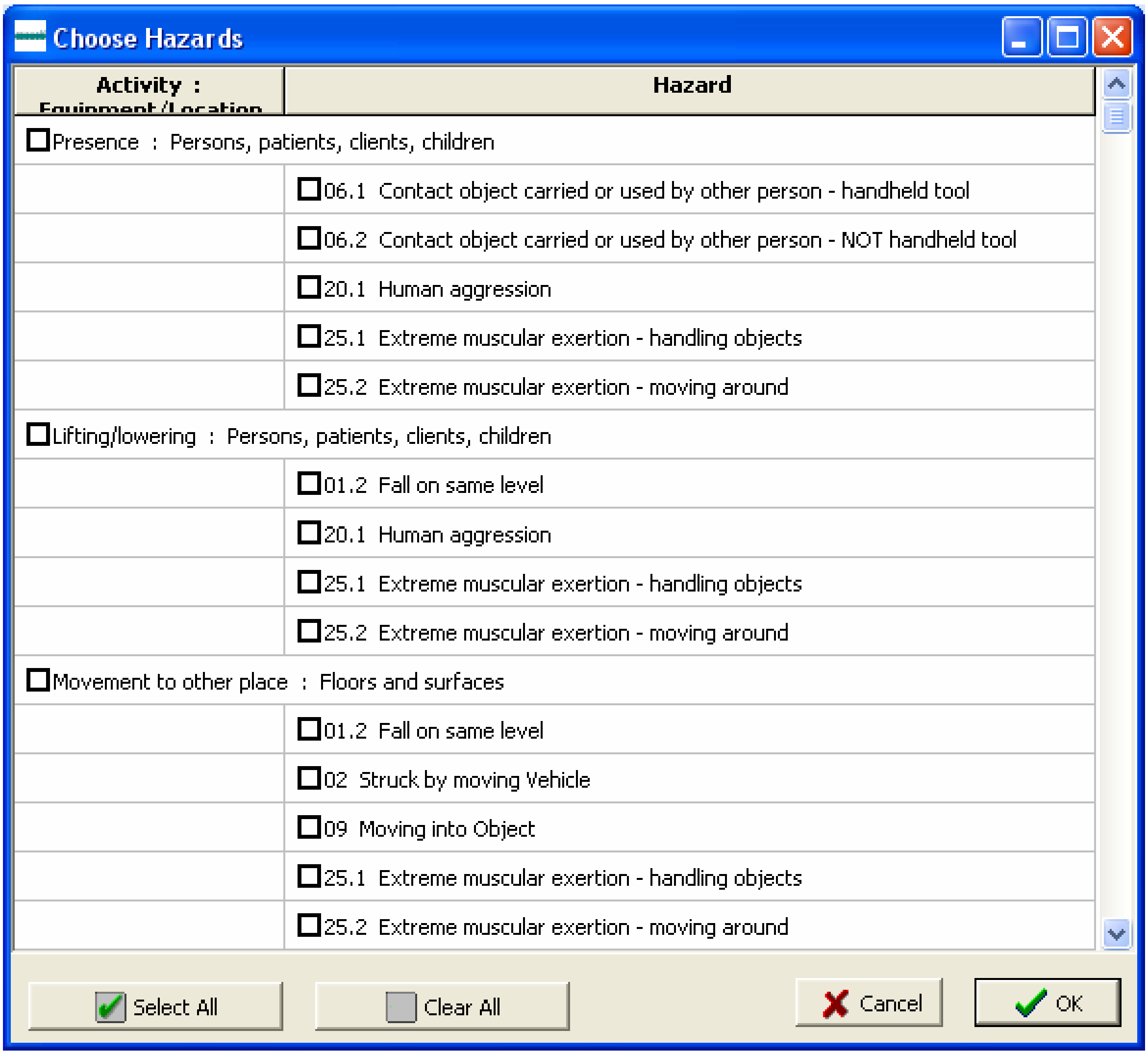

Figure 15 Example of part of an advisory list for nursing professionals: hospital activities

4 Main results

The ORM model, accident and survey data, and software developments provided the following:

1. the tools for doing a quantitative occupational risk analysis covering exposure to 63 types of occupational accident hazard, covering virtually all types of occupational hazard (see Annex 2).[10]
2. the software tool ORM enabling occupational accident risk assessment and cost-benefit advice at company, job or activity level
3. extensive data collections giving new insights into:
   a. accident analysis, causes, effects and consequences particularly in relation to safety barriers and barrier failures including for specific industry sectors and activities
   b. exposure to hazards and exposure to specific working conditions
   c. measures to reduce risk, their categories, effectiveness and costs
   d. the link between job, industry, activities, agents and hazards
4. the logical model itself providing the solution to the problem of how to make the calculation necessary to identify occupational risk and risk reduction priorities
5. additional spin-off in terms of software and information associated with occupational safety

4.1 Quantified occupational risks of accidents

Sixty three logic models connecting working conditions to the risk of an accident have been quantified. Three types of risks corresponding to the three types of the consequences (fatality, permanent injury, recoverable injury) have been calculated for each of the sixty three types of hazards. The results are given in Table 16 of Annex 3 and are further explained here.

Table 6 provides the metrics used in the risk calculations. Risk rates allow the customized calculation of risks for individual persons or companies when the duration of exposure to a particular activity significantly differs from the average over the working population. For example different types of occupation require different times of work on a placement ladder. Risk per year is a more general metric representing the risk a worker faces each year of work and incorporates the time the worker spends during the year exposed to the corresponding hazard. Number of accidents per year is used in calculating risk rates.

Ranking of hazards depends substantially on the particular risk metric used and it differs substantially from the ranking on the basis of the number of accidents per unit of time (accident rate). Figure 17, Figure 18, and Figure 19 show respectively the ranking of the various hazards on the basis of the risk to a worker per year for the three types of consequences fatality, permanent injury, and recoverable injury. Relative values have been used in order to include three different types of risk metrics in each figure. The values of the various risk metrics are expressed as percentages of the maximum observed value. Absolute values can be found in Table 16 in Annex 3.

With respect to the risk of dying during a year of average exposure, the most risky hazard is ‘Contact with falling objects-other’ (bow tie 3.5). The worker is being hit by a load falling from a shelf, from a pile or various other loads other than loads in the other categories which are: cranes or crane load (bow tie 3.1), mechanical lifting (bow tie 3.2), load falling from vehicles (bow tie 3.3) or from normal handling (bow tie 3.4). Bow tie 3.5 is also characterized by the largest number of fatalities per year.

[10] There were 64 bow ties but fall from rope ladder was excluded from the ORM risk assessment tool due to paucity of data.

‘Struck by a moving vehicle’ comes second in terms of the observed fatalities per year. The risk of dying of a particular individual from this hazard in a year is, nevertheless, 20 times lower than (i.e. 5% of) the maximum risk of ‘Contact with a falling object-other’.

Table 6 Metrics of quantified occupational risk

RISK METRIC	DEFINITION	USE
Risk rate (single hazard)	Probability of an accident with a given consequence per unit of time of exposure to the hazard	It is used to compile composite risk estimates for workers that are exposed for different amounts of times to different hazards
Risk per year (single hazard)	Probability of an accident with given consequence in a year given the total yearly exposure to a particular hazard.	Useful for comparing types of hazards taking into consideration the yearly exposure to this hazards
Number of observed accidents per unit of time (single hazard)		Used in deriving risk rates
Number of observed accidents per year and per worker	Number of observed accidents over a year divided by the number of workers exposed to this hazard over a year	Equivalent to the risk per year

Risk metrics are more suitable than numbers of accidents to guide policy decisions at an individual level, at a company level, at an industrial sector level or even at a national level. For example, a worker who must decide whether to use a placement ladder or a mobile scaffold to perform a job at a height should decide which one is less risky. As can be seen in Table 16 in Annex 3 the number of fatal accidents from falls from a placement ladder per year (bow tie 1.1.1.1) is twice as large as that from falls from a mobile scaffold (bow tie 1.1.2.1). The risk of a fatal accident per hour spent on a placement ladder is, however, half the risk per hour spent on a mobile scaffold. As a result, it would only be safer for a worker to perform a particular job using a mobile scaffold instead of a placement ladder if use of the scaffold results in reducing the time required to complete the job by a factor of two or more. This shows that it can be misleading if, for example, only accident frequencies are being looked at in making policy decisions and not the complete risk picture.

Risk per year on the other hand, is a better measure to compare occupational hazards associated with a job performed on a regular basis but not involving the same amounts of time. For example, the risk of death as a result of a fall from a non-moving vehicle (bow tie 1.1.5.2) per unit of time on the vehicle is higher (by a factor of 2) than that from contact with a falling object per hour of work around or in a crane (3.1) (see Figure 16). Nevertheless, a worker who has to work at height on a non-moving vehicle faces a much lower risk per year (by a factor of 4) than a worker working near or in cranes since the former spends (on the average) less time on a non-moving vehicle than the latter spends near or in cranes per year of work.

It is noteworthy that the number of accidents per year per worker (or per 100,000 workers) is a metric equivalent to the risk per year. This statistic can therefore be used interchangeably with yearly risks in supporting risk management decisions when yearly risk is a suitable metric. It cannot be used however, when the effect of risk reducing strategies are to be measured

Risk of a particular injury to a specific worker or to a specific group of workers largely depends on the specific mixture of activities performed and the corresponding exposure to specific hazards for specific periods of times. To calculate the resulting risk correctly, risk rates are necessary as outlined in section 4.2.

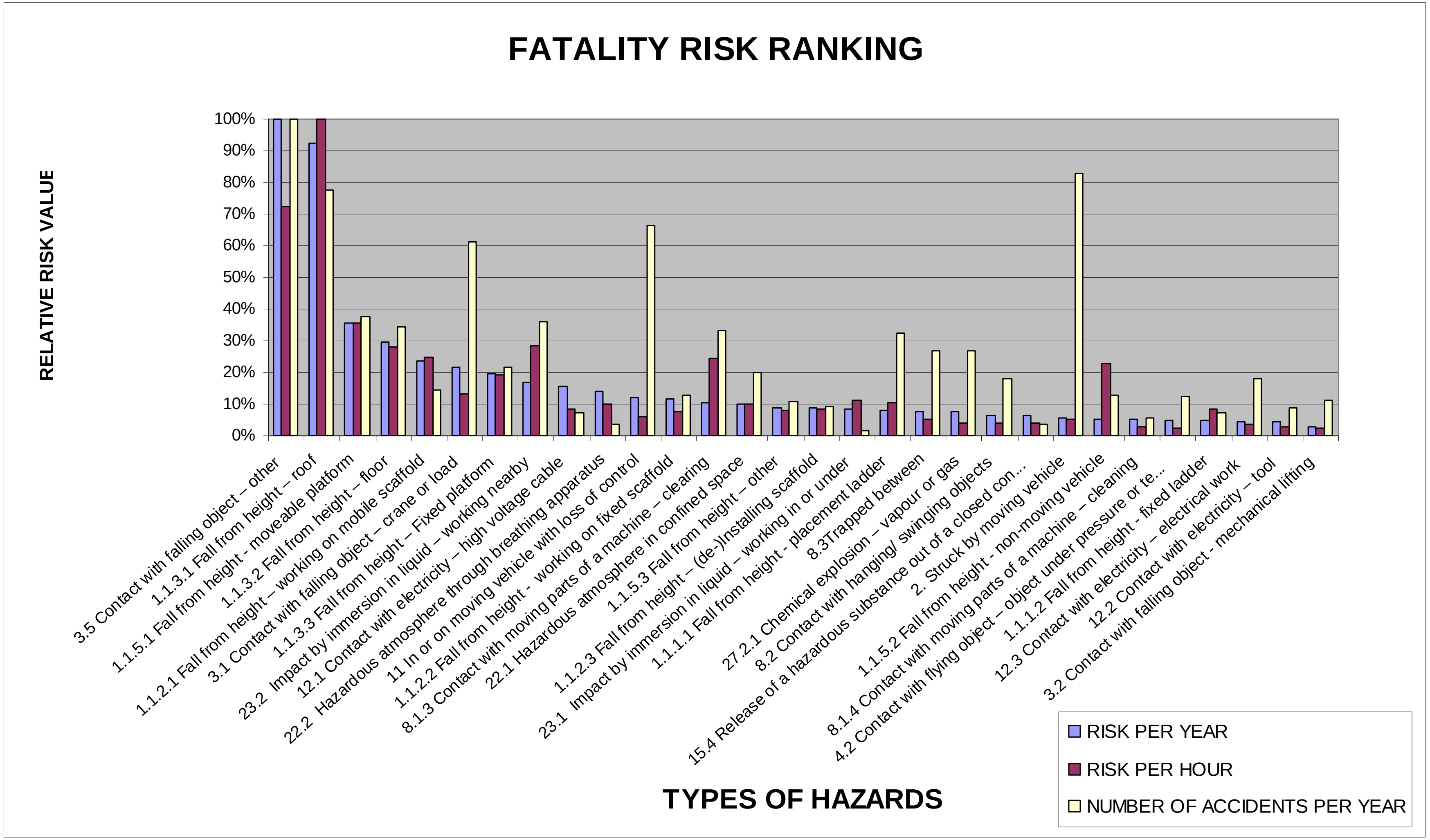

Figure 16 Fatality risk. Hazard ranking in terms of the probability of a fatal accident per year of average exposure. Hazard with highest probability of fatal accident per year 'Contact with falling object – other'. Hazard with highest probability of fatal accident per hour of exposure: 'Fall from roof'. Hazard with highest number of observed accidents per year 'Contact with falling object – other'.

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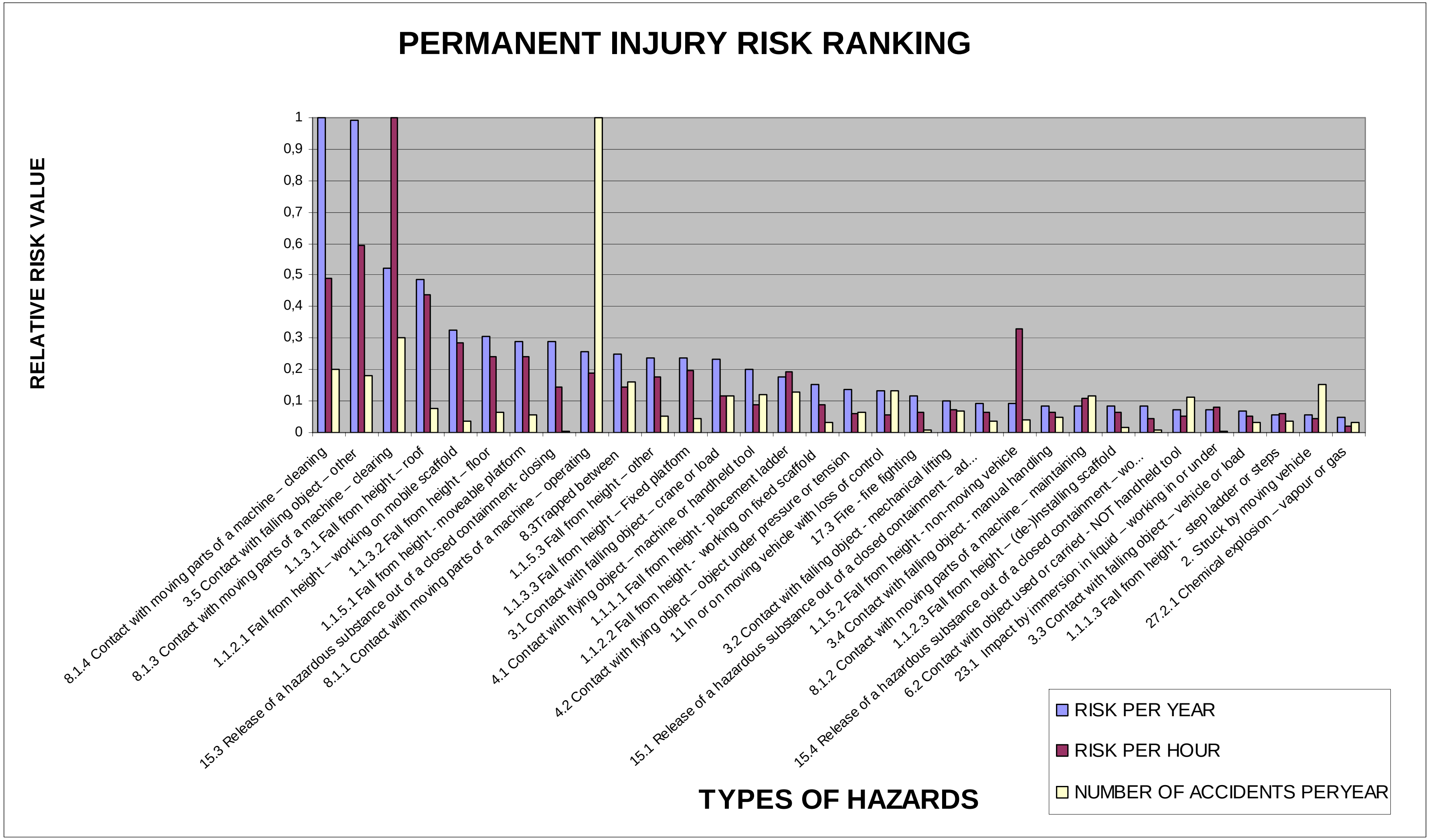


Figure 17 Permanent injury risks. Hazard ranking in terms of the probability of a permanent -injury accident per year of average exposure. Hazard with highest probability of permanent injury per year 'Contact with moving part of a machine-while cleaning'. Hazard with highest probability of permanent injury per hour of exposure: 'Contact with moving part of machine while clearing'. Hazard with highest number of observed permanent-injury accidents per year 'Contact with moving part of machine while operating'.

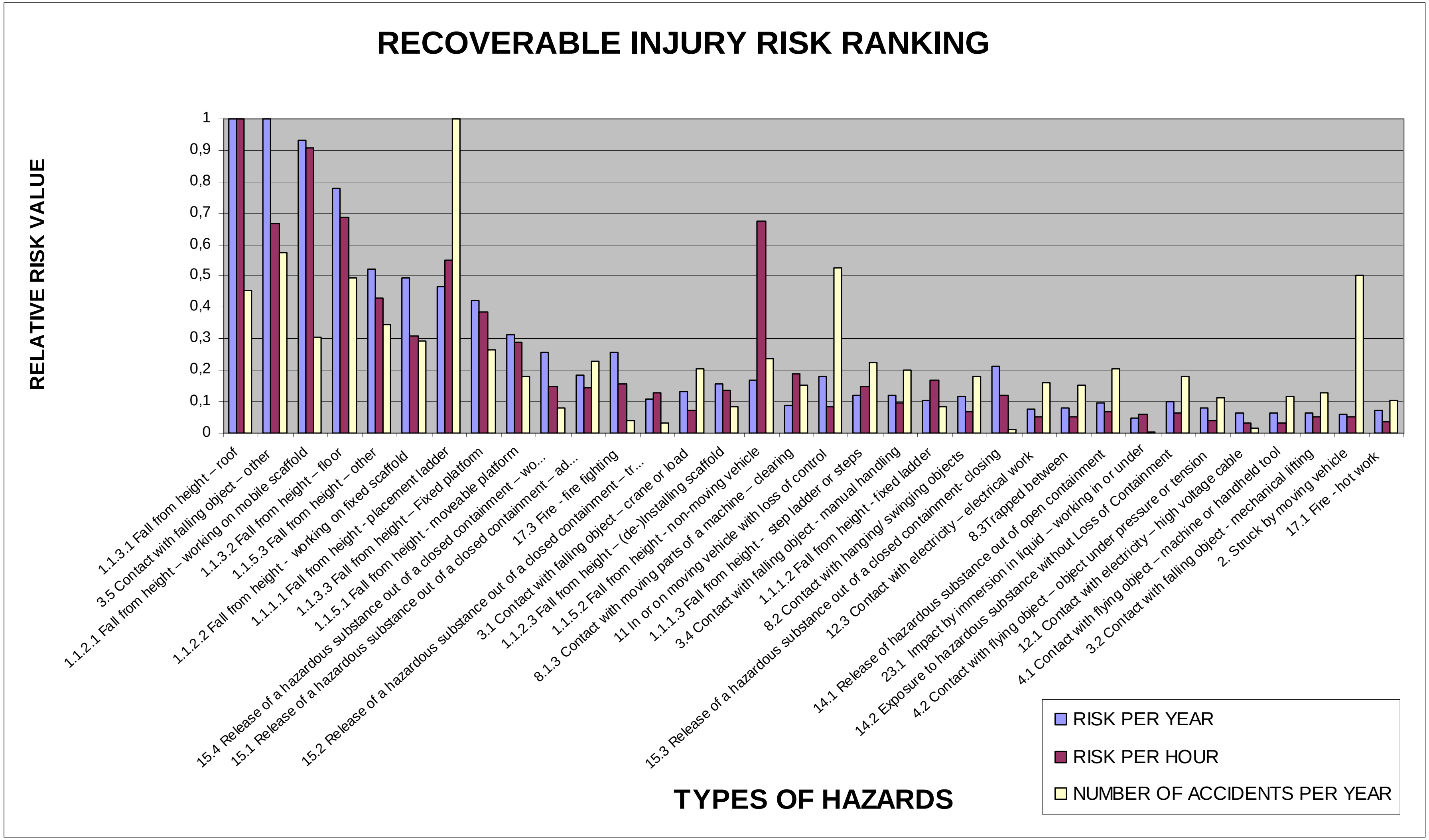


Figure 18 Recoverable injury risks. Hazard ranking in terms of the probability of a recoverable-injury accident per year of average exposure. Hazard with highest probability of recoverable injury per year ‘Fall from height - roof ‘. Hazard with highest probability of recoverable injury per hour of exposure: ‘Fall from height - roof’. Hazard with highest number of observed recoverable-injury accidents ‘Fall from placement ladder’.

4.2 Software: occupational risk management tool

Accident data, exposure times, and working condition frequencies when inserted in the developed risk models provide all the necessary ingredients for developing case-specific risk models and providing support to risk management decisions. The overall approach to risk model building and decision support has been integrated into a software tool, the Occupational Risk Model (ORM) tool. A working prototype is available that can be used to:

- prioritise occupational accident risks for individuals or groups
- identify the most cost-effective approaches to reducing the risks
- reduce the uncertainty about what measures to choose to reduce risks and in predicting how much that is going to cost
- give objective insights into the total risk to a worker of having an occupational accident
- compare the risks to different workers and also the risks to a specific worker from the different activities he or she undertakes
- pose risk targeted questions about the quality of safety barriers in the workplace covering all occupational accident hazards and which are benchmarked with Dutch National Average percentages
- provide risk information at sector level, available for benchmarking

4.2.1 Description of the software tool

A company can get the risk picture at different levels of breakdown from across the company to an activity of a worker. Furthermore advice on sets of risk reducing measures can be obtained on the basis of their overall risk reduction and the associated cost. The software takes the user through four main steps: 1 Working unit and exposure, 2 workplace questions, 3 risk calculations and 4 optimisation of measures calculation to reduce the risk.

4.2.1.1 Step 1: specify working unit and exposure

The first step consists in defining the working unit to be analysed which for the economy of the discussion will be called a *company*. To guide the user in a user-friendly way, the software takes the activities of a company as the starting point. This is done in four stages, one of which is optional, namely:

1. Specification of the jobs and industries, the *positions in the company*
2. Specification of the a*ctivity/agent pair* that is relevant for this position. (optional)
3. Specification of the associated *hazards* from the bow tie-list relating to each position in company
4. Specification of the *exposure* to each hazard.

The user can start by indicating the industry in which the company is active and the jobs that are carried out in the company. Workers performing these jobs undertake activities that need to be specified.

The user has to specify all the people in his organisation (positions in the company) who are to be included in the risk evaluation. This is done by specifying each individual, with their own particular activities, or by specifying groups of workers who are engaged in the same activities, or by a mixture of the two. The user can select the combination(s) of activities, and agents, he wants to attach to the positions defined.

The structure of the risk model requires that for each position one or more hazards are selected. In order to help the user specifying these topics, the model offers a stepwise selection process.

These hazards can be shown per type of hazard, per job or per activity. Then the user has to specify how often and for how long the worker is exposed to the hazards while carrying out the activities.

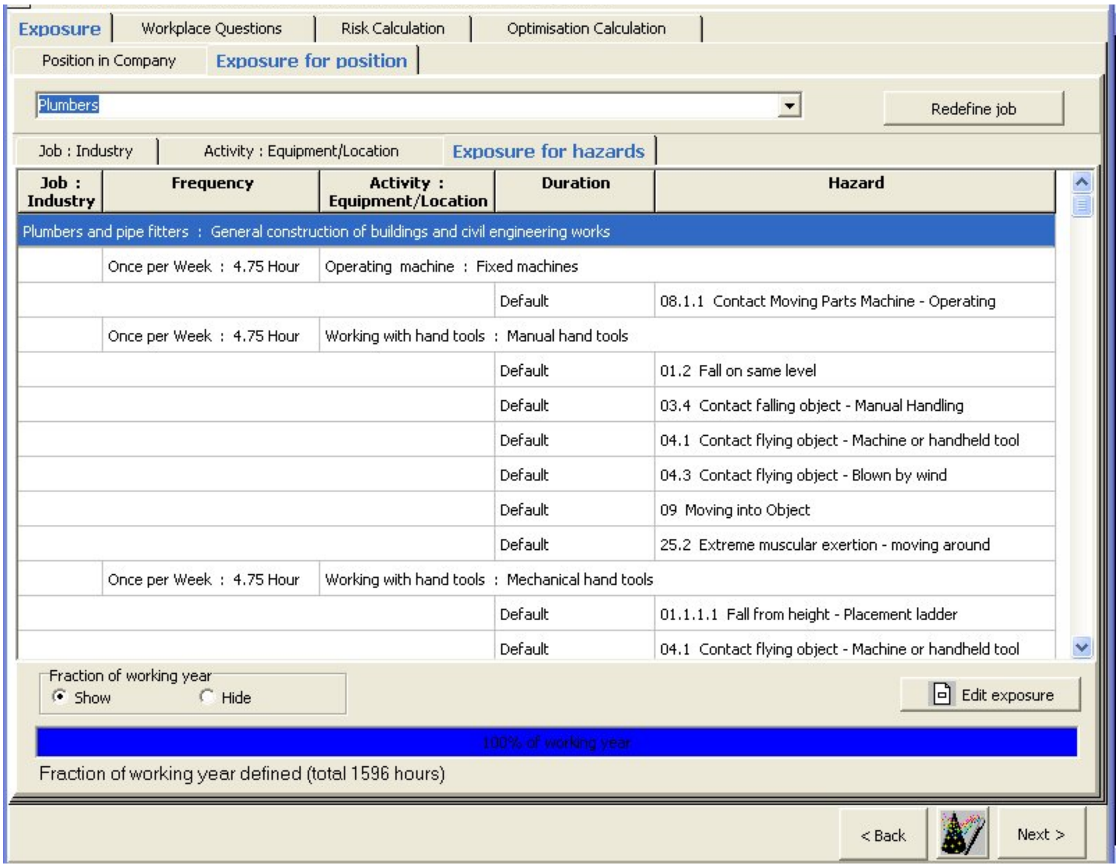


Figure 19 Input exposures to hazards

Figure 19 shows how a user has to put in the exposure for his workers (in this case for the plumbers) in terms of the hours per week they are exposed to the hazards related to their activities (e.g. when working with tools).

4.2.1.2 Step 2: workplace questions

It is an assumption of the model that the occurrence of an accident, i.e. the realisation of a hazard, is influenced by the working conditions. So the user is asked to assess his own working conditions as they relate to the company's potential hazards as defined by its activities. This is where the user is confronted with the average Dutch exposure to working conditions, the Dutch National Average (DNA). This is shown in Figure 20 The user can indicate the company's own workplace conditions by putting in his figures and then can immediately see how his situation relates to the DNA as shown in Figure 21. So the user can either simply accept all the average figures already given by default and get the average assessment and advice, or give the factual situation for his company to get a real tailor made assessment and advice.

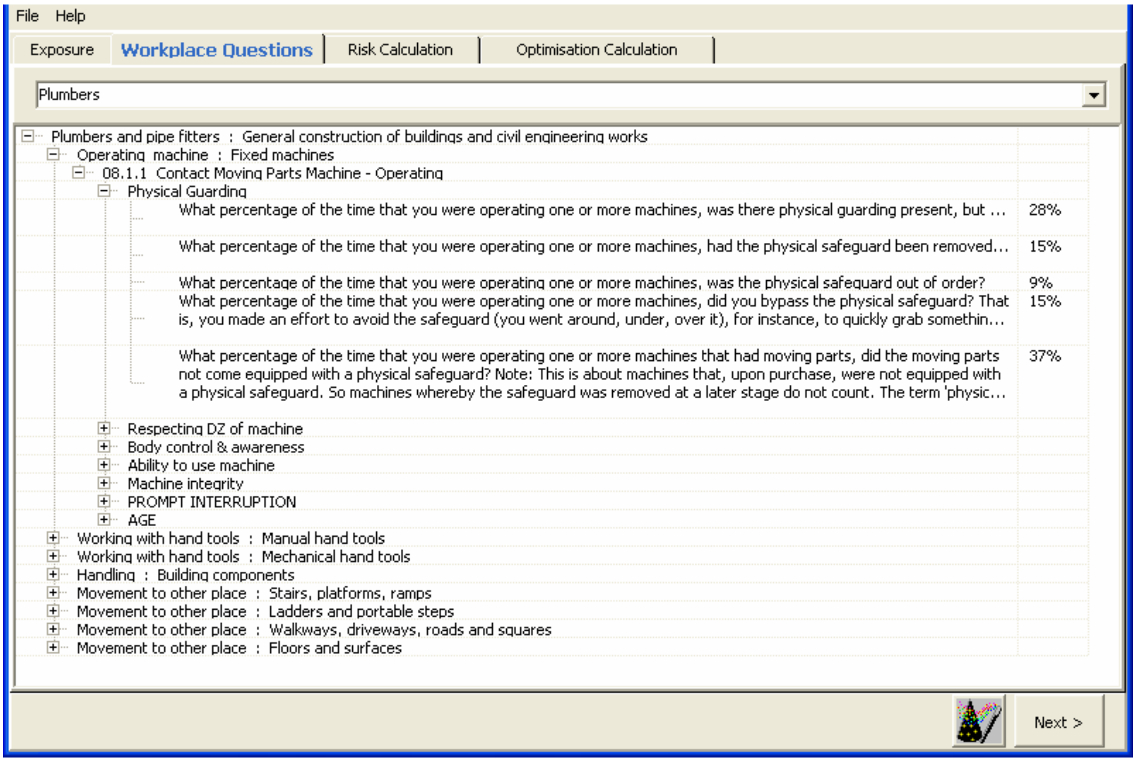


Figure 20 Screenshot showing the Dutch national average working conditions for the PIEs of the safety barrier *Physical Guarding* for one of the hazards associated with the activities of a plumber in the construction industry. The activity *Operating machine: fixed machine* is associated with the bow tie: *Contact with moving parts of machine while it is being operated*

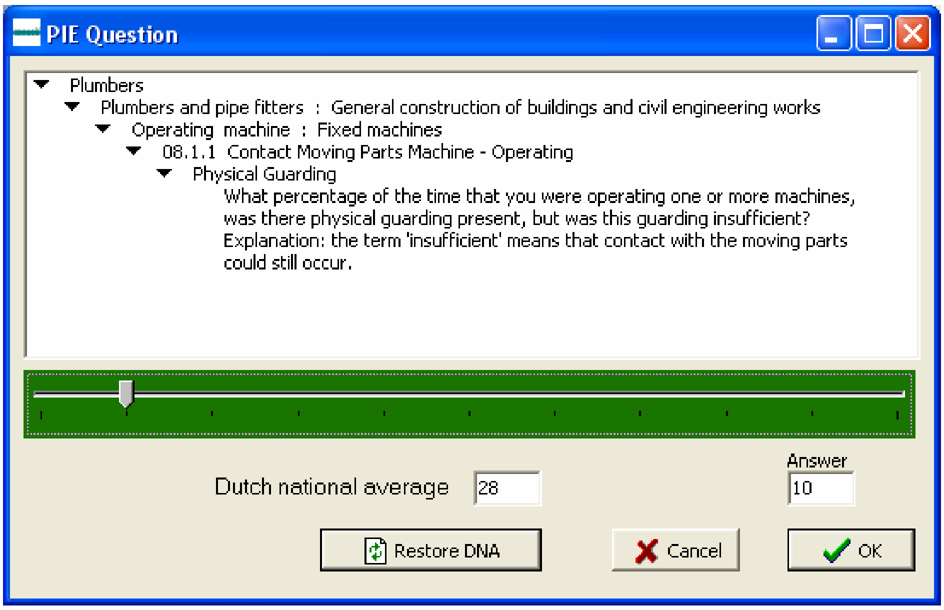


Figure 21 To put in the workplace conditions specific to the situation of the company the user can change the DNA for any PIE and enter their own PIE value. In this case the DNA was 28% and the user enters 10%. The bar turns green because that is a better condition to have

4.2.1.3 Step 3: risk calculation

After having filled out the working conditions, the user can push the button to receive the company risk profile. The risk is calculated for, and can be shown at, all levels: per company, per job, per type of hazard, per activity. This is the quantitative risk assessment in relation to the DNA.

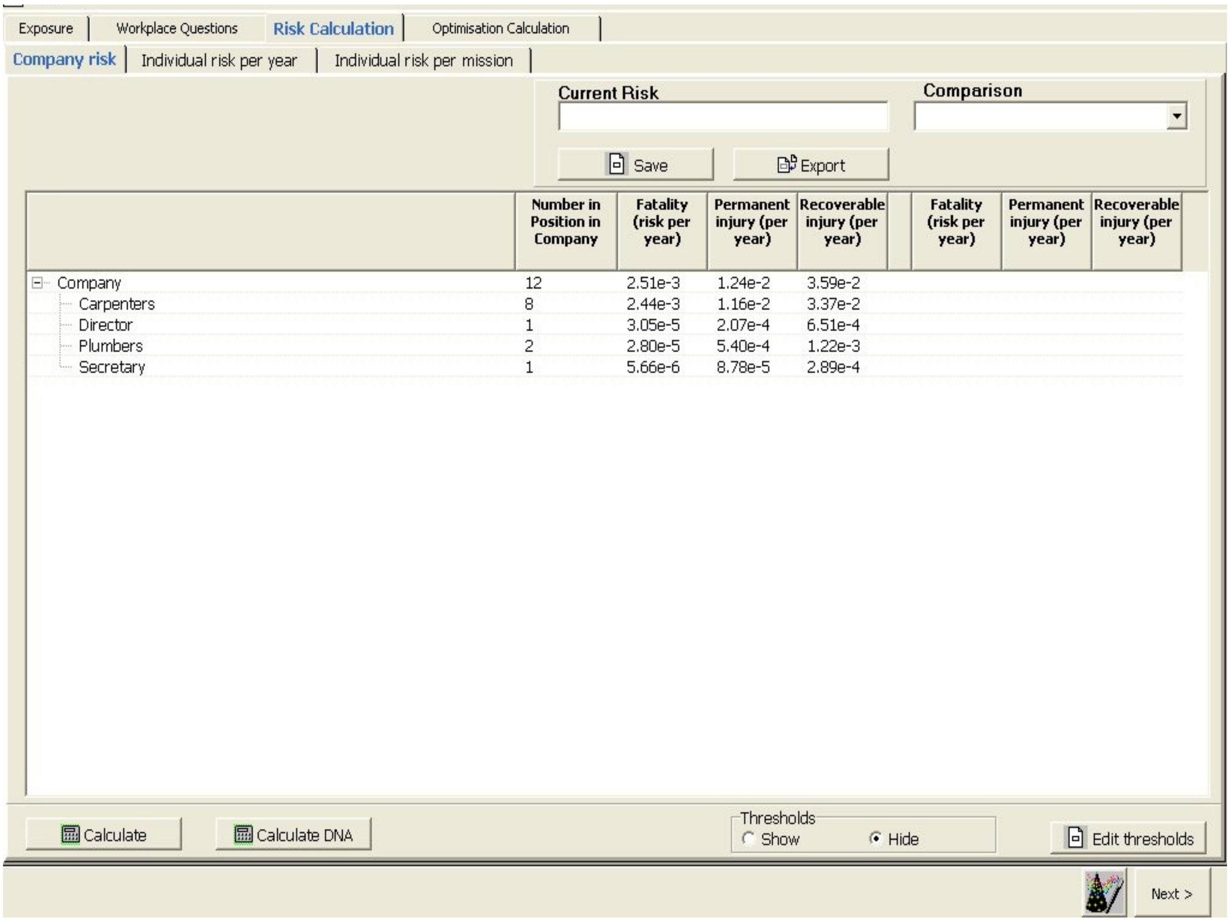


Figure 22 Risk results as displayed for a small company in construction, at company level and per worker

Figure 22 shows the risk results of a small company in construction with eight carpenters, two plumbers, a director and a secretary when the Dutch average working conditions are used.
For further insights, the user can check in more detail per position at the level of activities.

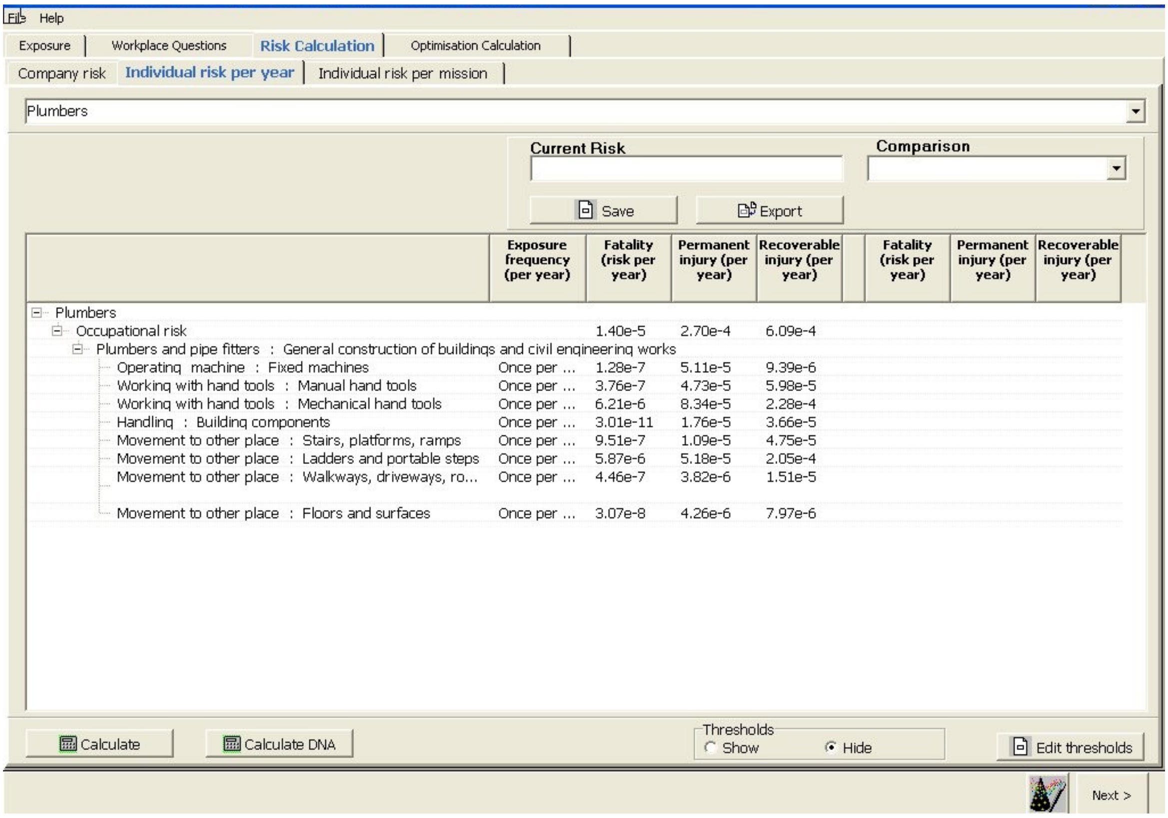


Figure 23 Breakdown of risk per activity for a worker, in this case the plumber in construction

Figure 23 shows how the plumbers are exposed to risk of death and injuries during the various activities they carry out during their job.

Results up to this point offer a detailed analysis of the present risk situation in the specific company. The various risk metrics can be compared with internal, industry wide or national standards if available.

4.2.1.4 Step 4: optimisation calculation

A number of measures are available for risk reduction if such a reduction is desired. In the particular example considered there are 120 measures available. An extremely large number of combinations of these measures represent an equally enormous number of potential risk-reducing strategies. ORM provides support by sorting out only those combinations that are *efficient*. That is, they provide the maximum risk reduction at a given cost and for several levels of cost. An overall view of these results is indicated in Figure 24.

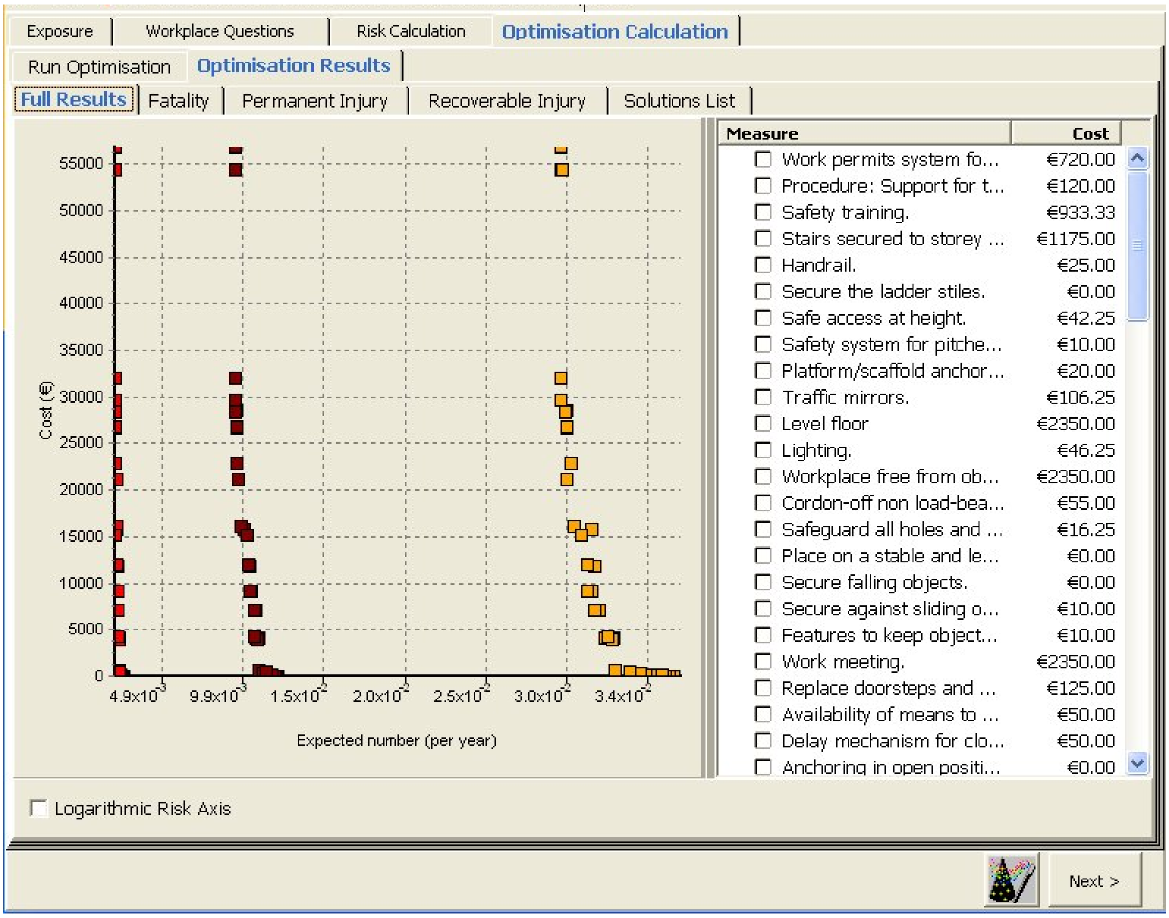


Figure 24 Display of sets of measures (individual points in the curves) and their costs for a small company in construction for the 3 types of consequence

By selecting a point on the curves, the associated set of measures is indicated in the right hand side of the screen. .The user can select a cost level and see which set of measures result in the maximum risk reduction. Alternatively the user can set a risk level and see which set of measures achieve this risk at minimum cost.

More importantly results like those shown in Figure 24 provide a basis for coherent and meaningful discussion at various company levels about possible measures to improve safety at work. Measures that have a significant risk reduction at negligible cost can immediately be adopted, while measures that incur minimum to insignificant risk improvement at rather substantial levels of cost can be rejected. Discussions then can concentrate on a smaller number of risk reducing strategies and decide which the best is for that particular company. The decision-making might take into consideration additional implicit attributes not explicitly considered in the model.

4.3 Datasets for the Dutch working population

Accident data, exposure times and data on working conditions and possible risk reducing measures have been generated with the prime objective to support the quantification of the risk models and provide support to risk management through the quantified risk measures. However, the datasets themselves are valuable sources of information useful in their own right.

4.3.1 Accident facts and figures

Thirty-six Storybuilds [11] (Annex 2) have been made as graphical bow tie structures with accident scenarios mapped on. They cover all types of occupational accidents based on Dutch reportable accidents over a period of six years. This can bring new insights in accident causation. Structural reconstruction of accident scenarios provide unique qualitative and quantitative information on the immediate and underlying (root) causes of accidents, including information on management delivery system failures and their contribution to the provision, use, maintenance and monitoring of barriers. This level of analysis provides an additional basis for barrier failure investigation.

Table 7 shows the top ten types of accidents ranked by the number of accidents per year. Interest from the Labour Inspectorate in the datasets on accidents and causes gave rise to many questions for analysis of data as a basis for inspection programs and as a resource for information on specific industry sectors. Data were provided to directly support inspection tasks and incident investigation. In addition to answering specific questions it was decided to deliver standardised sets of ‘facts and figures’. These were the highlights that could be distilled from the 36 storybuilds. The result was a set of three page facts and figures sheets for each of the 36 types of accidents. These can be found in Technical Report 3.

[11] The 36 Storybuilds have been further subdivided into 64 logical models for the ORM.

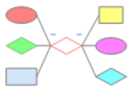
Table 7 Accident top 10 ranked by type of accident per year[12]

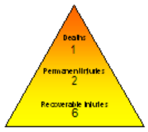
Order	Story build number	Storybuild name	Years 1998-Feb 2004	Years 2002-2003	% of total per year	Total accidents analysed	Accidents per year
1	8.1	Contact with moving parts of machine		x	**20.96%**	797	398.5
2	1.1.3	Fall from height - roof/platform/floor	x		**9.36%**	1099	178
3	1.1.1	Fall from height ladders	x		**9.10%**	1069	173
4	3.2	Contact with falling objects NOT cranes		x	**8.89%**	337	169
5	2	Struck by moving vehicle	x		**4.68%**	550	89
6	1.1.2	Fall from height scaffold	x		**4.52%**	530	86
7	11	In or on moving vehicle with loss of control	x		**4.47%**	522	85
8	1.2	Fall on same level	x		**3.52%**	416	67
9	4	Contact with flying/ ejected objects	x		**3.31%**	390	63
10	3.1	Contact with falling objects - cranes		x	**2.68%**	102	51

An example of such a sheet is shown in Table 8 regarding the hazard type ‘Fall from height – roof, platform or floor’. Firstly the number of accidents and their consequences are given. Then the activities the victims were carrying out as the accident happened. This information is relevant for companies and workers to raise awareness.

[12] This ranking is based on total number of accidents (regardless of consequence severity) and across various subtypes of work (e.g. ‘contact with moving parts of machines in all four phases: operating , maintaining, clearing, cleaning)

Table 8 Example Facts and Figures sheet: Accident consequences ratios and activities of victims at the time of the accident fall from height – roof, platform or floor





01.1.3 Fall from height - roof, platform or floor

Based on : 1099 GISAI ACCIDENTS FROM 1998 - FEB 2004

Table 1 Accident consequence frequencies

STORYBUILD	AVERAGE NUMBER OF GISAI ACCIDENTS PER YEAR				RATIOS		
	Deaths	Permanent injuries	Recoverable injuries	Unknown injury type	Deaths	Permanent injuries	Recoverable injuries
01.1.3 Fall from height - roof/platform/floor	12	21	78	65	1	2	6

Table 2 Activity of victim at the time

Victim activity	Description	% of accidents	Nr. Accidents 1998-Feb 2004	Nr. Accidents per year
Working on roof/platform/floor	Ongoing construction or roof jobs.	35.6%	391	63
Standing on or crossing roof/floor/platform		32.9%	362	59
Constructing roof/platform/floor	Includes on site demolition/renovation	23.5%	258	42
Unknown activity[1]		3.4%	37	6
Removing/placing edge protection	also Fall Arrest	3.2%	35	6
Climbing		1.5%	16	3

[1] Unknown means that the accident report did not give enough data to categorise the activity on the roof/platform/floor

STORYBUILDER INFORMATION SHEET F d05 0113 Fall from height roof platform floor 070719 MD.doc

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Secondly, the barrier failure modes are analysed, showing how often they failed in order of most to least frequent. In this case edge protection failure dominates. This is where one can see which causes are most important and which barriers should be improved.

Table 9 Example Facts and Figures sheet: Barrier failure modes (not necessarily mutually exclusive) giving the most important causes of fall from height – roof, platform or floor

BARRIER FAILURE MODE	Description	% of roof fall accidents	Nr. Accidents 1998 – Feb 2004	Nr. Per Year
CAUSES OF FALL				
Roof edge protection failure	(Temporary) guardrail failure, edge protection is absent, insufficient or has been removed. NB: Includes edge protection on perimeter and alongside openings holes, ducts, skylights and roof access (e.g.: roof shutters). NB: a window or door in a wall along a floor is also considered edge protection!	45.1%	496	80
User Ability Failure	Skill - balance - to stay on roof/floor/platform fails	27.8%	306	50
Roof/working platform/floor (parts) not intended to support exerted weight	Parts include skylights, roof gutters, vent holes not designed to bear weights.	22.6%	248	40
(Part of) Roof/ floor deficient condition	Structural deficiency or parts of floor, roofs, ceilings are substandard (e.g. in bad condition or unstable)	13.9%	153	25
EMERGENCY RESPONSE				
Fall arrest failure	No (use of) fall arrestors or safety nets. Includes cases where harnesses were worn, but no safety line was attached.	24.8%	273	44
No (adequate) emergency response		1.8%	20	3

Analyzing the underlying causes more deeply gives the top failures in barrier tasks and in the management deliveries to these tasks. Here it can be seen that providing edge protection dominates, but 9% of accidents also show it is not good to rely on people keeping their balance. Failures in the procedural system for providing edge protection and motivating the attention of workers to keeping their balance are amongst important groups of contributors.

Table 10 Example Facts and Figures sheet: Barrier task failures and management delivery failures giving the most important underlying causes of fall from height – roof, platform or floor

Underlying failure	Description	% of accidents	Nr. Accidents 1998-Feb 2004	Nr. Per year
Barrier task failure	**Description**			
Provide edge protection	Failure to provide edge protection (absent 22%, incomplete/insufficient 6%)	31.7%	348	56
Provide fall arrest	Failure to provide adequate fall arrest (mostly absent)	14.8%	163	26
Provide roof strength	Failure to provide sufficient roof/floor/platform strength to support weight	9.8%	108	18
Use ability to keep balanced	Failure by victim to keep their balance on the height (4% due to slips/trips, 1% due to external force)	9.1%	100	16
Delivery system failure	**Description (and % of accidents per barrier support task)**			
Plans and procedures for edge protection	Inadequate or no plans and procedures for edge protection:- for providing edge protection (11.5%), for using edge protection (1.3%), for maintaining edge protection (1%) and for monitoring edge protection (0.2%)	14.0%	154	25
Motivation to ensure user able to keep balanced	Insufficient motivation or commitment to the user keeping their balance when using the roof/floor/platform (5%), to ensuring that keeping balance is possible (2%), or to the maintenance of means to keep balanced (1%)	8.7%	96	16
Motivation/commitment for edge protection	Insufficient motivation or commitment to ensuring adequate edge protection is provided (4%), used (1.4%), maintained (1.4%), and monitored (0.2%)	7.0%	77	12
Plans and procedures for fall arrest	Inadequate or no plans and procedures for providing (4.9%), using (1.3%), maintaining (0.3%) or monitoring (0.3%) fall arrest	6.8%	75	12

Incident investigation can be supported by using the information on past barrier failures such as have been highlighted in these sheets. The Labour Inspectorate used the 'Fall from height: scaffold' Storybuild in the analysis of the Amercentrale accident, for example (Van Santen et al., 2007).

As an example of a sector specific question from the Labour Inspectorate, data were asked for on the construction industry to support the identification of important inspection points. Extracts from an example answer is shown in Table 11 which lists the top 10 inspection points derived from the data based on accident cause frequency in the building industry sector (industry code 45).

Table 11 TOP 10 inspection points derived from analysing barrier failures in the construction industry

Barriers in the points below are underlined ▪ Presence of sound <u>edge protection</u> on roofs, floors, platforms ▪ <u>Placement of ladders</u> - whether the conditions are suitable for placement of ladders, the ladders are of appropriate length and they are placed on stable and flat ground at a safe angle, and secured against movement ▪ Provision and use of <u>fall protection</u> when working at height without edge protection ▪ Attention to ensuring that <u>building components are well secured</u> ▪ <u>Keeping people out of danger zones</u> where there are hanging loads and from being below places where there is the danger that an object can fall from height such as under an object when it is being installed. ▪ <u>Secure attachment of loads</u> ▪ Presence of sound <u>edge protection</u> on scaffolds and monitoring of control measures which ensure that the <u>edge protection</u> remains present and in a good state ▪ <u>Sound construction of scaffolds</u> (particularly supports and anchors) and condition of scaffold walkways (e.g. connection to the building) ▪ Presence of reliable <u>machine guards</u> and sufficient competence to ensure <u>ability of the machine operators</u> to operate the machines safely ▪ Checking that <u>electrically charged parts are not charged when working on them</u> including measures to ensure that they remain so throughout the work activity (lock-out)

These ten points above address half the accidents that occur in the construction industry.

The underlying causes of barrier failures in the building sector were also identified. Failure to motivate and have procedures for the provision in particular as well as the use of barriers dominated as can be seen in Table 12 below.

Table 12 Underlying causes of barrier failures in the construction industry

Analysis of the underlying causes in construction accidents gives the following statistics:

(1) Failures in barrier tasks (PUMMs = the Provide, Use, Maintain, Monitor tasks)

- Not providing the barrier: 47%
- Not using the provided barrier or not using it in the right way: 39%
- Not maintaining the good condition of the barrier or ensuring it is kept in place.: 8%
- Not monitoring the state of a (provided) barrier: 6%

(2) Failures in what is delivered by the management system to the task

(underlined words refer to the name of the management delivery system):

- Inadequate motivation and alertness: 30%
- Inadequate plans and procedures :16%
- Inadequate or substandard equipment: 15%
- Inadequate competence of personnel : 11%
- Inadequate communications:10%
- Inadequate resolution of conflicts with safety: 10%
- Substandard ergonomics: 6%
- Insufficient availability of suitable personnel: 2%

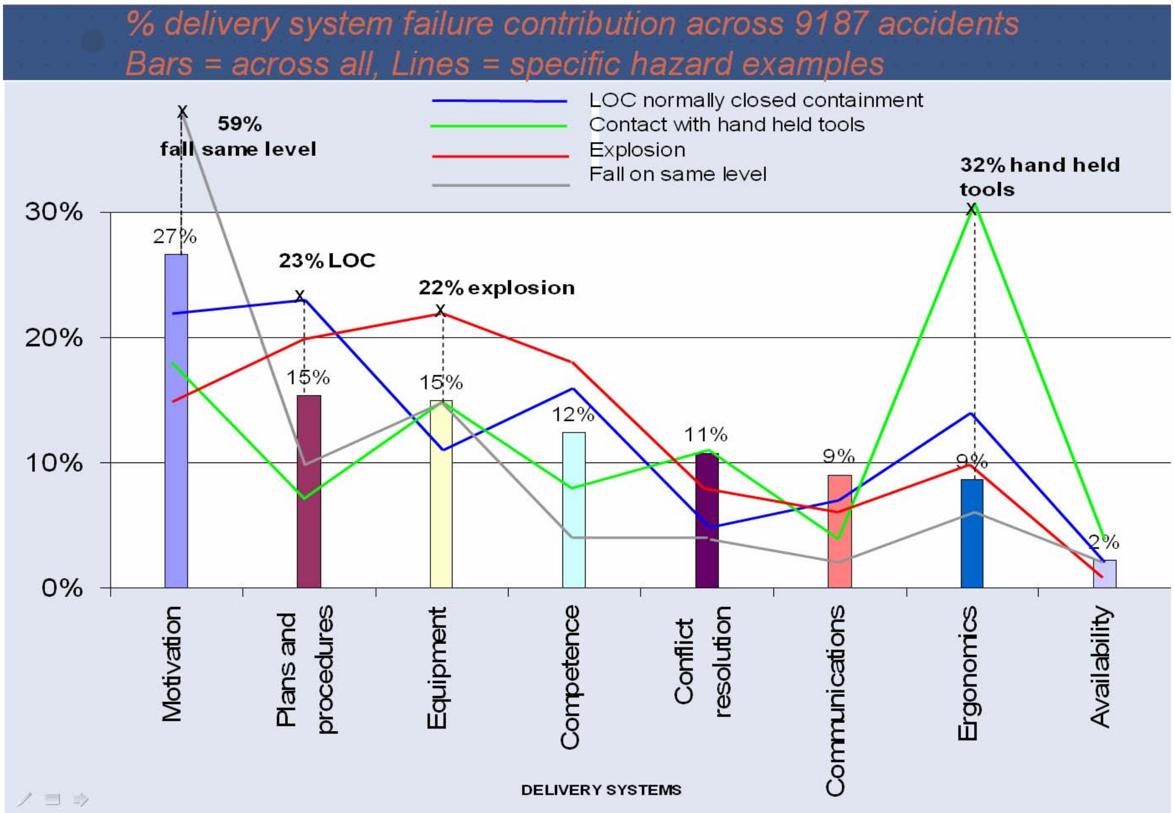

Figure 25 Management delivery system failures analysed

Table 12 for the construction industry is consistent with the general pattern of the frequency of management delivery system failures in general. The chart in Figure 25 shows these general delivery system failures for 9187 Dutch reported accidents across 36 storybuilds. The bars give the contribution for all known delivery system failures across all the accidents, expressed as a percentage of total known delivery system failures. What this means is that in general the management system motivation is the most frequent contributor to system failure and availability is the smallest. But when looked at for specific storybuilds, the delivery systems score differently. The figure shows the difference between 4 storybuilds. Look for example the difference between Loss of Containment (LOC) and hand held tools. For LOCs the highest contributors to the accidents are motivation and plans and procedures which are consistent with the general picture but in the case of hand held tools it is ergonomics which is totally inconsistent with the general picture. This means that in a situation where hand held tools are often used one cannot rely on the general distribution of accident contributors but must have specific attention for the delivery system ergonomics. This could explain the discrepancy which is often seen in companies between for instance the failure of delivery system components which are responsible for LOC and the more typical occupational accidents like slip trips and falls and contact with hand held tools which are used in lost time injury calculations and form a performance indicator for safety. So for major hazards (see LOCs and explosions in the diagram) motivation, plans and procedures and equipment are frequent underlying failures in accidents. The 59% for fall on same level is actually right off the page for motivation (not shown properly scaled here for that reason) so any programme that only addresses motivational issues may reduce slips trips and falls considerably but will not be addressing the two other major contributors namely plans and procedures and equipment. This is consistent with the findings of the recent Baker Report as follow-up to the 2005 BP Texas City refinery explosion in the US (Baker, 2007).

These kinds of analyses have given new insights to policy makers and inspectors that enable them to better target accident prevention with a sound empirical basis. They also confirm the experiences of industry that different jobs and workplaces demand different emphases in managing safety. It might seem obvious that ergonomics is important for hand held tools and competence does not do much for falls on the same level but for the first time there are data to direct thinking towards how management of these different hazards can be prioritised.

4.3.2 Exposure to hazards

As described in chapter 3, the mission survey resulted in data on the total number of hours workers are at risk of having the accidents described in each of the bow tie models in ORM. These exposure data are representative for the Dutch working population. The survey resulted in a unique set of figures on total duration of exposure of workers in The Netherlands to the various types of hazards. As an example, Figure 26 shows the distribution of the total exposure hours per year to the hazard of being struck by a moving vehicle in the Dutch working population.

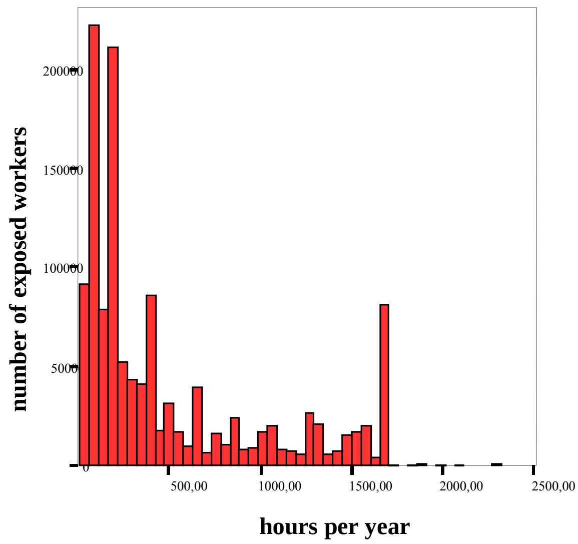

Figure 26 Distribution of the total number of hours per year workers in the Netherlands are pedestrians at locations with moving vehicles

These exposure data can be linked to accident data as is done in ORM.

Demographic characteristics are available, so the data allow for calculation of exposure for subgroups of the population. The dataset includes many background variables like sector, occupation, type of employment, company size, age, sex and educational level.

Illustrations of these results are:

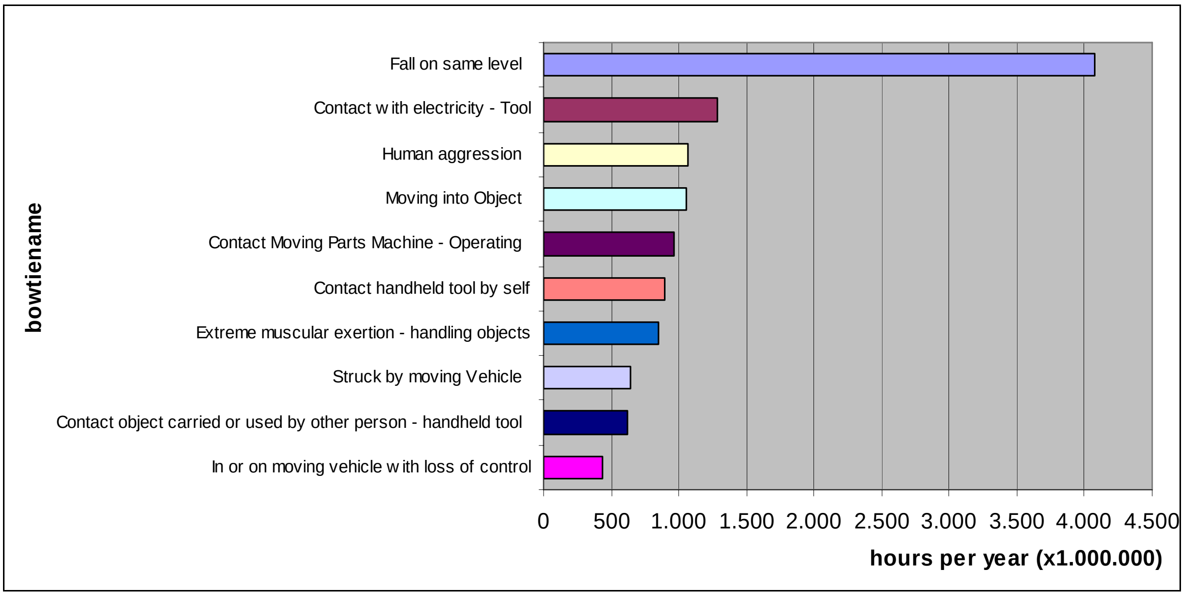

Figure 27 Top 10 of hours of exposure to hazards in the Netherlands

Figure 27 shows the top 10 bow ties with the highest exposure: the total number of hours per year that workers in the Dutch working population are exposed to the hazards associated with the bow ties. It shows that the largest number of hours of exposure is to the hazard ‘fall on the same level’. These figures only show exposure and they are not related to accidents, so they do not give the risk picture, of which they are an essential part. Figure 28 shows in which sectors the exposure to being struck by a moving vehicle is the largest.

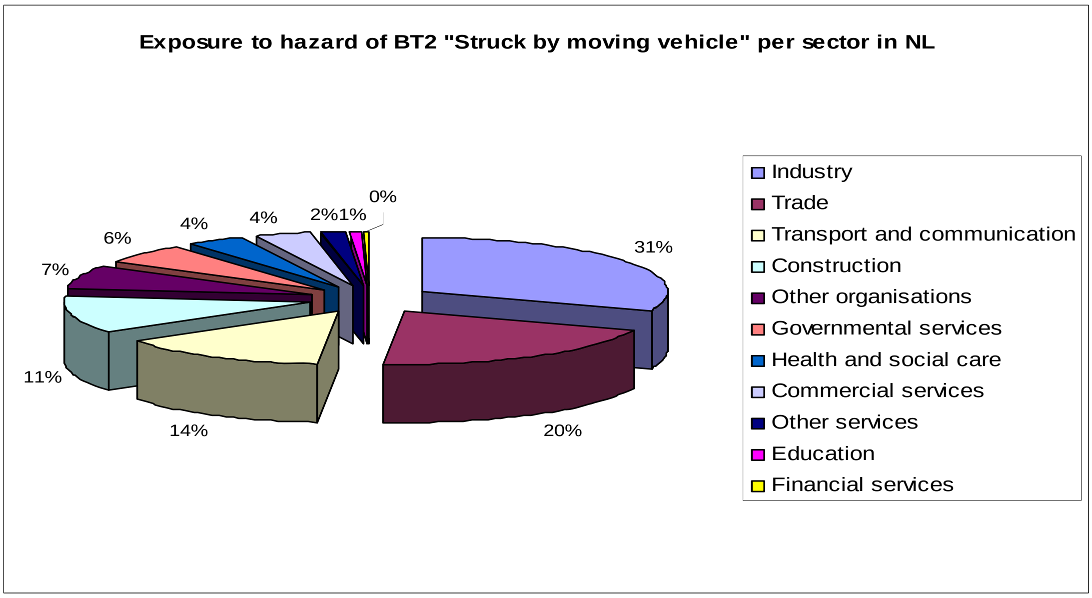

Figure 28 Distribution of the total Dutch exposure to the hazard of bow tie 2 ‘Struck by moving vehicle’ among sectors in the Netherlands

4.3.3 Working conditions

For 63 bow tie models, the bow tie specific surveys resulted in the Dutch national average PIE probabilities, consistent with the quantification requirements for ORM.
Exposure refers to the occurrence of failing PIEs, presented as the average percentage of the time workers were exposed to the hazard at hand. These results are illustrated in Table 13.

Table 13 Average PIE probabilities of barrier 'location/position' in bow tie 2 'struck by moving vehicle'

Barrier	PIE description	failure mean	95% conf. int. low	high
Location/position of pedestrian	measures for separating pedestrians and other traffic	30%	28%	33%
	use of measures	19%	17%	21%
	passing close in front or behind vehicle	19%	17%	20%

4.3.4 Measures

Another result of the data collection is a database containing all the measure related data needed by ORM and structured according to ORM specification. This structure is the key to linking the measure, effectiveness and cost data to the other quantification efforts (surveys, storybuilds). The database also contains additional information which is not required by ORM but which may be useful in future.

With everything in place the model is capable of presenting the optimal solution (based on low cost and high risk reduction) for the companies own unique situation. The user can however influence the selection of measures.
This can be useful if certain measures or types of measures cannot be implemented or if they are already implemented[13]. Companies, workers and other stakeholders can make a decision on which risk reduction strategy to take. A risk reduction strategy is a combination of measures. ORM shows several combinations that are possible to reduce a specific risk. Measures will improve the quality of barriers through their influences on PIEs. There are other strategies that can improve safety that cannot be explored by using measures, like reducing exposure time.

The measures database itself contains 350 measures and for each measure the effectiveness and costs and about 1.700 PIE-Measure combinations listed as PIE actions. The relations of the measures to the underlying causes of accidents are also included. The Dutch standardisation institute NEN added relevant standards, which resulted in a description of the standards for 67 measures.

Table 14 shows the number of measures per category. Users will be able to select measures from a specific category. The database contains more technical than organizational or behavioural measures. Three categories are not filled: technical measures that influence the organization, and behavioural measures that influence the organization or human. These types of measures cannot be related to a barrier.

[13] ORM is currently 'unaware' of the level of measure implementation of a company

Table 14 Number of measures per category

	Application:	Technique	Organisation	Human
Source	**Total**	**156**	**17**	**177**
Technical measure	**126**	64	0	62
Procedural measure	**194**	62	17	115
Behavioural measure	**30**	30	0	0

4.3.4.1 Costs

For every measure the costs are defined. Both fixed and variable costs are given. The user can adapt the parts to his specific situation; e.g. he can change the number of employees or the wages.

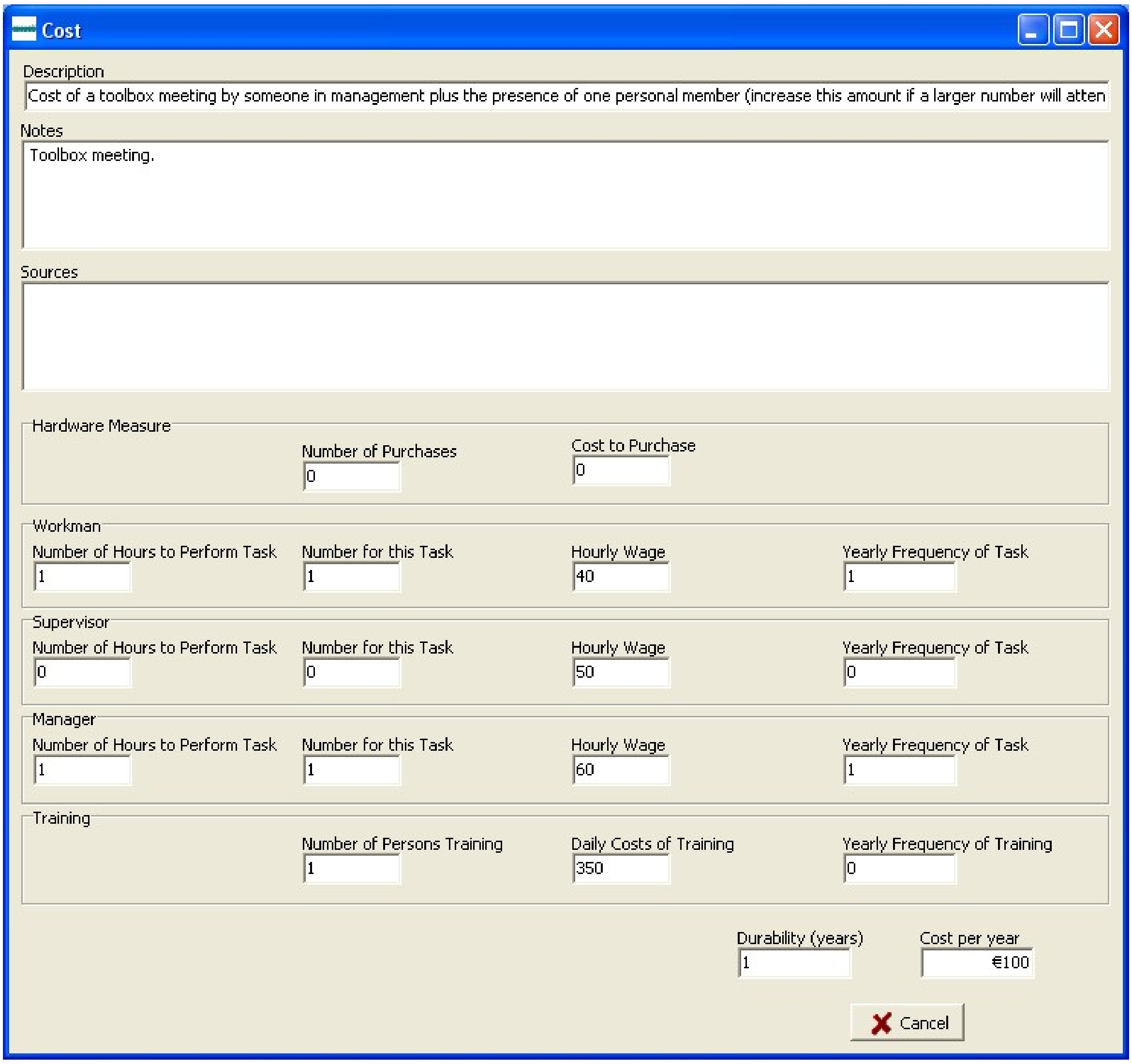

Figure 29 Screenshot of the costs module for measures

The table below shows the outcomes in the database, the range of each cost part.

Table 15 Range of each cost part

Cost part	Range
Purchase of a hardware measure	€ 0 - € 2,500
Number of purchases	0 – 2
Number of hours to perform task per person (workman)	0 – 8
Number of workman for this task	0 – 1
Number of hours to perform task per person (supervisor)	0 – 8
Number of supervisors for this task	0 – 1
Number of hours to perform task per person (management)	0 – 16
Number of persons management for this task	0 – 2
Number of persons training	0 – 1
Yearly frequency of the task (workman)	0 – 235
Yearly frequency of the task (supervisor)	0 – 235
Yearly frequency of the task (management)	0 – 1
Yearly frequency of the task (training)	0 – 3
Durability of the measure[14]:	0.25 – 10

4.3.5 Job, activity, hazard link

A final result of the data collection is the database based on Danish accident data containing a link between job, industries, activities, agents and hazards. After processing the data according to the requirements of the risk model, this database consists of over 376,000 accident cases. Theoretically the list of job and industry incorporated in the risk model leads to some 314,000 possible combinations of job and industry. The Danish dataset consist in practice of some 68,000 combinations of job and activity with data on activity, agent and hazard. This means that the overall likelihood of getting advice while choosing a combination of job and industry is almost 22%. This likelihood can be increased to almost 80% by choosing a combination of job and industry at the most aggregated level, e.g. craft and related trades workers in the construction industry. The advice given however is less specific of course.

The database can be used to get insight in the hazards that are associated to activities with specific agents or at specific locations in a specific job and industry. Two examples of a hazard list for a specific combination of job and industry are shown in Figure 30 and Figure 31. The first example concerns a teacher in primary education and shows the five frequent activity/agent accident combinations for this job, based on the Danish database RAW.

[14] ‘Durability defines the period a Measure will stay effective after purchase and/or application. Some hardware Measures have a Durability or lifespan of 10 years. A Health Check has a Durability of 0.25 because it is thought to be valid for just 3 months (and a previous health check will not influence the next).
A Safety Training can have a Durability of 3 years with a yearly frequency of 3 (in the year of application). It means that within the first year the training is offered three times (each time learning from the previous course) and is then valid for 3 years before the cyclus has to be repeated.’

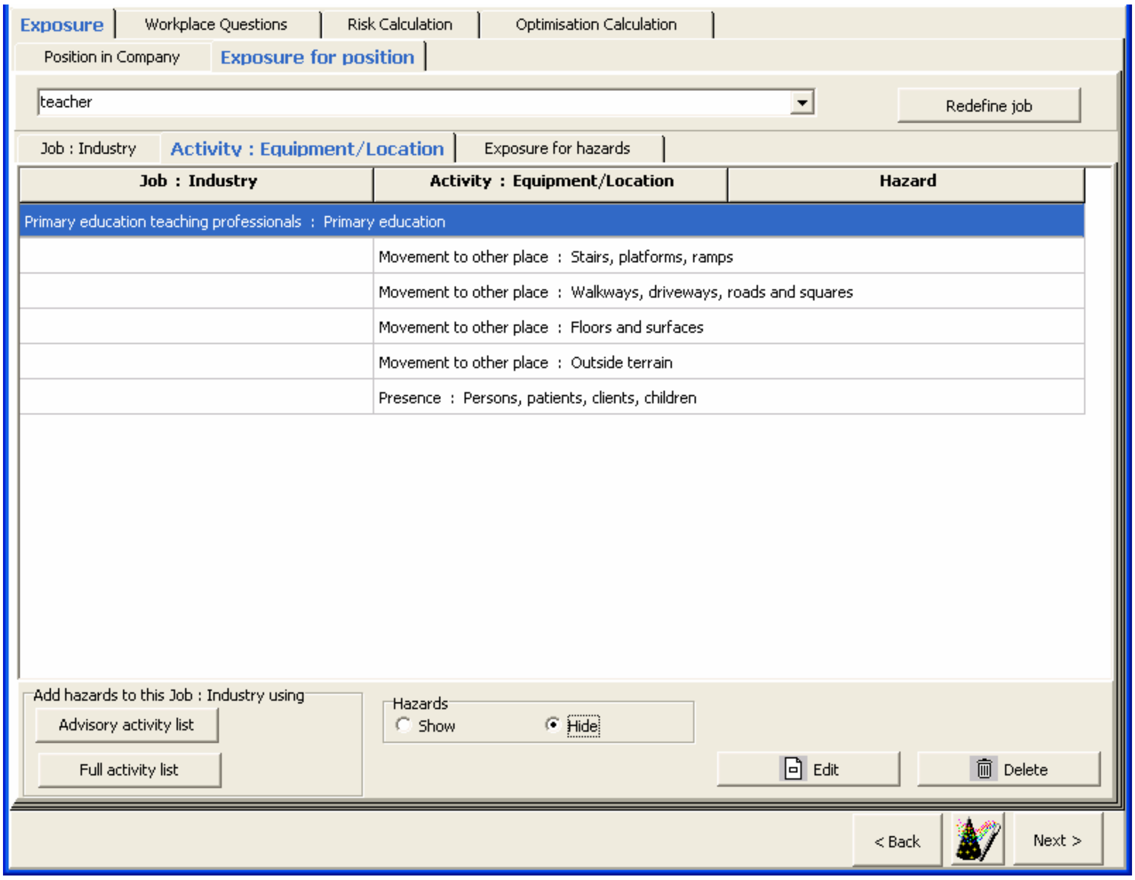

Figure 30 Relevant activities and related agents for a teacher in primary education

The hazards related to these activities are:

- fall from height
- fall on same level
- fall down stairs or ramp
- struck by moving vehicle
- contact with flying object
- hit by rolling/sliding object or person
- contact with object used or carried by other person –hand held tool
- contact with object used or carried - NOT handheld tool
- trapped between
- moving into object
- contact with hot or cold surfaces or open flame
- release of hazardous substance out of open containment
- human aggression
- animal behaviour
- extreme muscular exertion – handling objects
- extreme muscular exertion – moving around

A second example concerns a forest labourer in the logging industry. Figure 31 shows the five most hazardous activity/agent pairs for this job.

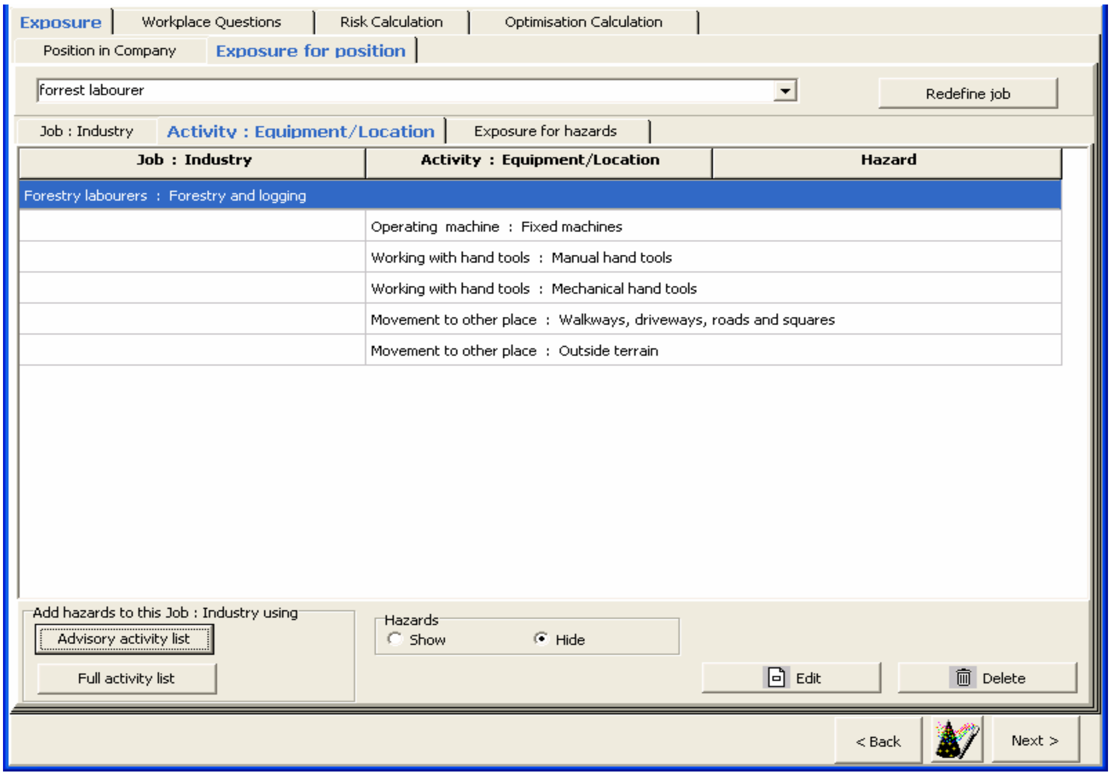

Figure 31 Example of relevant activities and related agents for a forest labourer in the logging industry

The hazards related to these activities are:
- fall from height
- fall on same level
- struck by moving vehicle
- contact with falling object - manual handling
- contact with falling object – other
- contact with flying object
- contact with hand held tools operated by self
- contact with moving parts of a machine – operating
- trapped between
- moving into object
- contact with hot or cold surfaces or open flame
- release of hazardous substance out of open containment
- animal behaviour
- extreme muscular exertion – handling objects
- extreme muscular exertion – moving around

These two examples show that jobs that may seem very different, with very different activities and related agents, still can be exposed to similar hazards. Some of the hazards for both jobs are not very obvious, e.g. struck by moving vehicle or animal aggression. But based on the Danish historical accident data both hazards are typical for the jobs and need attention.

These kinds of data can give new insights to companies and intermediates and policy makers and inspectors into job-profiles. Furthermore the production of the database has shown that it is possible to construct these kinds of data with accident data classified according to the international standard classifications ISCO, NACE and ESAW. This means that accident data from other countries may be processed in a similar way to give insight in country-specific job-profiles, provided that the available data are detailed enough.

5 Spin off

Several products were realised as an unexpected side-product that can be used independently by risk professionals. These products are:

- Storybuilder
- Storyfilter
- Bowtiebuilder
- measures, effectiveness and costs database

5.1 Storybuilder

A tailor-made software development, Storybuilder, was used to analyse the accident data. It provides a new way of analyzing and presenting accident data (Bellamy et al., 2006, 2007, 2008). The basic idea was to identify causes of accidents in a highly structured yet flexible way and to capture other information without losing the detail of accident reports. The method of data presentation enables the fine details of hundreds if not thousands of accidents to be presented simultaneously on a single screen as shown in Figure 32. These data can be further queried on screen by the user with enormous flexibility and with the possibility to export and tabulate queried data. The mode of presentation combines graphics similar to fault and event trees with text boxes and lines which follow the individual accident pathways ('horrible stories') through the model structure. The data is quantified by counting the number of pathways through a node (box) or combinations of nodes using a Boolean syntax.

Storybuilder can be adapted to analyse other sets of data too including company specific data.
In terms of application Storybuilder has uses which include:

- training in understanding accident cause and prevention[15]
- incident investigation/accident analysis (Van Santen et al., 2007)
- getting accident statistics (Ale et al., 2007a, 2007c)
- further developing storybuild bow ties in more detail (e.g. Baksteen et al 2007)

[15] NVVK workshop in October and November 2006 had around 300 participants. Storybuilder method is also part of the MoSHE course run by the TU Delft

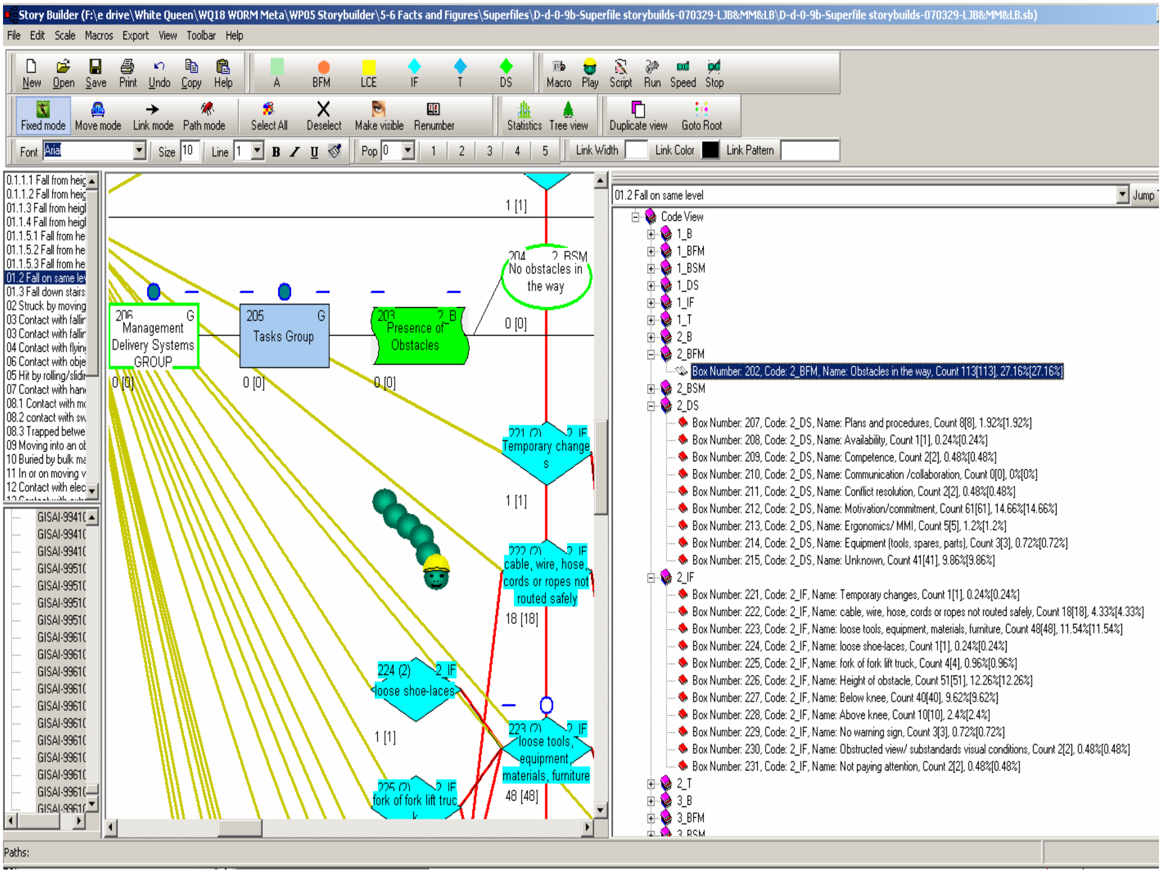

Figure 32 Screenshot of Storybuilder showing the different data views

The information in Storybuilder contains more detailed information on management delivery systems and barrier task failures than in ORM. English and Dutch inspectorates have shown interest in using Storybuilder as a tool for accident analysis. Also larger companies have indicated that they have an interest in using the tool to analyse their company specific data.

The use of Storybuilder is described in more detail in Technical Report 3 and the user manual in Technical Report 11.

5.2 Story filter

To couple the Facts and Figures from the Storybuilder data with other fields in accident databases, a specific tool was developed, a sort of pocket GISAI database (Dutch data) and a pocket RAW-database (Danish data, used to classify activities as described in section 3.4).

Amongst the sort of filtering possible is:
– age
– industry sector
– job type
– year of accident

Figure 33 gives an example of the accident analysis for the building industry sector 45.

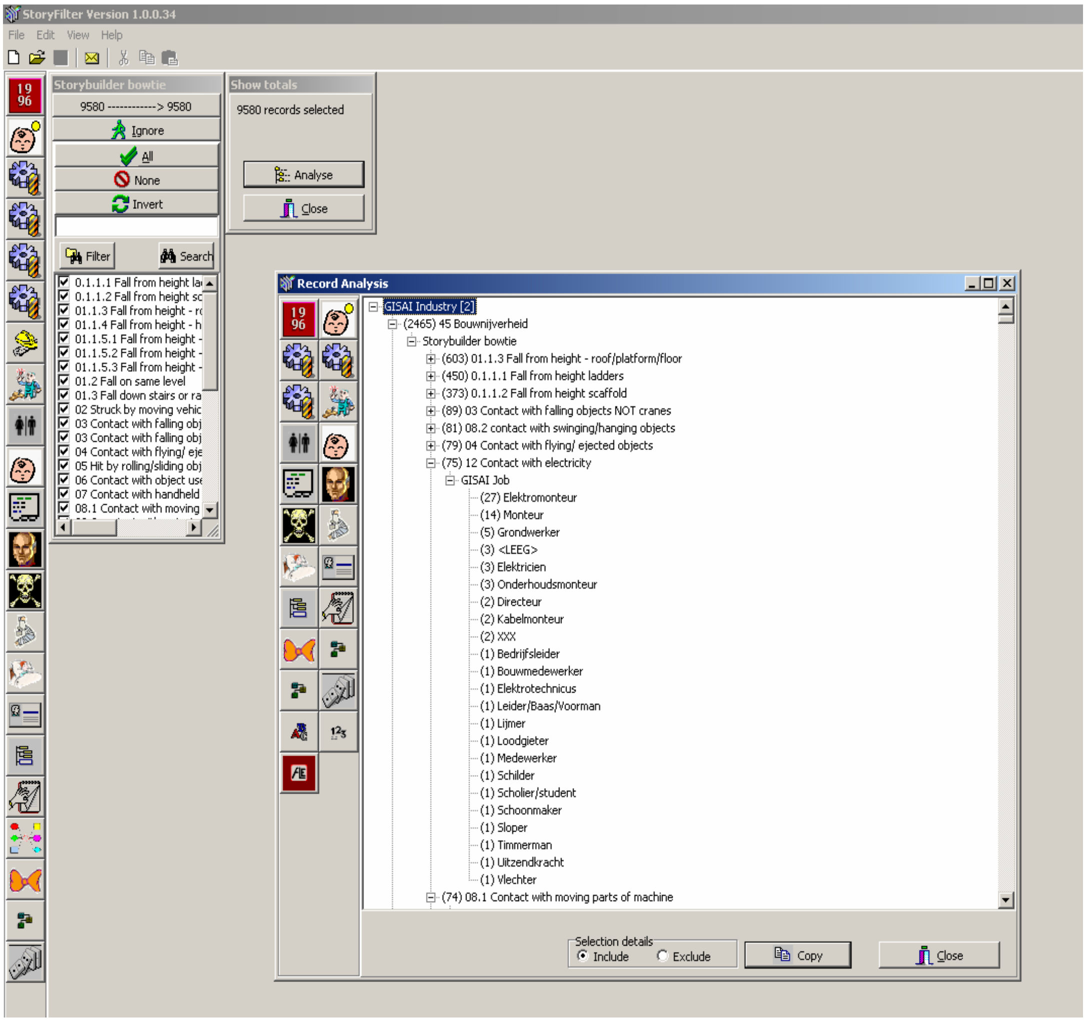

Figure 33 Storyfilter showing accident frequencies for a sector (construction) per storybuild (contact with electricity) and job

The use of the Danish data, analysed in terms of bow ties derived from Dutch data, shows that the classification of the data into storybuilds and bow ties could be applied internationally. The Danish database contained nearly half a million accidents. Figure 34 shows an example of the filtering screen using RAW. Different combinations of factors such as activity, material agent and bow tie can be used to filter a set of accident data for further analysis as was shown in the previous figure.

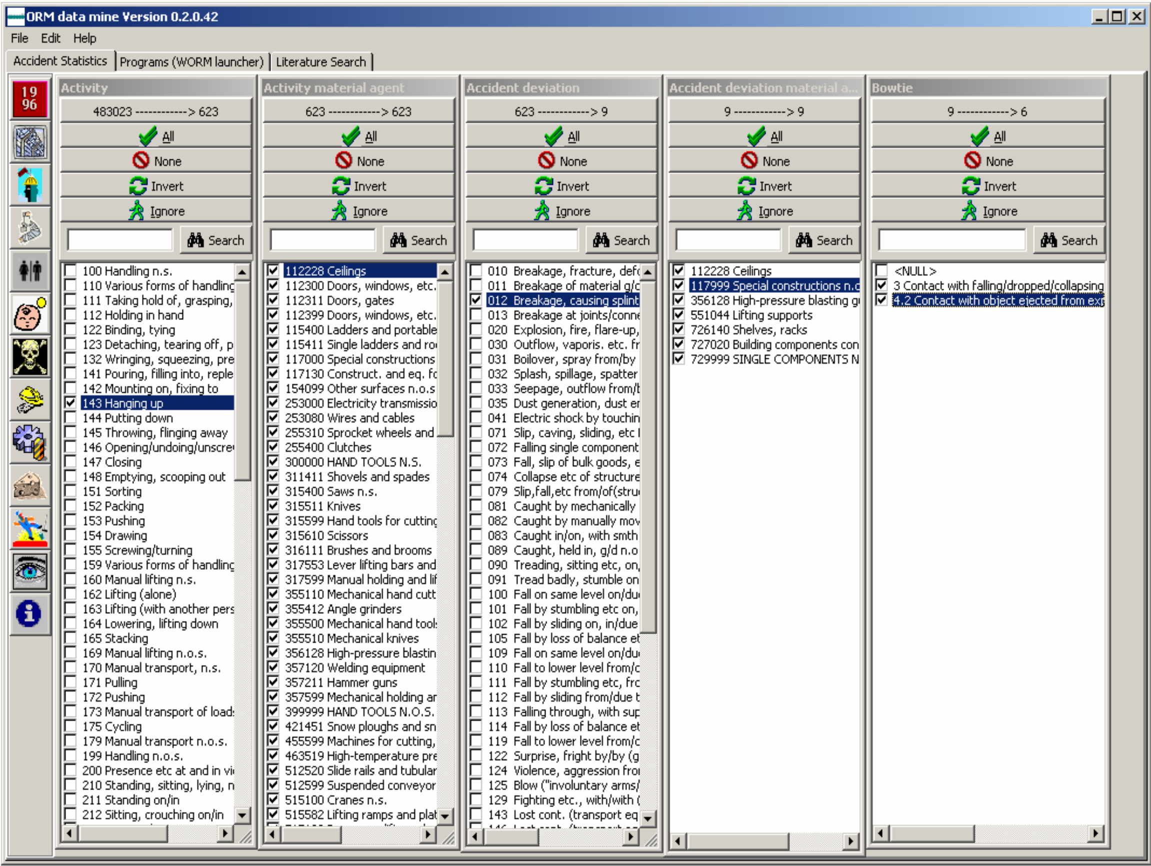

Figure 34 Story filter showing a filtering selection screen for the Danish RAW data

Story filter is described in more detail in Technical Report 3.

5.3 Bowtie builder

ORM is a piece of software using sets of programs and data. One of these programs is Bowtie builder, a program that develops and quantifies the logical models used in ORM. Bowtie builder allows the automated translation of an influence diagram into an event tree, the quantification of the tree and the simplification into a workable model. Any application that uses an event tree as a logical model can use this tool. Bow tie builder supports the building of the logical model connecting the consequences of a specific occupational hazard with its root causes and the mitigating factors step by step through the decomposition of the adverse consequences into simpler events. The diagrams of these models take the form of a bow tie, as presented in Figure 35 for the case of fall from roof.

Bow ties consist of the following major parts: a) centre event, which in this case represents a fall or not from a roof b) events preceding the centre event (fall from roof) and preventing it to occur c) events following the centre event and consisting mainly of measures mitigating the effects of the centre event or otherwise affecting the consequences of the centre event and d) consequences.

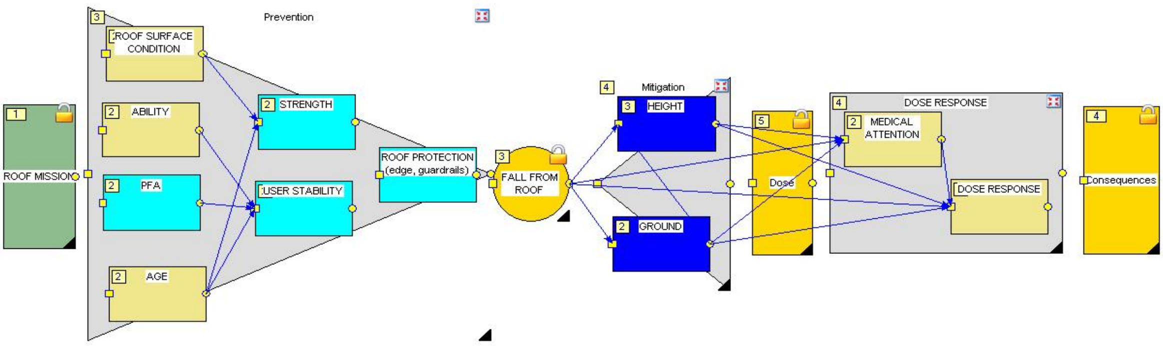

Figure 35 Bow tie for fall from roof

Bow ties can accommodate multi-state events and general probabilistic dependence among the events and are similar to an influence diagram, since each and every block can influence the probabilities of the outcomes of one or more other blocks in the model. Statistical dependences are presented by arrows between events, as for example in case of User stability, which is influenced by Ability, Personal Fall Arrest (PFA) and age. Dependent probabilities are be provided to the model, as shown in Figure 36 giving the probabilities of keeping of and loss of user stability dependent upon the condition of ability, personal fall arrest (PFA) and age.

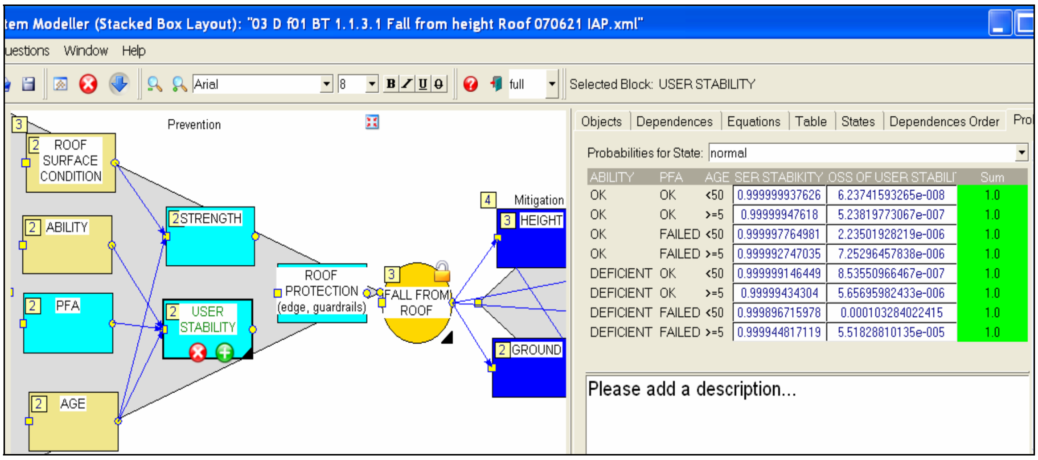

Figure 36 Dependences between events in bow ties showing probability of loss of user stability

Bow ties are equivalent to event trees and their quantification provides risk for every possible state of the system and also the risk of undesired consequences, such as recoverable injury, permanent injury and death, as presented in Figure 37.

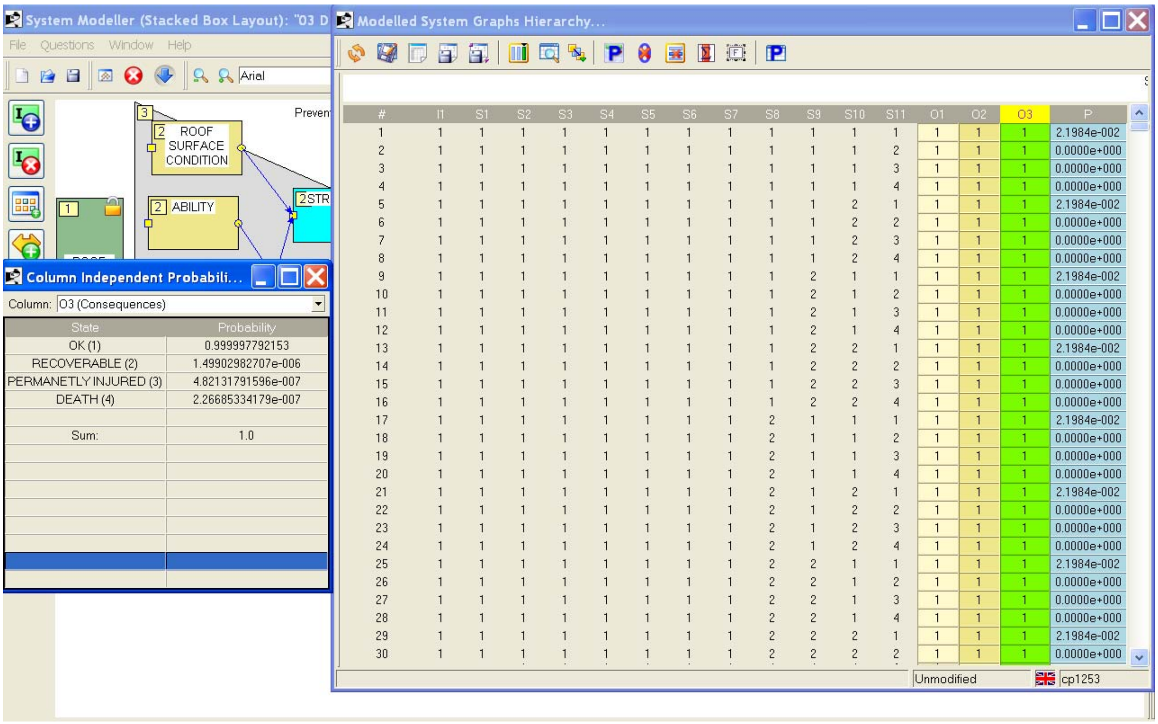

Figure 37 Automated quantification of the logical model in the Bowtie builder

All event tree sequences are generated, displayed and quantified as shown in the large window in the right of the picture. The first set of columns (I1-S11) corresponds to the blocks (barriers) in the bow tie. Each row corresponds to a state of the system and the elements of the row indicate the state of each block in the bow tie. The next three columns O1-O3 indicate specific characteristics of each system-state: O1 indicates the type of the centre event that corresponds to the system state (e.g.1 means success, 2 means centre event has occurred). O2 corresponds to the level of Dose the victim has received for the particular centre event outcome; O3 indicates the final consequence (1 Success, 2 recoverable injury, 3 permanent injuries, 4 fatality). The probability of occurrence of each row is calculated taking into consideration all existing probabilistic dependencies and is given in the last column of the table. Summing all row-probabilities of the same type provides the total probability of the four possible consequences and they are shown in the smaller window in the left of the picture

The tool can be used for different purposes, for constructing a logical model for another system, e.g. health risk, chemical accidents, transportation accidents, medical accidents, environmental issues, etc, using the influence diagram as a basis.

Bowtie builder is described in more detail in Technical Report 12.

5.4 Measures database

The whole collection of measures, costs and effectiveness is now available in a database together with for instance PIEs, single-hazard risks and storybuild management factor information. These data are now available which make it possible, given any hazard from ORM or even given one single root cause of an accident, to select all relevant measures, its description, its ultimate objective, together with norms and standards and information on how to implement the measure and a checklist when it is successful. Every measure is described in detail. As an example the description of a toolbox meeting is shown in Figure 38.

Measure i.d.	99
One liner	Toolbox meeting
Practical measure	Hold periodic toolbox meetings with personnel about day to day safety in the workplace and each time discuss a different topic
Goals	To inform and refresh safety knowledge on a specific theme. Emphasis on daily safety and the individual safety responsibilities of personnel. Make safe behaviour in the workplace a living thing
Meaning	Get people to think for themselves about safety. Safe behaviour can only be realised if there are the provisions in the workplace to work safely. Resources that are needed for carrying out the work safely should be improved or made readily available, for example.
Implementation	Planning of toolbox meetings, A scheme of subjects should be established, identifying also additional items that should be offered
Success	As many workers as possible who in their daily work have something to do with the subject of the toolbox meeting should be present. These toolbox meetings with different subjects should be on a regular basis (e.g. once a month)
For whom	Personnel who in their daily work have something to do with the subject of the toolbox meeting
Effectiveness	40%
Motivation Effectiveness	Behaviour: agreement
Sources	www.toolboxmeeting.com

Figure 38 Example Measures database: screenshot of the measure 'toolbox meeting'

This is a tool waiting to be explored and improved. The database, the Measure Effectiveness and Cost (MEC) database is developed according to strict specifications dictated by the ORM data structure. To use the measure data outside ORM some improvements are necessary. Although it is recommended to keep the structure intact, there is no reason not to expand the database; adding extra tables which could enrich the already collected data. Furthermore, the MEC has a user interface which was designed to accommodate the team that was collecting the measure data. This interface should be adapted to the needs of professional users.

Both companies and the Labour Inspectorate can be shown the advantages of having these data available such as:
- being able to monitor the level of implementation of measures;
- checklists to establish success of measures;
- quick and to the point selections that show only relevant measures for a single hazard or a combination of hazards;
- identify common root causes of different accidents that can be targeted with measures already implemented or ready for implementation
- compare the management system failures identified in the accident analysis with the present situation.

In future, one may also need to consult the potential users on how they would like to use the tool. For instance a PDA version may be asked for. The MEC database could have an interface allowing for users to query, combine, select, sort, add, modify and print data. Adding data is not only filling the gaps in existing fields. New data fields can be added as well. The current database has a few options to sort the measures but more could be added (functions like detection or response).

The use of the MEC database as a spin off tool can also help future versions of ORM. Users can add new PIEs to barriers – PIEs not previously identified – and connect new measures to PIEs as well as comment on the effectiveness and costs of measures. When working with the model and the measures, adding these data can be very instrumental for the activities of inspectors and safety professionals and can be used as a check on completeness of the collection of measures as now available.

5.5 Potential for expansion towards Health Impact Assessment

ORM is limited to accidental risks at work. Work related diseases due to chronic exposure are also important for the labour safety. Hence, it is the intention to develop a Health Impact Assessment (HIA) model for risk of diseases due to chronic exposure at work. In the project, the feasibility and possibilities of the HIA model were explored.

5.5.1 Requirements of the HIA model

The overall aim is a HIA model for work-related, chronic exposure to illness causing agents.

The most important requirements of the model are that it should:
- be (semi-) quantitative
- be useful at three different levels, namely:
  - at a company level, primarily to be used by small and medium enterprises (SME)
  - at a national level for policy decisions
  - at a national level for (prioritizing) labour inspections
- identify the diseases related to the work conditions in the company
- give insight into:
  - the risk factors and their importance
  - the risk for a specific job due to the chronic exposure to illness causing agents
  - risk reducing measures, their effectiveness and their costs
  - the risk to the company's workforce
- help to develop a cost-effective risk reduction strategy
  - at company level
  - at national level
- be complete (at the cost of detail). When necessary, assumptions should be made in order to complete the model.

The requirements of the model are too broad to be addressed in one single model. There will be a difference between a model for policy decisions on a national level and a model for small and medium enterprises. Therefore, different implementations of the HIA model are expected based on similar data.

5.5.2 Outline of the HIA model

Two different models were studied as a basis for the development of the HIA model, namely ORM and 'Stoffenmanager' (www.stoffenmanager.nl):

- ORM calculates the risk to employees in a company based on bow ties. ORM is a probabilistic risk model. Even if all barriers are provided, there is still the possibility that an accident does happen. Vice versa, even if barriers are missing, the mission may be completed without an accident. Bow ties are constructed on basis of case descriptions.
- The Stoffenmanager is a priority instrument for a company to rank the chronic exposure hazards of activities and to advice on control measures for the exposure pathways inhalation and dermal contact. Based on a substance hazard classification and an exposure classification, a 'risk' indicator of the activity is calculated. Stoffenmanager is deterministic in the description of the effect of barriers (measures): it is assumed that a barrier is used correctly and does work all the time. The effectiveness of a barrier is a realistic number based on practical experience. However, the model does not consider the probability of a barrier not used correctly.
- Based on these model approaches, an overall occupational HIA model may be structured according to Figure 39. As an example the activity of a baker, 'making dough', is used, which results in the inhalation of fine organic dust and possible effect Chronic Obstructive Pulmonary Disease, COPD.

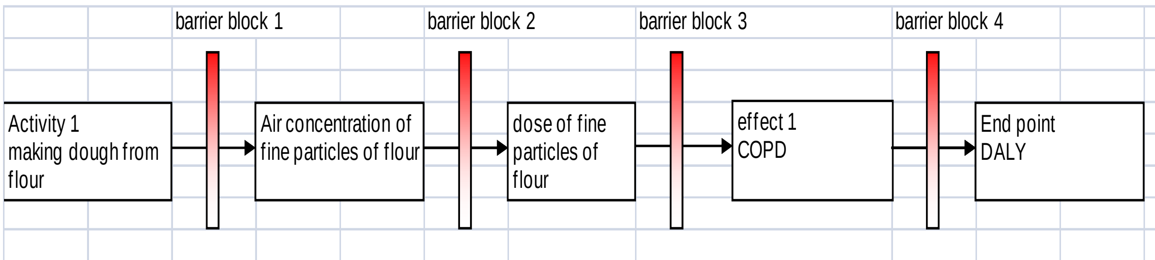

Figure 39 Outline of a HIA model - exposure to fine organic particles

The different barrier blocks in the model are:

- Barrier block 1 consisting of barriers influencing the concentration of fine organic particles in the air. Examples of such barriers are the working conditions, like room size, ventilation, the presence of a local exhaust.
- Barrier block 2 are barriers for the dose received by the baker. Examples of such barriers are personal protective equipment (dust mask) and behaviour (human activity, like eating at the workplace).
- Barrier block 3 influences the effect, e.g. a visit to the family doctor when the first symptoms show up and proper treatment is possible, whereas barrier block 4 is added for completeness.

In the model, a common end point is used for all diseases. The DALY concept (Baars et al., 2005) is considered as a useful measure for the model on a national level[16].

5.5.3 Data requirements and availability

In order to quantify the HIA model, data are needed for each step. With respect to the effectiveness of a barrier, there is a difference in data need between the Stoffenmanager approach and ORM approach:

- In the Stoffenmanager approach, a generic effectiveness is used for a barrier. It is assumed that if the barrier is present, the barrier is fit for the job and used correctly. Therefore, a generic factor is

[16] The Disability Adjusted Life Year or DALY is a health gap measure that extends the concept of potential years of life lost due to premature death (PYLL) to include equivalent years of 'healthy' life lost by virtue of being in states of poor health or disability (1). The DALY combines in one measure the time lived with disability and the time lost due to premature mortality. One DALY can be thought of as one lost year of 'healthy' life and the burden of disease as a measurement of the gap between current health status and an ideal situation where everyone lives into old age free of disease and disability. This concepts allows for the possibility to relate health risk to consequences on a quantified basis

used for the effectiveness of the barrier. Data on the effectiveness of barriers are available in Stoffenmanager, based on experimental data.

- In the ORM approach, the effectiveness of a barrier depends on a number of factors, like the probability that the barrier provided is fit for the purpose, the probability that the barrier is used correctly and the influence of factors like inspection, training and maintenance on the probabilities

It appeared that case descriptions with a sufficient level of detail are hardly available as a source of information on the relation between the working conditions and the incidence of an effect. This is also inherent to the problem, since chronic exposure takes place over a very long period of time. In order to have reliable information on the effectiveness of barriers in reality, job observations and surveys are probably the way forward.

5.5.4 Follow up towards Health Impact Assessment

In the discussions towards a Health Impact Assessment model it appeared that, up to now, an HIA model is feasible, although there will be limitations. The use of the probabilistic ORM barrier approach in combination with the Stoffenmanager information is expected to have added value for both policy decisions at national level as well as measures at company level.

In order to achieve this, the following approach is proposed:

1. Install a project group of experts to draw up a (conceptual) HIA model, taking into account the availability of data;
2. Select a pilot combination of agent and disease, based on the feasibility, the availability of data and the importance of the problem;
3. Define the data need of the model for this pilot study, the method to achieve the data, and the associated costs;
4. Based on the results of the previous steps, a go/no go decision is required.

6 Conclusions and recommendations

6.1 Important conclusions of the project

The WORM Metamorphosis project resulted in a quantified occupational accident risk model based on Dutch national data. A set of around 9000 occupational accident investigation reports of the Dutch Labour Inspectorate taken from a six year period were analysed resulting in 36 'storybuild' bow tie structures with very detailed cause and effect information.. The storybuilds were further developed as 63 logical bow ties which have been quantified to give the risk rates per hour and the risk per year for all hazards for the Netherlands by using data obtained through extensive surveys. With risk rate in this case is meant the probability of an accident per hour of worker exposure to a certain hazard and risk per year is the probability of an accident anytime during a year. Furthermore the probabilities in the bow tie models enable risk assessment to be performed for specific job and workplace cases. A prototype software tool developed for this purpose also gives users advice on the most cost-effective measures to reduce occupational risk whether at job level, company or for and entire industry branch

This development, from the unusually detailed capture of underlying causes through to a complete risk quantification, is an absolute first in occupational safety. The possibility of producing such a result was considered extremely challenging (Rimington et al., 2003) and indeed each step in the process brought new problems and hitherto unforeseen hurdles. Faced with this study the Ministry decided to put together the best project team possible consisting of the foremost scientists and experts from Greece, the Netherlands, Denmark, the UK, and the European Commission. Some of these team members have been working together for more than 15 years on other challenging projects like the EU IRISK project (Bellamy et al., 1999).

To keep the momentum and the policy and political support it was decided that the project results would be marketed and delivered as early as possible. Within a year there was a first mock-up of the final tool, which gave interested parties insight into what the final risk assessment tool would look like. The results of the incident analysis were put into a tool called Storybuilder, which was received very positively both in the Netherlands and the EU. Both companies and inspectorates are starting to use this tool to understand the underlying causes of incidents, and Storybuilder 'Facts and Figures' have been published on the Ministry SZW website. It was in fact a request from the Dutch parliament to do so. The Dutch Labour inspectorate uses results from Storybuilder for training and inspection purposes and the UK HSE will start training their inspectors in the use of this tool. Storybuilder was used to analyse complex accidents like the one at the Amercentrale in the Netherlands (Van Santen, 2007) and Buncefield in the UK. (Baksteen et al., 2007)

Bow tie Builder the tool that converts Storybuilds into mathematical logical Bow ties also received great international interest and will be marketed as a separate tool.

The exposure and effectiveness of the measures study, where 60,000 persons were interviewed with respect to all the hazards, is unique and has given great insight into the exposure of the worker population and the implementation of measures in companies. It is almost certain that the results of this work will be further analysed and it will possibly cause a paradigm shift in our safety thinking.

The Measures Effectiveness and Costs (MEC) database provides insight into the effectiveness of measures to reduce risk and is a good starting point for cost benefit safety analysis in companies, underpinning the risk assessment.

The risk tool itself, the final deliverable of this project, has a lot of potential for companies and for policy. It has changed the way we look at occupational risks and makes it possible to assess the consequences of policy changes and decisions. One of the examples is the political decision to discourage the use of ladders in favour of scaffolds. The risk model indicates that this could be a wrong decision and that working on a mobile scaffold could have a greater risk, unless it sufficiently reduces the exposure. Companies are now able to determine what the largest risks are and, given a certain budget, decide what the most effective risk reducing set of measures is.

The striving for missing data and the process of resolving modelling issues put extreme demands on the team resources. Therefore it is not surprising that there are many improvements and expansions of the model and data that could be made. However, it is considered a priority to also bring the results to potential users and ensure that future developments are properly adapted to their needs. Also some potential users have needs that go beyond occupational safety to health impacts. The areas for consideration are:

1. user involvement in development of the software interface
2. marketing approach towards regulators and inspectors, large company users, and intermediates and other stakeholders like sector organisations and insurance companies
3. actively providing user relevant data through appropriate communications media and strategies.
4. software and data maintenance and some further user directed model developments
5. expansion of the model towards occupational Health Impact Assessment

6.2 User involvement in further developments

However good the model, the user interface is one of the critical parts of the acceptance of the software. ORM and Storybuilder should be designed to become more user centred, so users first have to be attracted to using these tools. In order to get ORM and Storybuilder to the market, web based products could be developed at the same time having the functionality to get feedback on what users want. As user needs are assessed it may be useful to develop separate modules for different target groups, such as assisting in a sector specific way. Answering users' questions will be a prime focus

Other aspects to consider are the speed and accuracy of the results, such that exploring ways for making the model and tools more efficient for the user are desirable. The software presents the user with many options which, while giving flexibility, could be narrowed down, making the tool less flexible but better adapted for specific user groups. So, different solutions may be required. Delivering training and workshops would also be a way to promote the tool in the market and assist the user in being able to make appropriate demands.

6.3 Marketing

A market analysis has shown that different types of users should be targeted as follows:
1. involving regulators and inspectors
2. account management of pilot cases for large companies

3. attracting intermediates with specific business interests (consultancy, insurance companies)
4. enhancing compliance in small and medium sized enterprises (SMEs).

This 1-4 ranking of these target groups indicates the likelihood of positive reception of the products by end users given criteria such as commitment, professionalism, expected effect and accessibility via market channels. So, SMEs are not a good target. A business plan has been produced (Postma et al., 2007).

6.4 Availability of data

To facilitate access to the data by a wider group of stakeholders a website (the so called Arboportal) should be established in combination with a helpdesk.

The knowledge provided by the WORM-M project includes data covering occupational accidents, exposure, measures, effectiveness and costs of measures and norms and standards. Work has to be done with respect to the data design in order to make it accessible to target groups and find the appropriate method of responding quickly to user questions and communicating the results. Shared definitions and contexts are also important to enable a question and answer interchange.

The communication interface with the user is therefore important. While products, such as fact sheets, checklists or web films can be developed, finding a means to enable users to access and combine data in the way they want to is also desirable. At the same time the interests of the user should be feeding back into that system.

Particular data modules of the complete tool could also be developed as stand-alone products, like the measures, effectiveness and costs database, MEC. Storybuilder is already a more mature stand alone tool in that respect, but is a challenge to developers who have so far focused on the builder as user. It is the builders who know the tool well, and although there have been many developments for getting data back out, the less experienced user is in need of training.

6.5 Model and data maintenance and development

During the WORM and WORM-Metamorphosis projects a lot of data have been collected and analysed. Accident and exposure data from the Dutch working population have been used to calculate the risk metrics associated with different occupational hazards and for providing facts and figures information on underlying causes of the various types of occupational accidents and their occurrence in various sectors. Danish accident data have been used to associate those hazards with specific activities of a job or industry. British accident data have been used to follow up on issues associated with loss of containment accidents in chemical installations. Problems with respect to differences in sources, classifications, definitions and other quality aspects have had to be faced. For the risk model many of these problems have been solved. However, the usability of the data can also be improved by validation, further analysis, updating and combination with other data sets.

Further analysis

Not all available accident reports of the Labour Inspectorate were analysed for the selected period. The more frequency dominant accident categories of falling loads and contact with moving parts of machine were only analysed over a two year period rather than six. This makes sector comparisons of accident frequencies more difficult and provides reduced information for risk calculations compared to the other bow ties. Further analysis of the remaining accident reports is therefore recommended so that all risk metrics are quantified with data over the same periods of time. Such quantification will make risk rates and yearly risk comparisons more reliable. Uncertainty assessment is also needed for this purpose to assess the robustness of the results into likely variations in the input data.

Data on exposure and accidents have been combined without distinguishing between industrial sector, age, gender, educational level, type of employment and type of company. Consequently the results represent the Dutch National Average (DNA). More specific analyses are possible, the extent currently being limited by the size of the resulting data subsets. This area can be explored to see what is feasible to analyse at a more detailed level, with consideration of what more data might be worthwhile to collect in the longer term.

Specialised analyses could provide models which are more applicable to particular sectors for example, reducing the burden on users to adapt the data themselves. This would mean that a potential ORM user could develop their own cases with a smaller amount of input than the current generic model demands. Some specific guidance is already given in the form of a job-industry specific advisory on which bow tie hazards to select but this is only part of the issue. What for example are typical durations of activities for a particular kind of job?

Validation

In testing the validity of the risk results of ORM there are 2 validation issues which could be explored:

1. Are the developed models structurally valid: In other words are they complete?
2. Are the quantitative results reliable and representative of the actual occupational risk?

<u>Completeness issue</u>

Logic models link root causes with the occurrence of occupational accidents through the occurrence of specific sequence of events that can lead to specific consequences. These models have been based on the analysis of a large number of reported accidents in the Dutch working population. The first question that can be raised is whether these models are complete, that is whether they include all the possible root causes and the failure modes that result in the specific occupational accidents.

With respect to model ‘width’ additional fundamental ways which can lead to loss of control and to the Centre Event of the models may be assessed if completely different sets of data referring to completely different working environments in other countries are analysed.

With respect to model ‘depth, being the level of detail of analysis and root-cause assessment, the developed models may benefit from further analysis. It is already known that the logic models have been truncated at a level where management and organisational issues are not included in the model. Even the low level root causes and working conditions (the PIEs) are indirectly tied to the logic models. Further development of the models to include management and organisational issues might uncover existing dependences among the causes and consequences of accidents not presently included in the models. It is noteworthy that any extension of the basic logic models would require a large amount of the missing data like exposures in addition to the accident data already analysed.

<u>Reliability issue:</u>

Quantitative (and qualitative) risk analysis like the one performed in the WORM-M project relied on data about things that happened in the past. The final quantitative risk assessments as well as any risk reducing strategies based on the results of the ORM model are valid to the extent that the statistical and probabilistic paradigms are valid i.e. that the future will be a repetition of the past in terms of the working environment and the prevailing working conditions. In this sense a validation of the model would consist of observation of the same population under similar conditions or under known condition changes and observing accident rates or more complex results according to the predictions of ORM.

Further reliability issues are posed by the reliability of the data used in quantifying the model. Were the accidents reported in GISAI the only reportable accidents during the analysed period or is there an underreporting issue? Are the exposure times accurately assessed through internet interviews of workers? A variability or uncertainty study could indicate how sensitive the results of the various models are to variations (and hence possible deficiencies) in the input data. Alternative ways for assessing exposure times and working conditions can be used, namely those of actual observation of a suitable sample of workers in a suitable set of workplaces. An example of such an alternative approach is a Danish data collection project, DANWORM, which is looking at the alternative ways to collect exposure data and identifying and solving the difficulties in the process. The project focuses on small companies and the workers are observed carrying out their activities and tasks.

Updating sets of data
A variability or uncertainty analysis would indicate how sensitive the results are to existing variability or the relative paucity of information in the input data. The additional information as it becomes available through continuing observation of the Dutch working population would either reduce the variability in both the input and the output of the model or indicate major changes in the input data resulting from specific risk reducing strategies or the lack thereof.

Collection of such additional information can be facilitated if barrier failure modes and other useful components of the analysis of accident data in Storybuilder are introduced into the management of reportable accident investigation by the Labour Inspectorate.

Exposure surveys could also be updated periodically both at mission level and at the level of working conditions. In the future, observed changes in the basic inputs of the model can serve, in conjunction with the model, as indications of whether occupational risk is increasing or decreasing. Since changes in exposures and/or working conditions are much easier to observe in relatively short periods of time, such changes can be used as precursors or indicators of approaching occupational risk changes.

International use
The model is defined by the Dutch context, having used Dutch accident data and having measured exposure of the Dutch workforce. However, given the magnitude of accident data analysed and the sample size for the exposure data leading to figures for the entire working population, insights gained can also be relevant internationally. The logical models and the Dutch data may be used as a basis for comparison with similar business sectors. The ORM software database is available in either Dutch or English.

6.6 Quantified occupational Health Impact Assessment

The current model deals with occupational accident risk only. Since the number of deaths related to occupational health issues for the Netherlands is estimated at 4000 persons every year it is advisable to explore the possibility of expanding the model to deal with occupation related health risks. In this project considerations for the development of a Health Impact Assessment (HIA) model for chronic exposure have been explored. As described in section 5.5 it has been investigated if the Occupational Risk Model for accident risks can be used as a basis to quantify the broad scheme of occupational health risks, like chronic exposure.

The Occupational Risk Model for accidents uses three different end points, namely death, permanent injury and recoverable injury. Death can also be used as an end point for a health model. However, the use of death as an indicator results in an underestimation of the health damage since e.g. skin diseases do not lead to mortality. The same problem holds for indicators such as days of absence from work or days in hospital.

An indicator for work-related health damage could combine mortality, illness and other health effects. On a national level, the concept of DALY (Disability Adjusted Life Years) is generally accepted and already used in the various studies into the contribution of work-related exposure to substances to the prevalence of the illness. The concept may also be useful in the integration of the HIA model and the Occupational Risk Model for accidents because it is feasible to turn the end points for the latter into DALYs

The goals of the model are probably too broad to be addressed in one single model. There is expected to be a difference between a model for policy decisions on a national level and a model for small and medium enterprises. Therefore, different implementations of the HIA model are expected based on similar data.

In order to quantify the HIA model, data are needed for each step. The feasibility of the model strongly depends on the data availability. An important foundation for the ORM model is the case descriptions from the GISAI database. These case descriptions give information on how a particular accident happened and which barriers were at the time of the accident present and their status at the time of the accident as there is a direct link between the accident itself and the working conditions at the time of the accident. For the HIA model, the link between the effect and the working conditions is less clear and the use of case descriptions is not straightforward. The effect (disease) results from the accumulation of exposure over a large number of years, and the presence and status of barriers varies in time and is not well recorded. Furthermore, the effect may result from combinations of chemicals, either simultaneously or consecutively. Another aspect is the availability of case descriptions. Descriptions are probably only available for a limited number of cases, e.g. specific illnesses like asbestosis and chronic toxic encephalopathy (CTE).

These are new challenges to be overcome in future work.

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Annex 1 Glossary of terms

Accident
An unforeseen incident, where the intent to cause harm, injury or death was absent, but which resulted in injury. The Occupational Risk Model used reported reportable occupational accidents in The Netherlands between 1998 and February 2004 using the data from the Dutch Labour Inspectorate GISAI database.

In the Arbowet 1998 (Dutch Law) a work accident is given as a sudden unwilful event in the course of carrying out work with immediate consequences for health and which leads to absence through illness or death more or less immediately

The European definition (European Commission, 2001) is a discrete occurrence in the course of work which leads to a physical or mental harm. The phrase ‘in the course of work’ means ‘whilst engaged in an occupational activity or during the time spent at work’. This includes accidents in the course of work outside the premises of his business, even if caused by a third party, and cases of acute poisoning. It does not include occurrences having only a medical origin (such as heart attack ay work) or occupational illness.

Notifiable accidents in the Netherlands are work accidents which cause serious physical or mental injury or death. Serious can be understood as meaning damage to health which within 24 hours of the time of the accident leads to hospital admission for observation or treatment or which is by reasonable judgement deemed to be permanent. Exceptions are Commuter traffic accidents even in the case of work. These are traffic accidents and not incorporated in Labour Inspectorate data.

Not all work accidents are reported. Other sources of information include the Letsel Informatie Systeem (LIS) (injury information system) of the Consumer Safety Institute. The sources are patients who register by the emergency department of a hospital. Another is the Central Bureau of Statistics survey of the working population. An accident is defined as a sudden unintentional and unforeseen event resulting physical injury; incidents of intentional violence or food poisoning are not included. Industrial accidents resulting in fatalities are also excluded.

The following data more or less used throughout are Europe:

a. Fatal accidents at work (accidents leading to death within a year)
b. Accidents at work resulting in more than 3 days’ absence from work (further: 1/2 year, 1 year absence, permanently disabled etc.)
c. Accidents at work resulting in 1 – 3 days absence from work
d. Accidents that lead to injury but not resulting in absence from work

However the known classifications in the Netherlands are based on the methodology of registration;
1) fatal – 2) medical treatment – 3) no-medical treatment (Dutch surveys)
1) fatal – 2) permanent injury – 3) hospital treatment (Labour Act - Arbowet)

Accident path
An accident path is a defined route with a temporal sequence through a structure of events this structure being a Storybuild or Bow tie. All accident paths go through the centre event of a bow tie. All accidents paths are given a unique number so that their origin is always traceable. An accident may have a path which splits into sub-paths if there is more than one victim of an accident and the effects and/or consequences are different..

Activity
Activity is defined as the specific physical activity of the worker at risk.. By performing this activity workers are exposed to one or more hazards that may lead to an occupational accident. ORM uses two kinds of activity lists. One is based on the Danish RAW data and ESAW classification of Specific physical activity. The other is a list of activities which are directly related to a specific hazard e.g. working in an area where there could be falling objects.

Agent
Agent is defined as the principal material agent associated or linked with the specific physical activity performed by the worker at risk. The agent list, incorporated in ORM, is based on the ESAW classification of Material Agent.

Barrier
A barrier[17] (as used in the accident modelling in Storybuilder) is a physical entity (object, state, or condition) that acts as an obstacle in an accident path. Barriers can be created or enforced by actions (measures) and need to be controlled to be effective (management control loop: provide – use – maintain- monitor).
In the quantified risk model the barrier (or basic event/block) aims either to prevent something from happening (e.g. the centre event) or to mitigate the consequences of something that has happened, thus influencing the probability of the centre event or its consequences.
Examples are the ability of the user, or the stability of equipment. In ORM the terms support safety barrier and primary safety barrier are used to distinguish between two types in the model.

Barrier failure mode
A barrier failure mode (BFM) is one way in which the barrier failed in an accident scenario e.g. a structure not being strong enough for the exerted load.

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[17] The hazard – barrier – target model is originally based on a paper by William Haddon jr, 1973.
Within the safety science, for more than 30 years potential accidents are modelled with the Hazard – Barrier – Target model. In particular, occupational accidents have been modelled with the use of hazard-barrier-target models. In the occupational accident model the target is the human being, (in other models it could be the environment or the company economy). The hazard is the physical or chemical phenomenon that causes harm to the target once released outside its design envelope. Barriers are put in place to prevent the hazard from harming the target.
Typical barrier functions are:

- prevent presence, build-up, or release of the hazardous agent/energy
- separates hazardous agent/energy in space (safe distance) or time (safe moment)
- prevents the undesired transmission of energy / hazardous agents
- prevents incompatibility of materials
- prevents unsafe process conditions (pertains to sequence, temperature, pressure, composition)
- prevents unsafe physical conditions (pertains to structural integrity, strength, stability)

Barrier tasks
The management delivery systems of resources, controls and criteria are delivered to the barriers through four categories of tasks. These are **P**rovide, **U**se, **M**aintain, **M**onitor. When a barrier fails only one of these tasks has failed. The tasks, particularly the use and maintain tasks, are operable on a lower level in the overall system: i.e. at the barrier level where operators/workers and maintenance fitters are working. The provide task is, on the other hand often a management task.
The tasks fail as follows:

- **Provide-[barrier] failure**
  = It does not exist, has not been well designed, or it is not provided and / or sufficiently/easily available when you want to use it. Such a barrier can be hardware or a specific method (sequence, composition, or other parameter(s) with safe limits).
- **Use-[barrier] failure**
  = the correct barrier is provided, but the way in which the provided barrier is used is incorrect, it is only partially used, or it is not used at all. A ‘use’ failure is also the case, when somebody chooses to use a barrier other than the correct one, despite the correct one being available.
- **Maintain-[barrier] failure**
  = the barrier is not kept available according to its designed function; i.e. in an adequate state. This does not only cover the maintenance aspect but also the management of change aspect of a barrier, i.e. a barrier is modified without ensuring that it maintains its barrier function.
- **Monitor-[barrier] failure**
  = the barrier condition is not checked/ measured/observed/inspected. This task relates directly to the state of the barrier, or to the supervision of the use of the barrier.

Bow tie
The complete model consists of a complex of events that together form a logical structure leading from causes to accidents with a certain probability. This model is called the bow-tie. Such a model has a level of abstraction which is difficult to grasp especially for those who are not used to the complex mathematics of logical and numerical tree structures. For this reason events or non-events that prevent a cause from developing further towards an accident are depicted as barriers in the causal chain. For modelling reasons these barriers are further divided into two types: Primary Safety Barriers (PSB) are directly in the causal chain to the centre event and the intention of the Safety Support Barriers is to prevent the PSBs from failure. The states of the barriers determine the probability of subsequent events. Loss of control events (LCEs) in Storybuilder end up as failures of a PSB in the bow-tie.

Centre event
A centre event is the centre of a bow tie or storybuild through which all accidents pathways for that bow tie or storybuild pass. It is the point at which the hazard agent is released in the event sequence and characterises the hazard e.g. fall from a roof, loss of containment, contact with handheld tool.

Death
In ORM death is defined as the result of an occupational accident resulting in death within one year after the accident. The assumption is that the victims who die within one year after the accident will not return to work before they die. So, the injured person will not return to work and dies within one year.

The ESAW (European Commission, 2001) definition of fatal accident is an accident at work leading to the death of the victim within a year (after the day) of the accident. In fact, the majority of the accidental deaths occur either immediately at the time of the accident, or within a few days or a few weeks after the accident.

Dose Determining Factor (DDF)
Dose Determining factors are one of the things that influence the severity of the consequences following a centre event. By definition they are located to the right of the centre event and affect the size of the effect of the hazard agent. For example the height of a fall, the weight of a falling object, the velocity of a vehicle are all DDFs

Effectiveness
Effectiveness is the ability of a *measure* to decrease the probability of a negative state of a *PIE*, expressed as a percentage. The percentage is the percentage decrease of the gap between the current state of the PIE and the optimum state.

ESAW
European Statistics on Accidents at Work. A project commissioned by the European Commission, aiming at collecting EU-wide comparable data on occupational accidents and establish a database.

Exposure
The amount of time or percentage of time a worker does something where they are exposed to a particular hazardous condition. For instance:
- number of hours a year working on a ladder = number of hours exposed to falling from a ladder or
- % of time ladder used which does not have non-slip feet = % of time population of users is exposed to ladder with non-slip feet.

Failure mode
See barrier failure mode

GISAI
Integrated Information System of the Dutch Labour Inspectorate (In Dutch: Geïntegreerd Informatie Systeem ArbeidsInspectie)

Hazard
A hazard is anything with the potential to cause harm

Industry
The industry is defined as the economic activity of the employer. The industry list, incorporated in the model, is the international standard classification NACE [European Commission 2002].

Job
Job is defined as the occupation of the victim of the accident. The job list incorporated in the model is based on the international standard classification ISCO-88-COM[18].

Left Hand Side (LHS)
Indicates the position of a block (factor) in the bow tie model. Left Hand Side (LHS) means to the left of the centre event, i.e. previous in time. For example: a LHS barrier can prevent the centre event occurring (prevention).

[18]: In the context of International Standard Classification of Occupation (ISCO)-88 a job is defined as a set of tasks and duties which are (or can assigned to be) carried out by one person.

Loss of control event
A loss of control event is an event(s) that occurs when a primary safety function fails. In the accident path sequence it is the direct cause or causes that lead to the centre event. Loss control events can also be included on the right hand side of scenario models as events that directly lead to the (severity of) the consequences.

Management delivery
Management deliveries are the resources and commitments delivered by the management systems in place, through the tasks towards the technical system to enforce the barriers that prevent accidents and/or reduce their consequences. A management delivery failure can be seen as an underlying (base or root) cause of an accident.

Management delivery systems
The management delivery systems are subsystems of the management system. These subsystems deliver the necessary controls, criteria and resources to the barrier tasks for keeping the barriers intact. These controls, criteria and resources were resolved into eight systems based on a task analysis of safety management carried out in the I-Risk project[19]. These eight systems are plans & procedures, availability, competence, communication/collaboration, motivation/commitment, conflict resolution, ergonomics and equipment.

Measure
A measure is defined as a collection of specific actions that result in a change of the probabilities of PIEs. A measure strengthens barriers by reducing the probability that the barrier is in a so called negative state. A measure has a specified % effectiveness (see effectiveness)

Measure attributes can be further described as follows. The source attribute describes the measure itself. The application attribute describes the environment it affects. In case of overlapping characteristics the most predominant feature is chosen to estimate the effectiveness. The distinction is used as an aid in estimating the effectiveness. The following working definitions have been used to guide the categorisation:

Technical/hardware
As source: Object, equipment or machine (part) that performs at least one of the following functions in a work process: operating within set (safe) boundaries, detecting anomalies, signalling/warning, protection against consequences of operating outside boundaries.
As application: Provide and strengthen the functions listed above of objects, equipment and machines

Procedural/organisation
As source: Corporate decisions/actions and rules/working procedures that structure the working process
As application: Provide and strengthen organisational structure and streamline the working process

Behavioural/human
As source: Individual decisions/actions based on knowledge, skills and attitudes while performing tasks/function/role
As application: Providing, improving, influencing knowledge, skills and attitudes

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[19] Bellamy et al., 1999

Mission
Those activities or situations during which the worker is at risk of having the accident as described in the centre event of the bow tie. For quantification of the risks, ORM requires the total duration (number of hours) of exposure to each of these missions in the Dutch working population.

An example definition of a mission, for struck by moving vehicle bow tie, is: Number of hours workers are pedestrians at locations with moving vehicles during work. This includes working on industrial premises, in warehouses or at loading/unloading bays, or along the public highway in the role of (for example) road construction worker, garbage collector, roadside vehicle repair mechanic/pick-up service or police officer. Normal traffic activity as a user of the public highway (including commuting and business travel) is not included.

Mitigation
The reduction of the severity of the consequences of an accident by events on the right hand side of the centre event of a bow tie e.g. emergency response.

Occupational accident
An accident occurring at work - See accident.

Permanent injury
A permanently injury is one which, according to reasonable judgement, will remain longer than two years after its origin. Two situations can be distinguished:

1. The function of the body-part is partly lost for at least two years
The injured body-part will not totally recover after a period of recuperation; the original function of the involved body part is partly lost. The result is that the injured person will only partly return to work after recuperation. Significant variables are days lost as a consequence of the time period of recuperation in which the person could not work or could work only part-time and years lost as a consequence of the percentage of disability e.g. the person can only work 2 out of 5 days.

2. The function of the body-part is completely lost for at least two years
The injured body-part will not totally recover after a period of recuperation; the original function of the involved body part is completely lost. The result is that the injured person will never return to work.

PIE, Probability Influencing Entity
Probability Influencing Entities are factors that influence the probability that the *safety barrier* is in a good state. They are constituted by the specific working conditions that have an impact on the state of barriers. Per safety barrier one or more PIEs can be identified. The PIEs are independent of one another and each PIE contributes to the state of the barrier. For the quantification of ORM data are assessed on the average occurrence of the negative state of PIEs, as a percentage of the total time workers in the Dutch workforce are exposed to the associated bow tie hazard.

PIE action
A PIE action describes an action that, when performed by a company/worker, will affect the state of the *PIE* it is associated with. In ORM a PIE action is always presented in combination with a *measure*. A PIE action specifies what to do or look for when a measure is applied. Each PIE action-measure combination can have its own effectiveness.

Prevention
The prevention of the occurrence of the centre event of a bow tie through addressing the causes on the left hand side

Primary safety barrier
A primary safety barrier is a barrier which if it fails will result in the occurrence of the centre event. For example the stability of the user of a ladder is a primary safety barrier.

RAW
Register of Accidents at Work: Danish Working Environment Authority register of reported reportable occupational accidents resulting in at least one day of absence of work.

Recoverable injury
A recoverable injury is an injured body-part which will totally recover after recuperation or which regains its original function completely. The result is that the injured person can return to work after the period of recuperation. The significant variable is the days lost as a consequence of the time period of recuperation in which the person could not work or could only work part-time.

Reportable occupational accident
A reportable occupational accident is an unforeseen and unintended event that occurred to an employee while carrying out his activities at work and where the intent to cause harm, injury or death was absent, but which immediately resulted in health damage that eventually led to serious physical or mental injury or death. Injuries are considered serious when the health damage leads to hospitalisation within 24 hours after the occurrence of the accident for reasons of observation or treatment, or when injuries are reasonably considered permanent. Employers are legally obliged to report serious occupational accidents to the Dutch Labour Inspectorate within 24 hours (Arbowet Artikel 9, lid 1).

Right Hand Side (RHS)
Indicates the position of a block (factor) in the bow tie model. Right Hand Side (RHS) means to the right of the centre event, i.e. later in time. For example: a RHS barrier can reduce (mitigate) the consequence of the centre event.

Risk
A risk is the likelihood that a hazard will cause a specified harm to someone or something

Safety barrier
See barrier, support safety barrier, primary safety barrier

Scenario
A scenario is a temporal sequence of events describing the accident, the events that caused it and the events leading up to the outcome.

Storybuild
A storybuild is a graphical model of cause and effect events shaped like a bow tie whose centre is a point through which all accident paths pass. It is built according to a set of rules (Bellamy, 2005). Storybuilds are made with the software tool Storybuilder. Storybuild structures were frozen after the first 100 accidents analysed for a particular type of centre event like a fall. From then on accidents were added without changing the basic structure. On the left hand side are the events which cause an accident and their underlying causes further to the left of these, like losing balance and why that

happens like not being provided with the right competences or not using the right kind of shoes. On the right hand side are what happens once the hazard agent is released, such as the consequences of falling, like hitting an object as you fall, falling a certain distance, hitting the ground and sustaining certain injuries which might be permanent. The names of storybuilds are given by their centre event and sometimes also the activity which lead to that e.g. fall from height ladder, contact with moving parts of a machine. 36 storybuilds built up from accidents were turned into 64 Bow ties.

Support safety barrier
This is a barrier which supports the primary safety barrier by making it less likely to fail. For example user ability is a supporting barrier which supports the primary safety barrier stability of the user.

Annex 2 Storybuild and bow tie list

Note:
Some Storybuild numbers are missing from the sequence. These are:

Storybuild 16: *LOC hazardous substances (passive)*. This became part of Storybuild 15 Loss of Containment from normally closed containment and then Bow tie 15.4

Storybuild 18: *Exposure to damaging noise dose* (only 8 cases found). This was combined with Storybuild 27 Explosion

Storybuild 19: *Exposure to damaging non-ionising radiation dose* (only 3 cases identified) was excluded

Storybuild 21: *Trapped in hazardous space* was incorporated in Storybuild 22

Bow tie model *1.1.1.4 Fall from height rope ladder* only has mission data and is not a fully quantified bow tie due difficulties obtaining data

Nr	Storybuild - number and name	Nr	Bow tie Model - number and name
1	1.1.1 Fall from height – ladders & steps	1	1.1.1.1 Fall from height - placement ladder
		2	1.1.1.2 Fall from height - fixed ladder
		3	1.1.1.3 Fall from height - step ladder or steps
		4	1.1.1.4 Fall from height - rope ladder
2	1.1.2 Fall from height – scaffolds	5	1.1.2.1 Fall from height – working on mobile scaffold
		6	1.1.2.2 Fall from height - working on fixed scaffold
		7	1.1.2.3 Fall from height – (de-)Installing scaffold
3	1.1.3 Fall from height - roof/ /floor/platform	8	1.1.3.1 Fall from height – roof
		9	1.1.3.2 Fall from height – floor
		10	1.1.3.3 Fall from height – fixed platform
4	1.1.4 Fall from height - hole in the ground	11	1.1.4 Fall from height – hole in the ground
5	1.1.5.1 Fall from height - moveable platform	12	1.1.5.1 Fall from height - moveable platform
6	1.1.5.2 Fall from height – non-moving vehicle	13	1.1.5.2 Fall from height - non-moving vehicle
7	1.1.5.3 Fall from height – other	14	1.1.5.3 Fall from height – other
8	1.2 Fall on same level	15	1.2 Fall on same level
9	1.3 Fall down stairs or ramp	16	1.3 Fall down stairs or ramp
10	2 Struck by moving vehicle	17	2. Struck by moving vehicle
11	3.1 Contact with falling objects – cranes	18	3.1 Contact with falling object – crane or load
12	3.2 Contact with falling objects NOT cranes	19	3.2 Contact with falling object - mechanical lifting
		20	3.3 Contact with falling object – vehicle or load
		21	3.4 Contact with falling object - manual handling
		22	3.5 Contact with falling object – other

Nr	Storybuild - number and name	Nr	Bow tie Model - number and name
13	4 Contact with flying/ ejected objects	23	4.1 Contact with flying object – machine or handheld tool
		24	4.2 Contact with flying object – object under pressure or tension
		25	4.3 Contact with flying object – blown by wind
14	5 Hit by rolling/sliding object or person	26	5 Hit by rolling/sliding object or person
15	6 Contact with object used/ carried	27	6.1 Contact with object used or carried–hand held tool operated by other person
		28	6.2 Contact with object used or carried - NOT handheld tool
16	7 Contact with handheld tools operated by self	29	7 Contact with hand held tools operated by self
17	8.1 Contact with moving parts of machine	30	8.1.1 Contact with moving parts of a machine – operating
		31	8.1.2 Contact with moving parts of a machine – maintaining
		32	8.1.3 Contact with moving parts of a machine – clearing
		33	8.1.4 Contact with moving parts of a machine – cleaning
18	8.2 Contact with hanging/swinging objects	34	8.2 Contact with hanging/ swinging objects
19	8.3 Trapped between	35	8.3Trapped between
20	9 Moving into object	36	9 Moving into object
21	10 Buried by bulk mass	37	10 Buried by bulk mass
22	11 In or on moving vehicle with loss of control	38	11 In or on moving vehicle with loss of control
23	12 Contact with electricity	39	12.1 Contact with electricity – high voltage cable
		40	12.2 Contact with electricity – tool
		41	12.3 Contact with electricity – electrical work
24	13 Contact with hot or cold surfaces or open flame	42	13 Contact with hot or cold surfaces or open flame
25	14.1 LOC Open containments	43	14.1 Release of hazardous substance out of open containment
26	14.2 Contact with hazardous substance without LOC	44	14.2 Exposure to hazardous substance without Loss of Containment
27	15 Loss of Containment from normally closed containment	45	15.1 Release of a hazardous substance out of a closed containment – adding, removing or opening
		46	15.2 Release of a hazardous substance out of a closed containment – transport
		47	15.3 Release of a hazardous substance out of a closed containment- closing
		48	15.4 Release of a hazardous substance out of a closed containment – working nearby
28	17 Fire	49	17.1 Fire - hot work

Nr	Storybuild - number and name	Nr	Bow tie Model - number and name
		50	17.2 Fire - working near flammables/ combustibles
		51	17.3 Fire - fire fighting
29	20.1 Human aggression	52	20.1 Human aggression
30	20.2 Animal behaviour	53	20.2 Animal behaviour
31	22.1 Hazardous atmosphere in confined space	54	22.1 Hazardous atmosphere in confined space
32	22.2 Hazardous atmosphere through breathing apparatus	55	22.2 Hazardous atmosphere through breathing apparatus
33	23 Impact by immersion in liquid	56	23.1 Impact by immersion in liquid – working in or under
		57	23.2 Impact by immersion in liquid – working nearby
34	25 Extreme muscular exertion	58	25.1 Extreme muscular exertion – handling objects
		59	25.2 Extreme muscular exertion – moving around
35	26 Too rapid (de)compression	-	-
36	27 Explosion	60	27.1 Physical explosion
		61	27.2.1 Chemical explosion – vapour or gas
		62	27.2.2 Chemical explosion – dust
		63	27.2.3 Chemical explosion – explosives
		64	27.2.4 Chemical explosion – exothermic reactions

Annex 3 Quantified occupational risks of accidents

Two general sets of data have been used in quantifying risks: a) The number of the various types of accidents reported over a period of time and stored in the GISAI data base (see subsection 3.1); and b) the corresponding exposure of the working population, that is the time spent by the workers performing tasks involving each hazard over the same period of time (see subsection 3.2.1). A relatively small number of accidents as recorded in the GISAI data base were not associated with a specific consequence. An even smaller number of accidents as were analysed and recorded in the Storybuilder were not associated with one of the 64 detailed bow ties. All these accidents have been reassigned into one of the completely determined categories, i.e. one of the 64 specific types of hazards having one of the three possible consequences. For this reason some of the entries in the first three columns of Table 16 might differ slightly with corresponding results given elsewhere in this report (e.g. section 4.3). The results are given in the table below.

Table 16 Occupational risk, Dutch National Average per type of hazard

Nr	Hazard type	Number of accidents[20]			RISK rate (/hr)			RISK per year		
		Recoverable Injury	Permanent Injury	Fatality[21]	Recoverable Injury	Permanent Injury	Fatality	Recoverable Injury	Permanent Injury	Fatality
1	1.1.1.1 Fall from height - placement ladder	628	159	18	8.28E-07	2.10E-07	2.38E-08	3.05E-04	7.73E-05	8.76E-06
2	1.1.1.2 Fall from height - fixed ladder	54	12	4	2.53E-07	5.55E-08	1.87E-08	6.88E-05	1.51E-05	5.08E-06
3	1.1.1.3 Fall from height - step ladder or steps	141	43	3	2.24E-07	6.78E-08	4.74E-09	8.02E-05	2.43E-05	1.70E-06
4	1.1.1.4 Fall from height - rope ladder			2			6.14E-08			2.44E-05
5	1.1.2.1 Fall from height – working on mobile scaffold	193	44	8	1.36E-06	3.13E-07	5.64E-08	6.12E-04	1.41E-04	2.54E-05
6	1.1.2.2 Fall from height - working on fixed scaffold	184	38	7	4.65E-07	9.57E-08	1.77E-08	3.23E-04	6.65E-05	1.23E-05
7	1.1.2.3 Fall from height – (de-)Installing scaffold	54	19	5	2.02E-07	7.21E-08	1.88E-08	1.02E-04	3.66E-05	9.53E-06
8	1.1.3.1 Fall from height – roof	286	93	43	1.50E-06	4.82E-07	2.27E-07	6.56E-04	2.11E-04	9.93E-05
9	1.1.3.2 Fall from height – floor	310	80	19	1.03E-06	2.67E-07	6.40E-08	5.12E-04	1.33E-04	3.18E-05
10	1.1.3.3 Fall from height – fixed platform	166	56	12	5.80E-07	2.15E-07	4.40E-08	2.77E-04	1.03E-04	2.10E-05
11	1.1.4 Fall from height – hole in the ground	58	14	2	4.85E-08	1.20E-08	1.68E-09	2.03E-05	5.02E-06	7.03E-07
12	1.1.5.1 Fall from height - moveable platform	113	70	21	4.33E-07	2.66E-07	8.06E-08	2.05E-04	1.26E-04	3.82E-05
13	1.1.5.2 Fall from height - non-moving vehicle	149	49	7	1.01E-06	3.61E-07	5.15E-08	1.10E-04	3.93E-05	5.60E-06
14	1.1.5.3 Fall from height – other	217	65	6	6.46E-07	1.94E-07	1.80E-08	3.43E-04	1.03E-04	9.56E-06

[20] The number of accidents for hazards 3.1, 3.2, 3.3, 3.4, 3.5, 8.1.1, 8.1.2, 8.1.3 & 8.1.4 correspond to a 2 year period. All other hazards have been analysed for 6.17 years.
[21] In cases where no fatalities have been observed over the analysed period, a very small nonzero number has been used to avoid zero risk rates.

Nr	Hazard type	Number of accidents[20]			RISK rate (/hr)			RISK per year		
		Recoverable Injury	Permanent Injury	Fatality[21]	Recoverable Injury	Permanent Injury	Fatality	Recoverable Injury	Permanent Injury	Fatality
15	1.2 Fall on same level	323	84	3	1.28E-08	3.41E-09	1.20E-10	8.32E-06	2.22E-06	7.80E-08
16	1.3 Fall down stairs or ramp	97	22	2	1.80E-07	4.10E-08	3.70E-09	5.31E-06	1.21E-06	1.09E-07
17	2. Struck by moving vehicle	314	189	46	7.86E-08	4.73E-08	1.15E-08	3.98E-05	2.40E-05	5.83E-06
18	3.1 Contact with falling object – crane or load	42	48	11	1.11E-07	1.28E-07	2.96E-08	8.78E-05	1.01E-04	2.34E-05
19	3.2 Contact with falling object - mechanical lifting	26	27	2	7.57E-08	7.76E-08	5.78E-09	4.22E-05	4.33E-05	3.22E-06
20	3.3 Contact with falling object – vehicle or load	13	13	0	5.57E-08	5.57E-08	2.76E-10	2.94E-05	2.94E-05	1.46E-07
21	3.4 Contact with falling object - manual handling	41	19	0	1.47E-07	6.95E-08	6.70E-20	7.90E-05	3.74E-05	3.60E-17
22	3.5 Contact with falling object – other	117	72	18	1.00E-06	6.56E-07	1.64E-07	6.56E-04	4.30E-04	1.08E-04
23	4.1 Contact with flying object – machine or handheld tool	72	147	2	4.86E-08	9.84E-08	1.34E-09	4.31E-05	8.72E-05	1.19E-06
24	4.2 Contact with flying object – object under pressure or tension	72	80	7	6.02E-08	6.75E-08	5.88E-09	5.28E-05	5.92E-05	5.15E-06
25	4.3 Contact with flying object – blown by wind	8	4	0	1.39E-08	6.54E-09	5.69E-11	1.10E-05	5.16E-06	4.49E-08
26	5 Hit by rolling/sliding object or person	62	37	3	3.69E-08	2.21E-08	1.79E-09	2.39E-05	1.43E-05	1.16E-06
27	6.1 Contact with object used or carried–hand held tool operated by other person	20	15	0	5.21E-09	4.00E-09	5.49E-13	3.58E-06	2.75E-06	3.77E-10
28	6.2 Contact with object used or carried - NOT handheld tool	71	140	1	2.85E-08	5.66E-08	4.04E-10	1.62E-05	3.22E-05	2.30E-07
29	7 Contact with hand held tools operated by self	127	107	0	2.29E-08	1.94E-08	1.04E-12	1.70E-05	1.44E-05	7.71E-10
30	8.1.1 Contact with moving parts of a machine – operating	74	401	1	3.80E-08	2.07E-07	5.17E-10	2.05E-05	1.12E-04	2.79E-07
31	8.1.2 Contact with moving parts of a machine – maintaining	14	46	2	3.67E-08	1.20E-07	5.26E-09	1.13E-05	3.69E-05	1.62E-06
32	8.1.3 Contact with moving parts of a machine – clearing	31	120	6	2.81E-07	1.10E-06	5.51E-08	5.79E-05	2.27E-04	1.13E-05
33	8.1.4 Contact with moving parts of a machine – cleaning	20	81	1	1.33E-07	5.40E-07	6.73E-09	1.07E-04	4.35E-04	5.42E-06
34	8.2 Contact with hanging/ swinging objects	114	90	10	1.00E-07	7.99E-09	8.85E-09	7.74E-05	6.19E-06	6.85E-06
35	8.3 Trapped between	96	200	15	7.65E-08	1.60E-07	1.20E-08	5.18E-05	1.08E-04	8.12E-06

Nr	Hazard type	Number of accidents[20]			RISK rate (/hr)			RISK per year		
		Recoverable Injury	Permanent Injury	Fatality[21]	Recoverable Injury	Permanent Injury	Fatality	Recoverable Injury	Permanent Injury	Fatality
36	9 Moving into object	59	67	0	8.98E-09	1.02E-08	1.17E-12	7.38E-06	8.39E-06	9.62E-10
37	10 Buried by bulk mass	13	4	0	2.11E-08	7.24E-09	2.27E-12	1.36E-05	4.68E-06	1.47E-09
38	11 In or on moving vehicle with loss of control	332	164	37	1.25E-07	6.15E-08	1.39E-08	1.17E-04	5.77E-05	1.31E-05
39	12.1 Contact with electricity – high voltage cable	10	4	4	4.85E-08	1.82E-08	1.91E-08	4.22E-05	1.59E-05	1.66E-05
40	12.2 Contact with electricity – tool	25	9	5	3.18E-09	1.09E-09	6.28E-09	2.49E-06	8.55E-07	4.93E-06
41	12.3 Contact with electricity – electrical work	101	35	10	8.01E-08	2.78E-08	7.94E-09	4.97E-05	1.73E-05	4.93E-06
42	13 Contact with hot or cold surfaces or open flame	7	4	0	3.87E-09	2.21E-09	1.15E-12	2.28E-06	1.30E-06	6.77E-10
43	14.1 Release of hazardous substance out of open containment	127	41	0	1.05E-07	3.35E-08	1.75E-11	6.20E-05	1.98E-05	1.03E-08
44	14.2 Exposure to hazardous substance without Loss of Containment	113	22	2	9.54E-08	1.89E-08	1.78E-09	6.69E-05	1.33E-05	1.25E-06
45	15.1 Release of a hazardous substance out of a closed containment – adding, removing or opening	143	47	2	2.19E-07	7.15E-08	3.00E-09	1.22E-04	3.98E-05	1.67E-06
46	15.2 Release of a hazardous substance out of a closed containment – transport	19	2	0	1.90E-07	2.00E-08	2.60E-11	7.11E-05	7.49E-06	9.73E-09
47	15.3 Release of a hazardous substance out of a closed containment- closing	8	7	0	1.80E-07	1.60E-07	1.50E-11	1.40E-04	1.25E-04	1.17E-08
48	15.4 Release of a hazardous substance out of a closed containment – working nearby	50	11	2	2.22E-07	4.80E-08	8.90E-09	1.69E-04	3.65E-05	6.77E-06
49	17.1 Fire - hot work	66	17	1	5.20E-08	1.34E-08	7.87E-10	4.82E-05	1.24E-05	7.30E-07
50	17.2 Fire - working near flammables/ combustibles	45	19	2	4.08E-08	1.70E-08	1.84E-09	2.37E-05	9.87E-06	1.07E-06
51	17.3 Fire - fire fighting	26	8	0	2.36E-07	6.95E-08	4.00E-11	1.70E-04	4.99E-05	2.87E-08
52	20.1 Human aggression	28	43	3	4.26E-09	6.54E-09	4.57E-10	2.23E-06	3.42E-06	2.39E-07
53	20.2 Animal behaviour	17	13	2	2.98E-08	2.38E-08	3.58E-09	1.38E-05	1.10E-05	1.66E-06
54	22.1 Hazardous atmosphere in confined space	34	5	11	7.13E-08	1.05E-08	2.31E-08	3.34E-05	4.92E-06	1.08E-05
55	22.2 Hazardous atmosphere through breathing apparatus	7	1	2	7.23E-08	5.60E-09	2.23E-08	4.87E-05	3.77E-06	1.50E-05

Nr	Hazard type	Number of accidents[20]			RISK rate (/hr)			RISK per year		
		Recoverable Injury	Permanent Injury	Fatality[21]	Recoverable Injury	Permanent Injury	Fatality	Recoverable Injury	Permanent Injury	Fatality
56	23.1 Impact by immersion in liquid – working in or under	4	4	1	8.78E-08	8.78E-08	2.51E-08	3.20E-05	3.20E-05	9.16E-06
57	23.2 Impact by immersion in liquid – working nearby	6	2	20	1.78E-08	4.86E-09	6.47E-08	5.03E-06	1.37E-06	1.83E-05
58	25.1 Extreme muscular exertion – handling objects	6	10	0	1.05E-09	1.81E-09	1.22E-13	4.71E-07	8.11E-07	5.47E-11
59	25.2 Extreme muscular exertion – moving around	17	6	0	1.05E-08	3.62E-09	1.96E-13	4.20E-06	1.45E-06	7.83E-11
60	27.1 Physical explosion	29	11	3	2.09E-08	7.85E-09	2.16E-09	1.80E-05	6.77E-06	1.87E-06
61	27.2.1 Chemical explosion – vapour or gas	72	39	15	4.47E-08	2.38E-08	9.26E-09	3.91E-05	2.08E-05	8.09E-06
62	27.2.2 Chemical explosion – dust	7	7	1	6.90E-09	6.90E-09	1.06E-09	6.89E-06	6.89E-06	1.06E-06
63	27.2.3 Chemical explosion – explosives	1	7	0	9.40E-10	6.58E-09	7.52E-13	8.12E-07	5.69E-06	6.50E-10
64	27.2.4 Chemical explosion – exothermic reactions	14	3	0	9.64E-09	2.07E-09	2.20E-13	7.65E-06	1.64E-06	1.75E-10

Annex 4 List of figures and tables

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Annex 5 Technical reports

The following Technical reports can be acquired by sending an e-mail to cev@rivm.nl.

1. Description of the project organisation
2. Overview of methodology, production steps and quality control
3. Occupational accidents in the Netherlands, Storybuilder & Storyfilter - The 36 Storybuilds
4. ORM logical model and Bowtiebuilder
5. Probability Influencing Entities and the PIE questions
6. Centre Event Mission Data
7. Exposure surveys
8. Bow tie models and quantification
9. Measures, effectiveness and costs
10. Activities, agents, jobs and bow tie links
11. Storybuilder software user manual
12. Bow tiebuilder software user manual
13. ORM software user manual

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