National Institute
for Public Health
and the Environment

Report 620860001/2010

P.A.M. Uijt de Haag et al.

A model for comparing occupational health and safety

rivm

RIVM Report 620860001/2010

A model for comparing occupational health and safety

P.A.M. Uijt de Haag (RIVM)
L.J. Bellamy (White Queen BV)
A. Burdorf (Erasmus MC, Rotterdam)
D.J.J. Heederik (IRAS, Utrecht University)
H.J. Manuel (RIVM)
I.A. Papazoglou (Demokritos, Greece)
L. Portengen (IRAS, Utrecht University)
A. Pronk (TNO)
E. Tielemans (TNO)

Contact:
P.A.M. Uijt de Haag
Centre External Safety
paul.uijt.de.haag@rivm.nl

This report has been produced for the Ministry of Social Affairs and Employment, The Hague

rivm

Abstract

A model for comparing occupational health and safety

Employees can be exposed to different risks at the workplace, for example chronic exposure to harmful substances, physical stress and accidents. Up to now, these risks were assessed and judged independently. It appears possible to develop one integrated model that evaluates these different risks on the same basis, thus making them comparable. This is the result of a feasibility study carried out by RIVM in collaboration with experts from the University of Utrecht - IRAS, TNO, Erasmus University of Rotterdam, White Queen B.V. and Y. Papazoglou under the authority of the Dutch Ministry of Social Affairs and Employment.

In the feasibility study, one integrated model is developed to compare different exposures for some selected jobs in the construction industry. The model calculates the occupational burden of disease of silicosis and lung cancer (due to exposure to silica), low back pain (due to lifting of heavy loads) and injury and mortality (due to accidents). In all cases, the DALY is used to measure the burden of disease. The functioning of the model is demonstrated by applying the model to a few selected jobs and diseases.

The first results of the pilot version of the OHIA model show that for three of the four selected jobs the occupational burden of disease, expressed in DALY, due to exposure to silica is one order of magnitude larger than the burden of disease due to lifting loads and incidents. For the carpenter, the burden of disease is comparable for the different working conditions. The model also shows the dynamic behaviour of the effects: the incidence of low back pain and incidents occurs only during the working life, whereas the incidence of lung cancer due to exposure to silica is for an important part after retirement. However, important information is still missing, and large uncertainties exist.

The feasibility study demonstrates that it is possible to develop an integrated model for occupational health and safety. This model gives insight in the working conditions having the largest occupational burden of disease and the possibilities for improvement. The model thus allows prioritizing the policy efforts and introducing better health and safety improvement programmes. The feasibility study also shows the areas where model improvements are required.

Key words:
occupational safety, occupational health, risk model, occupational incidents, silica

rivm

Rapport in het kort

De vergelijking van arbeidsveiligheid en arbeidsgezondheid – een haalbaarheidsstudie

Werknemers kunnen op hun werk blootgesteld worden aan verschillende risico's, zoals blootstelling aan schadelijke stoffen, fysieke belasting en ongevallen. De risico's van deze verschillende blootstellingen worden tot nu toe onafhankelijk van elkaar berekend en beoordeeld. Het blijkt haalbaar een model te ontwikkelen dat deze verschillende risico's op gelijke wijze berekent en daarmee vergelijkbaar maakt. Dit blijkt uit deze haalbaarheidsstudie van het RIVM in samenwerking met een consortium van deskundigen van de Universiteit Utrecht – IRAS, TNO – Kwaliteit van Leven, Erasmus Universiteit Rotterdam, White Queen B.V. en Y. Papazoglou in opdracht van het ministerie van Sociale Zaken en Werkgelegenheid.

In de haalbaarheidsstudie is voor enkele beroepen in de bouwnijverheid één model ontwikkeld waarmee verschillende blootstellingen vergeleken kunnen worden. Het model berekent de ziektelast van het optreden van silicose en longkanker (ten gevolge van de blootstelling aan silica), lage rugklachten (ten gevolge van het tillen van zware lasten) en sterfte en letsel (ten gevolge van ongevallen). Als maat is de DALY gebruikt, waarmee de verschillende ziektes vergelijkbaar zijn gemaakt. De werking van het model is zo gedemonstreerd voor enkele beroepen en enkele ziektes.

De eerste berekeningen met een pilotversie van het OHIA-model laten zien dat voor drie van de vier geselecteerde beroepen de ziektelast, uitgedrukt in DALY, ten gevolge van blootstelling aan silica een orde van grootte groter is dan de ziektelast ten gevolge van het tillen van zware voorwerpen en arbeidsgerelateerde incidenten, terwijl voor de timmerman de bijdragen van de drie blootstellingen vergelijkbaar zijn. Uit het model volgt ook dat de dynamiek van de verschillende blootstellingen heel anders is: het optreden van rugklachten en ongevallen gebeurt alleen tijdens het werkzame leven, terwijl bijvoorbeeld longkanker ten gevolge van silica-blootstelling voor een belangrijk deel pas na het werkzame leven gebeurt. Ook blijkt dat belangrijke informatie nog ontbreekt, en er nog grote onzekerheden zijn.

Uit de haalbaarheidsstudie blijkt dat het mogelijk is te komen tot een geïntegreerd model voor arbeidsveiligheid en –gezondheid. Hiermee is een perspectief ontwikkeld voor een model waarmee inzicht wordt verkregen in de sectoren en arbeidsomstandigheden die leiden tot de grootste ziektelast en waar de grootste verbeteringen mogelijk zijn. Hiermee kan de beleidsinzet beter worden geprioriteerd en verbeterprogramma's gerichter worden ingezet. De studie geeft ook inzicht in welke modelverbeteringen nog nodig zijn om te komen tot een praktisch toepasbaar model.

Trefwoorden:
Arbeidsveiligheid, arbeidsgezondheid, risicomodel, arbeidsongevallen, silica

Contents

rivm

List of tables and figures

Tables

Figures

rivm

Abbreviations

AR	Absolute Risk
DALY	Disability Adjusted Life Years – a measure used for the integration of different effects. DALY is the measure for the burden of disease and quantifies the loss of health due to premature death and due to life with illness. The DALY is the sum of the number of lost years due to premature death and the (weighted) number of lost years due to illness, where the gravity of a specific illness is expressed in the weighting factor. In this way all types of diseases are converted into one single number
ELR	Excess Lifetime Risk
HRCT	High-resolution computed tomography
ILO	International Labour Office
OHIA model	Occupational Health Impact Assessment model – Model to evaluate the impact of both incidents and chronic exposure to illness-causing agents at work
OR	Odds Ratio; the ratio of the odds of an event occurring in one group (here: the exposed group) to the odds of it occurring in another group (here: the non-exposed group)
ORCA	Occupational Risk Calculator – Model for the risk assessment of occupational accidents
PAGO	Periodiek Arbeidsgezondheidskundig Onderzoek; periodic medical examinations
RR	Relative Risk
TWA	Time Weighted Average
VASt	Versterking Arbeidsomstandighedenbeleid Stoffen – programme of the Ministry of Social Affairs and Employment 'Strengthening the health and safety policy on chemical substances'

rivm

Samenvatting

Inleiding
Het ministerie van Sociale Zaken en Werkgelegenheid heeft in het Programma ‘Versterking Arbeidsveiligheid’ een risicomodel voor arbeidsveiligheid laten ontwikkelen. Dit risicomodel, Occupational Risk Calculator (ORCA) genaamd, maakt het mogelijk de risico’s van werknemers te berekenen om gewond te raken of te sterven ten gevolge van een arbeidsgerelateerd ongeval. Ook kunnen de effecten van maatregelen doorgerekend worden, zodat het mogelijk is een optimale balans tussen kosten en baten van het implementeren van maatregelen te bepalen.
Het risicomodel ORCA is beperkt tot arbeidsgerelateerde *ongevallen*. Dit betreft naar schatting ongeveer 5 – 10% van de totale ziektelast ten gevolge van arbeidsomstandigheden. Het grootste deel van de ziektelast komt voor rekening van *chronische blootstelling*. Voor een integrale visie op het terugdringen van arbeidsrisico’s is het daarom gewenst een risicomodel te ontwikkelen, waarin zowel ongevallen als ziektelast ten gevolge van chronische blootstelling zijn meegenomen. Het OHIA-model, een acroniem voor *Occupational Health Impact Assess-ment* model, voorziet in deze behoefte.

Doel van het OHIA-model
Het model moet het mogelijk maken om de ziektelast van verschillende arbeidsomstandigheden, namelijk de chronische blootstelling aan gevaarlijke stoffen, arbeidsgerelateerde ongevallen en fysieke belasting, op gelijke wijze te berekenen en te beoordelen. Dit maakt een geïntegreerde aanpak van zowel arbeidsveiligheid als arbeidsgezondheid (‘gezond en veilig werken’) mogelijk op basis van wetenschappelijke kennis en inzichten, waarbij een optimale inzet van risicoreducerende interventies mogelijk moet zijn en de ziektelast kosteneffectief gereduceerd wordt. Het OHIA-model wordt dan ook ontwikkeld voor verschillende gebruikers:

- Op beleidsniveau kan het OHIA-model gebruikt worden om inzicht te krijgen in de sectoren en arbeidsomstandigheden die leiden tot de grootste ziektelast en waar de grootste verbeteringen mogelijk zijn. Hiermee kan de beleidsinzet beter worden geprioriteerd en verbeterprogramma’s gerichter worden ingezet.
- Op inspectieniveau kan beter bepaald worden welke maatregelen de grootste effectiviteit hebben, zodat de prioriteiten voor inspectie duidelijker worden.
- Op sector- en bedrijfsniveau kan bepaald worden welke beroepsgroepen de grootste ziektelast hebben en welke combinaties van maatregelen het kosteneffectiefst zijn.

Opzet van de haalbaarheidsstudie
De ontwikkeling van een volledig OHIA-model, waarin alle sectoren en arbeidsomstandigheden zijn meegenomen, vraagt een zeer grote inspanning in tijd en geld. Daarom is eerst een haalbaarheidsstudie uitgevoerd. Het doel van deze studie is tweeledig, namelijk (i) nagaan of het mogelijk is een OHIA-model te ontwikkelen en (ii) bepalen welke stappen nodig zijn voor een OHIA-model en welke witte vlekken er nog zijn. Een consortium van deskundigen van de Universiteit Utrecht – IRAS, TNO – Kwaliteit van Leven, Erasmus Universiteit Rotterdam, White Queen B.V., Y. Papazoglou en het RIVM werkten samen in de haalbaarheidsstudie. Ook de sector Arbouw is betrokken bij deze haalbaarheidsstudie. De studie is gestart op 15 oktober 2009 en afgerond op 31 augustus 2010.
De haalbaarheidsstudie is uitgevoerd binnen de sector bouwnijverheid voor de beroepen en arbeidsomstandigheden zoals beschreven in navolgende tabel. Een inschatting is dat hiermee ongeveer een derde van het aantal werknemers in deze sector en een significant deel van de blootstelling in kaart is gebracht.

Sector, beroepen, arbeidsomstandigheden en gevolgen in de haalbaarheidsstudie

Sector	Bouwnijverheid
Beroep	Timmerman, tegelzetter, betonboorder/zager en stratenmaker
Arbeidsomstandigheden	Blootstelling aan silica, tillen van lasten en ongevallen
Gevolgen	Silicosis en longkanker Rugklachten Herstelbaar letsel, permanent letsel en sterfte

Berekeningen met het OHIA-model
Het OHIA-model berekent de ziektelast door voor elk beroep uit te gaan van een groep gezonde werknemers van 20 jaar, en deze gedurende hun hele leven te blijven volgen, aannemende dat zij tot hun pensionering hetzelfde werk blijven doen. Dit is in overeenstemming met het uitgangspunt dat grenswaarden zo zijn vastgesteld dat werknemers bij blootstelling gedurende hun hele werkzame leven geen schade aan de gezondheid ondervinden. Voor de vergelijking tussen de verschillende arbeidsomstandigheden zijn de verschillende effecten teruggebracht tot één maat, de *Disability-Adjusted Life-Years* (DALY). De DALY is een maat voor het verlies aan gezondheid en combineert verloren levensjaren ten gevolge van vroegtijdige sterfte met verminderde levenskwaliteit door jaren met ziekte.

Resultaten van het OHIA-model
Het ontwikkelde OHIA-model is de eerste demonstratie dat in één model verschillende beroepen en verschillende typen blootstelling op uniforme wijze met elkaar vergeleken kunnen worden, op basis van al bestaande data. De ziektelast van zowel ongevallen als van chronische blootstelling wordt op dezelfde wijze berekend en kan met elkaar vergeleken worden. Dit maakt het mogelijk om voor bijvoorbeeld een sector te bepalen welke blootstellingen de grootste ziektelast veroorzaken en welke beroepsgroepen hieraan het meest zijn blootgesteld. Ook is het bijvoorbeeld mogelijk binnen een beroepsgroep de ziektelast voor een werknemer te bepalen, en welk type blootstelling de grootste bijdrage heeft. Omdat ook de effecten van maatregelen in het OHIA model doorgerekend kunnen worden, zijn de resultaten van het model bij uitstek geschikt voor het bepalen van de potentiële effectiviteit van verschillende verbeterprogramma’s.
De eerste berekeningen met een pilotversie van het OHIA-model laten zien dat voor drie van de vier geselecteerde beroepen de ziektelast, uitgedrukt in DALY, ten gevolge van blootstelling aan silica een orde van grootte groter is dan de ziektelast ten gevolge van het tillen van zware voorwerpen en arbeidsgerelateerde incidenten, terwijl voor de timmerman de bijdragen van de drie blootstellingen vergelijkbaar zijn. Uit het model volgt ook dat de dynamiek van de verschillende blootstellingen heel anders is: het optreden van rugklachten en ongevallen gebeurt alleen tijdens het werkzame leven, terwijl bijvoorbeeld longkanker ten gevolge van silicablootstelling voor een belangrijk deel pas na het werkzame leven gebeurt.

Beperkingen van het OHIA-model
De haalbaarheidsstudie heeft aangetoond dat het mogelijk is een geïntegreerd OHIA-model te maken waarmee risico’s van verschillende blootstellingen kunnen worden berekend en vergeleken op het niveau van een sector dan wel gemiddelde werknemer. Hiermee is er een duidelijk perspectief naar een volledig OHIA-model. Hoewel er in korte tijd veel bereikt is, ontbreekt nog belangrijke informatie voor een volwaardig OHIA-model. In een vervolgonderzoek moeten deze hiaten verder ingevuld worden.

Schatting van de blootstelling
Voor de indeling van beroepen is gebruik gemaakt van de Arbouwcode. Binnen één Arbouwcode zijn er echter heel verschillende activiteiten mogelijk. Zo valt binnen de code van stratenmaker niet alleen het werken met stenen, maar ook asfalteren. In de haalbaarheidsstudie is gebruikgemaakt van een gemiddelde waarde voor de blootstelling binnen een Arbouwcode, terwijl in werkelijkheid de blootstelling sterk zal variëren binnen deze beroepsgroep en ook per individu. In een vervolgfase moeten we de beroepen en de daaraan gekoppelde blootstelling beter karakteriseren.

Gebruik van vereenvoudigde modellen
In de berekeningen van de ziektelast zijn vereenvoudigingen gedaan. In een vervolgonderzoek moet het belang van deze vereenvoudigingen worden bepaald aan de hand van een gevoeligheidsanalyse. Dit leidt tot een prioritering voor modelverbeteringen.

Volledig maken van het OHIA-model
In de haalbaarheidsstudie zijn slechts enkele blootstellingen onderzocht, en het model moet nog uitgebreid worden met een aantal andere blootstellingen, zoals diesel. Hierbij moet wel opgemerkt worden dat zelfs voor de belangrijkste stoffen en belastingen nog veel informatie ontbreekt, zoals blootstellingsgegevens. Dit maakt in een vervolgfase meetcampagnes voor het verzamelen van dergelijke gegevens noodzakelijk.
Daarnaast zal een OHIA-model nooit volledig zijn in alle mogelijke blootstellingen: er zijn te veel stoffen waaraan werknemers kunnen worden blootgesteld, en een goede kwantitatieve relatie tussen blootstelling en ziektelast ontbreekt in veel gevallen. We kunnen uiteindelijk wel een OHIA-model ontwikkelen waarin per sector de belangrijkste stoffen en belastingen zijn opgenomen, zodat het model gebruikt kan worden voor effectieve interventies.

Eindpunt van de berekening
De vergelijking van de ziektelast is nu gebaseerd op de DALY. Dit betekent dat de vergelijking en afweging gebaseerd is op verloren levenskwaliteit en niet op verloren productiviteit. Er zijn verschillende studies naar het gebruik van dergelijke alternatieve maten. Het verdient aanbeveling na te gaan of deze alternatieve maten leiden tot andere inzichten.

Het maken van een software model
In de haalbaarheidsstudie zijn de berekeningen uitgevoerd met een aantal spreadsheets. Voor een OHIA-model dat bruikbaar is voor derden moet een gebruikersvriendelijke software-applicatie worden ontwikkeld. Hiervoor moeten eerst de specificaties worden opgesteld, zoals de benodigde invoer en uitvoer, de rekentijd, etc.

rivm

Summary and conclusions

Introduction
The Ministry of Social Affairs and Employment developed a risk model for occupational safety. This risk model, the Occupational Risk Calculator (ORCA), makes it possible to calculate the risk of injury or mortality to employees due to a job-related incident. The model can also be used to calculate the cost of risk-reducing 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 costs and the benefits of implementing risk-reducing measures.

ORCA is limited to job-related *incidents*. It is estimated that incidents only account for 5 to 10% of the total occupational burden of disease in the Netherlands, whereas *chronic exposure* accounts for the rest. To have an integrated approach to risk reducing at work, it is useful to develop a risk model, in which both incidents and chronic exposure are combined. The OHIA model, an acronym for Occupational Health Impact Assessment (OHIA) model, meets the need.

Scope of the OHIA model
The OHIA model should make it possible to evaluate similarly the burden of disease due to various working conditions, namely chronic exposure to harmful substances, work-related incidents and physical stress. This allows an integrated approach to occupational safety and health based on scientific grounds, leading to an optimal use of risk reducing interventions and a cost-effective reduction of the burden of disease. The OHIA model is developed for different end-users:
– At the policy-decision level, the OHIA model can be used to gain an understanding of the industry sectors and working conditions leading to the largest burden of disease and possible improvements. The model thus allows prioritizing the policy efforts and introducing better improvement programmes.
– At the inspection level, the most effective measures can be identified, thus helping in prioritizing the inspections.
– At industry sector and company level, the jobs with the highest burden of disease can be identified and the combination of measures that is most cost-effective.

The feasibility study
The development of a complete OHIA model, addressing all industry sectors and all working conditions, is a very demanding task in terms of time and money. Therefore, first a feasibility study is carried out. The aim of the feasibility study is twofold, namely (i) to determine whether it is possible to develop an OHIA model and (ii) to determine the steps needed for the development of the model and the areas where information is missing. The feasibility study was carried out by an international group of experts from the University of Utrecht, TNO, Erasmus University of Rotterdam, White Queen B.V., Y. Papazoglou and RIVM. Also a representative from the construction industry organization, Arbouw, was involved in the study. The study started on October 15, 2009 and was completed on August 31, 2010.
The feasibility study was carried out within the construction industry for the jobs and working conditions as described in the table. We estimate that about one-third of the employees in the sector and a significant part of the exposure are covered.

Sector, jobs, working conditions and effects addressed in the feasibility study

Sector	Construction industry
Job	concrete driller/sawyer, tiler, carpenter, road paver
Working conditions	Exposure to silica, lifting of loads, incidents
Effects	Silicosis and lung cancer Low back pain Recoverable injury, permanent injury, mortality

Calculations with the OHIA model

The OHIA model calculates the burden of disease for each job by starting with a fixed cohort of healthy employees of age 20, and following them until the last person dies. It is assumed that the employees keep the same job until retirement at age 65. This is in agreement with the concept of occupational exposure limits: an employee should not suffer detrimental health effects of life-time exposure to the limit value. To compare the different working conditions, the effects are reduced to one single measure, namely the Disability-Adjusted Life Years (DALY). The DALY is a measure for the loss of health and combines lost life years due to early death with loss of quality of life due to illness.

Results of the OHIA model

The OHIA model is the first demonstration that in one model different jobs and different working conditions can be compared similarly, based on existing data. The burden of disease of incidents and chronic exposure are calculated in the same way and compared. This allows determining on a sector level which working conditions have the largest contribution to the burden of disease and which jobs are most exposed. It is also possible to determine the burden of disease for an employee and the exposure with the largest contribution. Since the OHIA model also calculates the effects of an intervention measure, the results of the model are useful to determine the potential effectiveness of different intervention programmes.
The first results of the pilot version of the OHIA model show that for three of the four selected jobs the occupational burden of disease, expressed in DALY, due to exposure to silica is one order of magnitude larger than the burden of disease due to lifting loads and incidents. For the carpenter, the burden of disease is comparable for the different working conditions. The model also shows the dynamic behaviour of the effects: the incidence of low back pain and incidents occurs only during the working life, whereas the incidence of lung cancer due to exposure to silica is for an important part after retirement.

Limitations of the OHIA model

The feasibility study demonstrated that it is possible to develop an integrated OHIA model in which risks of different working conditions can be calculated and compared on the level of a sector or average employee, resulting in a valuable prospect to a complete model. Although a lot of progress was made, important information is still missing for a complete model. These deficiencies should be addressed in the next phase.

Estimation of the exposure

The Arbouw code was used to classify the jobs. It should be noted that one Arbouw code covers a large variety of jobs and therefore large variety of exposure. For example, the job title ‘road paver’ may include working with asphalt, concrete or cobble stones, having very different types of exposure. In the next phase, the Arbouw codes and alternatives need to be studied in order to have job descriptions that match the exposure data.

Simplified modelling
In the modelling of the exposure and disease, simplifications were made. In the next phase, it is recommended to do a sensitivity analysis to determine the most important factors in the OHIA model and to give guidance to further improvements.

Completeness of the OHIA model
The feasibility study was limited to a few selected jobs and exposures. The model should be extended to cover the most important exposures, among others diesel. It should be noted that even for the most significant agents important information is missing, like exposure data. Therefore measuring campaigns for collecting exposure data are probably needed in the next phases.
An OHIA model will never cover all exposures and diseases: the range of substances for which exposure may occur is too large, and a quantitative relation between exposure and burden of disease is often missing. However, it is possible to develop an OHIA model that covers the most significant agents per sector, and the model can be used to make effective interventions.

The use of DALY as measure
The study used the DALY as measure to compare the different exposures and diseases. The use of DALY means that we compare the health effects over the entire life of an employee, including the period after retirement. Alternative measures are possible, focusing on the loss of productivity of employees. It is recommended to determine whether these alternative measures lead to different conclusions.

The software model
In the feasibility study, the calculations are done with spreadsheets. To have an OHIA model that can be used by others, a user-friendly application must be developed. For this application, the requirements and specifications need to be formulated, e.g. the input and output, calculation time, etc.

1 Introduction

1.1 Background

In the Programme 'Strengthening Labour Safety' of the Ministry of Social Affairs and Employment a model for occupational risk (Occupational Risk Calculator – ORCA) is developed (Aneziris et al., 2008). ORCA 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.

ORCA is limited to job-related incidents. It is estimated that incidents only account for 5-10% of the total occupational burden of disease in the Netherlands, whereas chronic exposure accounts for the remainder (Eysink et al., 2007). There are already various models developed to calculate the health impact of combinations of agents and diseases for selected occupational groups. However, an overall health impact assessment model for occupational exposure is missing, thus hampering an overall view of the occupational burden of diseases and successful impact reduction strategies.

The Ministry of Social Affairs and Employment therefore wants to develop an integrated model, in which both incidents and chronic exposure are combined, the Occupational Health Impact Assessment (OHIA) model. With this model, the impact of both incidents and chronic exposure can be compared and evaluated, and a cost-effective impact reduction strategy can be developed.

1.2 Scope of the OHIA model

The scope of the OHIA model can be described as follows.

1. The OHIA model would show the occupational burden of disease for a selection of important agents, diseases, occupational groups and sectors using the population at risk.
2. The OHIA model would allow the comparison of the occupational burden of disease for a selection of important agents and diseases on the level of agent, disease and sector.
3. The OHIA model would allow the comparison between the risk of incidents and the impact of chronic exposure.
4. The OHIA model would facilitate to determine an effective impact reduction strategy per sector.

The OHIA model is primarily intended for risk and impact reduction strategies at the national level and at the level of a sector. It is not intended to be used at the level of an individual company. However, the results of the OHIA model are expected to be useful at company level also.

1.3 Target groups

The OHIA model has the following target groups.

1. Policy decision makers can use the OHIA model to determine the most relevant target groups for action programmes, i.e. sectors where the most health impact reduction can be achieved.
2. The labour inspectorate can use the OHIA model to prioritise the inspection capacity by focussing on the sectors where inspection may be most effective in improving safety.
3. Sectors can use the OHIA model to determine the activities with largest occupational burden and to identify optimal combinations of impact-reducing measures and their costs.

The end-users of the OHIA model are expected to be 'experts' at the level of health and safety services.

1.4 Pilot study

The development of an integrated OHIA model, covering all (major) exposures and diseases for all sectors, is a very time-consuming and costly project. Therefore, a pilot study was carried out, with the objective to investigate the feasibility of an OHIA model, to determine the limitations of such a model and to determine a route map to a complete OHIA model. The results of the pilot study are described in this report.

For the pilot study, a limited number of agents and diseases were selected, based on the importance for the total occupational burden of disease and the availability of data. The selected agents and diseases are given in Table 1; the selection process is described in more detail in Appendix A.

Table 1 Selected sectors, agents and diseases in the pilot study.

Sector	Construction industry
Agents	Silica, Lifting and Accidents
Diseases	Silicosis and Lung cancer due to exposure to silica Low back pain due to lifting Recoverable injury, permanent injury and death due to accidents

In this report, the results of the pilot study are described. Chapter 2 describes the model approach. The results for exposure to silica, incidents and lifting are described in the Chapters 3, 4 and 5 respectively. The results for the different exposures are compared in Chapter 6. Finally, in the Chapters 7 and 8 the feasibility of the OHIA model are discussed and recommendations for the follow-up are given.

2 Overview of the model approach

2.1 Introduction

Different types of models are used to determine the health impacts of silicosis and lung cancer due to exposure to silica, low back pain due to lifting and death and injury due to accidents. To combine these different models into one health impact assessment model, the common data input must be the same for all models. This means that the models should use the same life tables, job titles and end points.

2.2 Life tables

The most commonly used approach for health impact assessments is the estimation in change in excess lifetime risk (ELR), incidence or death as calculated from a life table. The life table risk represent the probability of a disease (or death attributed to a disease) during lifetime or up to a certain age. The life table risk takes into account that a cohort is dying out from other causes of death than the disease under study, in contrast to the conditional cumulative risk which is less accurate. The mortality rates and survival probabilities for all causes that were used for constructing life tables are shown in Appendix B.

In health impact modelling a disease model is used in combination with an average exposure level or exposure distribution to estimate (or simulate) the number of cases occurring each year. The advantage of this approach over risk assessment approaches is that a) population distributions of exposure can be used instead of fixed values and b) the effect of changes in the exposure distribution can be explored with regard to disease occurrence.

Besides a relative risk or absolute risk (RR or AR) as a function of exposure, several pieces of information are needed to calculate the ELR as a function of exposure with the help of a life table. These pieces are:

– The background rate of the disease or outcome of interest in each age group in the general population.
– The background all-cause morbidity or mortality rate in each age group in the general population. These should be gender specific, if the exposure distribution or the relative risks from the published study differ by gender.
– Depending on the purpose of the risk assessment, level of exposure in the target population.

The life table begins in a given year, starting with a fixed cohort of a certain size and age distribution, which is affected at every subsequent age by the mortality and disease rates for that age. The life table continues until the last person dies. The life table consists of age specific disease or mortality rates. With increasing age, increasing cumulative exposure is assumed (based on age, assuming that all workers started working at age 20 and are exposed to the same level).
With increasing cumulative exposure, the risk of disease increases and for each age category the mortality rate among exposed is calculated on the basis of the background risk (or risk in non-exposed) and the relative (in case of a disease that occurs among non-exposed) or absolute risk (in case of a disease that does not occur among non-exposed). This rate among

exposed can be used to calculate the number of cases in each stratum and this in its turn is used to calculate the risk at the end of the desired period. The number of cases in each stratum is adjusted for the probability that individuals die from other causes. To estimate the impact of exposure on the population with a certain age distribution in the start year a distinction between age and calendar year has to be made in the life table.

2.3 Selection of job titles

The selection of job titles in the pilot study is based on the periodic medical examinations (PAGO) in the construction industry in 2005 (total number n=36,741), as collected and provided by Stichting Arbouw. All construction workers are invited for this PAGO and approximately 60% will attend. The invitation scheme is age-dependent: workers below 40 are invited every 4 years, whereas workers of 40 and older are invited every 2 years. This implies that the age distribution will be skewed towards older age. A selection is made on the 20 jobs with most construction workers, excluding white-collar jobs. These jobs cover approximately 74% of all workers attending the PAGO and are shown in Table 2.

Table 2 Occupations in the construction industry

Arbouw code	Description	Number
9541	Carpenter (timmerman)*	11704
9511	Bricklayer (metselaar)**	2892
9311	Painter (schilder)*	2658
7021	Supervisor (uitvoerder B & U)	2253
9919	Bricklayer's assistant (opperman/bouwvakhelper)	839
9746	Machinist (machinist GWW)	764
9514	Road paver (straatmaker)	666
9913	Excavation Worker (grondwerker)	644
9551	Plasterer (stukadoor traditioneel)	577
9546	Carpenter (timmerman)**	572
9513	Tiler (tegelzetter)	491
9547	Carpenter/Bricklayer (timmerman/metselaar)	475
9741	Machinist mobile crane (machinist mobiele kraan)	416
9914	Craftsman (vakman GWW)	388
9855	Driver (chauffeur)	375
9595	Cable pipeline layer (kabel- en buizenlegger)	356
9544	Woodworker mechanized (machinaal houtbewerker)	327
9521	Concrete driller/sawyer (betonboorder/zager)	288
8457	Mechanic machine maintenance (monteur onderhoud machines)	266
9598	Mechanic ceiling/completion (plafondmonteur/monteur afbouw)	246

* Maintenance, renovation (onderhoud, renovatie)
** Newly built (nieuwbouw)

Four job titles were selected for the pilot study, based on the number of employees and their relevance to lifting, dust exposure and accidents, namely:
- concrete drillers/sawyers;
- tilers;
- carpenter;
- road paver.

2.4 Characteristics of the job titles

2.4.1 Cohorts

Four job titles were selected, representing high and low exposure levels for each exposure. For each job title two fixed (no inflow) cohorts of 10,000 workers were defined: one cohort of 20 year old workers just starting their employment in the construction industry, and one cohort with a mean age of 42 year (standard deviation 7.8) who had all worked in the construction industry since age 20. The age characteristics were based on an epidemiological survey among Dutch construction workers exposed to quartz-containing dust (Tjoe et al., 2003a). Workers were assumed to work in the same job until age 65 (45 years total).

2.4.2 Number of employees

The excess lifetime risk is calculated for cohorts of 10,000 employees for each job title. For the excess life time risk in the actual work force, a correction for the number of employees is needed. The correction is based on the following data:

– the total number of employees at the periodic medical examinations (PAGO) in the construction industry is 36,741 in 2005;

– the total number of employees in the construction industry (excluding painters) is 222,059 in 2006 (Rijswijk van, 2008).

Assuming that the job distribution of employees attending the periodic medical examinations is the same as the job distribution of all employees, we can calculate the number of employees per job by using a correction factor 6.5 (= 222,059 / (36,741–2658)). Table 3 shows the number of employees in the construction industry per job.

Table 3 Number of employees per job in the construction industry and correction factor cohort

Arbouw code	Description	Number PAGO	Number of employees
9541+9546	Carpenter	12276	80,000
9514	Road Paver	666	4300
9513	Tiler	491	3200
9521	Concrete driller/sawyer	288	1900

2.5 End point of the calculation

An indicator for work-related health damage should combine mortality, illness and other health effects. On a national level, the concept of DALY 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 OHIA model and the Occupational Risk Model for accidents. Since the DALY concept has become a standard, it is used in the pilot study. This means that the OHIA model would be directed at the total life expectancy.

Using the life tables, the life expectancy at the age of incidence of the disease/incident is used to determine the contribution of the disease in terms of DALY.

3 Silica exposure

3.1 General description of the model

Two models were developed for silica-related exposures: a lung cancer and a silicosis model. Section 2.2 gives a general description of the life table method. For lung cancer background lung cancer mortality rates were used in combination with a relative risk (increase in risk per increase in exposure) to calculate age specific lung cancer mortality rates. It was assumed that lung cancer incidence was equal to lung cancer mortality. The number of deaths was converted to DALY using a weight of 1 for each missed life year.
Silicosis does not occur among non-exposed subjects. Therefore an absolute risk (increase in incidence rate per increase in exposure) was used to calculate age specific incidence rates. Silica cases were assumed to leave the working population but have a normal life expectancy. The number of cases is converted to DALY using a weight factor of 0.43 for each life year with silicosis.

3.2 Exposure data

Pre-intervention mean (arithmetic mean) respirable silica exposure levels for the four job titles were extracted from the literature (Table 4). For concrete drillers and recess millers a mean eight-hour time weighted average (TWA) exposure level of 1.09 mg/m^3 has been reported for the Dutch construction industry (Tjoe et al, 2004), which was used for concrete drillers/sawyers. This study also reported a background mean eight-hour TWA exposure level of 0.006 mg/m^3. This value was used as an estimate for carpenters for whom only background levels of silica were expected. For tilers and road pavers no eight-hour measurements were available and task based exposure measurements and time spent on daily activities were used to calculate an eight-hour TWA exposure (Table 4). For tilers task based exposure measurements have been reported for removal of old tile and stucco layers, cutting, grinding or drilling of tiles, and cutting and grinding of bricks of sand-lime or cellular concrete (Spee et al., 2010). Average exposure levels for cutting and drilling of tiles were below the background exposure level as reported by Tjoe et al., 2004, and these tasks were considered unexposed. No exposure measurements were reported for removal of glue and cement, impregnating, preparing glue/cement, tiling, pointing and sponge off mortar, applying blocks, sealing, and wet cleaning. These tasks were also considered to be unexposed and a background exposure of 0.006 mg/m^3 was used (Tjoe et al, 2004). Average time expenditures on these daily activities as reported by workers were available (Onos and Spee, 2004). Combining the average exposure levels and average time expenditure, a pre-intervention eight-hour TWA exposure of 0.092 mg/m^3 was estimated (Table 4). For road pavers a task-based exposure measurement has been reported for cutting of paving kerb (Chrisholm, 1999), which was in the range of levels reported for cutting of concrete slabs (Thorpe et al., 1999). In addition, exposure levels have been reported for compacting of soil by plate compactors (Brouwer et al., 2001). The average time spent on these activities was estimated, resulting in an estimated pre-intervention eight-hour TWA exposure of 0.23 mg/m^3 (Table 4).
It should be noted that the eight-hour TWA exposure levels are point estimates rather than exposure distributions.

Table 4 Pre intervention eight-hour time weighted average (TWA) average silica exposure (mg/m^3) for concrete drillers/sawyers, carpenters, tilers, and road pavers.

	Percentage of time (%)	Average pre intervention silica exposure (mg/m^3)
Concrete driller/sawyer		
8 hr TWA exposure	100	1.09[g]
Carpenter		
8 hr TWA exposure	100	0.006[g]
Tiler		
Removing old stucco and tiles	10[a]	0.525[h]
Grinding and sawing of tiles	7,5[a]	0.2935[e,h]
Sweeping	1,3[a]	0.48[h]
Sawing sand-lime bricks or cellular concrete	7,3[a,b]	0.093[f,h]
Unexposed time	74[c]	0.006[g]
TWA exposure	100	0.092
Road paver		
Cutting of paving kerb	5[d]	3.8[i]
Compacting soil by plate compactor	10[d]	0.3425[j]
Unexposed time	85[c]	0.006[g]
TWA exposure	100	0.23

[a] Based on a range of the percentage of time spent on daily activities as reported by workers (Onos and Spee, 2004). The midpoint was taken.
[b] Total sawing time: 14.5%. Assumption: 50% sand-lime bricks or cellular concrete and 50% gypsum (no silica exposure).
[c] 100% – ∑percentage of time spent on exposed jobs.
[d] No data available, estimated.
[e] Pre intervention: always using an angle grinder (average of inside and outside was taken).
[f] Pre intervention: always using a hand held circular saw.
[g] Tjoe et al., 2004.
[h] Spee et al., 2010.
[i] Chrisholm, 1999.
[j] Brouwer et al., 2001.

3.3 Intervention measure

3.3.1 Intervention scenario 1

The Dutch MAC (Maximally Accepted Concentration) for silica is 0.075 mg/m^3 eight-hour TWA. As a first intervention scenario we assumed that for road pavers, tilers and concrete drillers/sawyers, for whom the average pre-intervention exposure levels exceeded this MAC, the average post intervention level was reduced to the MAC value of 0.075 mg/m^3 eight-hour TWA. Since we use an average value of exposure and exposure varies from worker to worker, this means that still a considerable number of workers is exposed at or above the MAC.

3.3.2 Intervention scenario 2

The second intervention scenario is based on reported efficacies of actual interventions reported in the literature (Table 5). Implemented interventions are wet dust suppression and switching to a different type of tool. A study of the efficacy of risk management measures on occupational exposures reported an average reduction factor of 5 for wet suppression (Fransman et al., 2008), which we used for this study. If possible this average reduction factor was compared to silica exposure reduction factors reported for specific applications.

Concrete drillers/grinders: Wet suppression was implemented during drilling and grinding, resulting in a post intervention exposure level of 0.218 mg/m^3. The reduction factor of 5 is in line with reduction factors of 3 – 7 reported by a study of water dust suppression during cutting of concrete (Thorpe et al., 1999).
Tilers: Wet dust suppression was implemented for removing old stucco and tiles and for sweeping.
The reduction factor of 5 is in the range of reported wet suppression reduction factors for demolition work (Brouwer et al., 2001) and sweeping (Tjoe et al., 2003b). In addition, for grinding and sawing of tiles a switch from angle grinder to a stationary saw with water suppression and for sawing of sand-lime bricks or cellular concrete a switch from a circular saw to a hand saw were implemented. Exposure levels for the use of these tools have been reported (Spee et al., 2010). These interventions resulted in a post intervention exposure level of 0.017 mg/m^3.
Road pavers: Wet suppression was implemented during cutting of paving kerbs and compacting of soil. The reduction factor of 5 is in the range of reduction factors reported during soil compacting (Brouwer et al., 2001) and cutting concrete (Thorpe et al., 1999). These interventions resulted in a post intervention exposure level of 0.050 mg/m^3.

Table 5 Post intervention eight-hour time weighted average (TWA) average silica exposure (mg/m^3) for concrete drillers/sawyers, carpenters, tilers, and road pavers for intervention scenario 2.

	Intervention measures scenario 2	Average post intervention silica exposure scenario 2 (mg/m^3)
Concrete driller/sawyer		
8 hr TWA exposure	Wet suppression: reduction factor 5[a]	0.218
Carpenter		
8 hr TWA exposure	NA	0.006[b]
Tiler		
Removing old stucco and tiles	Wet suppression: reduction factor 5[a]	0.105
Grinding and sawing of tiles	Stationary saw with water	0,0098[c]
Sweeping	Wet suppression: reduction factor 5[a]	0.096
Sawing sand-lime bricks or cellular concrete	Hand saw instead of circular saw	0.001[c,d]
Unexposed time	NA	0.006[b]
TWA exposure		0.017
Road paver		
Cutting of paving kerb	Wet suppression: reduction factor 5[a]	0.76
Compacting soil by plate compactor	Wet suppression: reduction factor 5[a]	0.0685
Unexposed time	NA	0.006[b]
TWA exposure		0.050

[a] Fransman et al., 2008.
[b] Tjoe et al., 2004.
[c] Spee et al., 2010.
[d] After the intervention measure, the residual exposure appears to be less than the background value, as different sources of information are used.

3.4 Dose response

3.4.1 Lung cancer

For silica and lung cancer risk several meta-analyses are available. The most appropriate one which describes the exposure response relationship between cumulative silica exposure and lung cancer risk (expressed as relative risk) has been published by Lacasse et al., 2009. The modelling in this analysis was legitimately criticized, but in the rebuttal (Lakhal and Lacasse, 2009) a smoothed exposure response relationship was given through the origin (cumulative exposure=0, RR=1) which could be used in this health impact analysis. A meta analysis including 9 dose response studies of silica exposure and lung cancer roughly demonstrated a linear increase in lung cancer risk up to a RR of 1.8 for exposures between 0 and 5 mg/(m^3.year), which levelled off to a steady RR of 1.8 for exposures above 5 mg/(m^3.year) (Lakhal and Lacasse, 2009) (Figure 1).

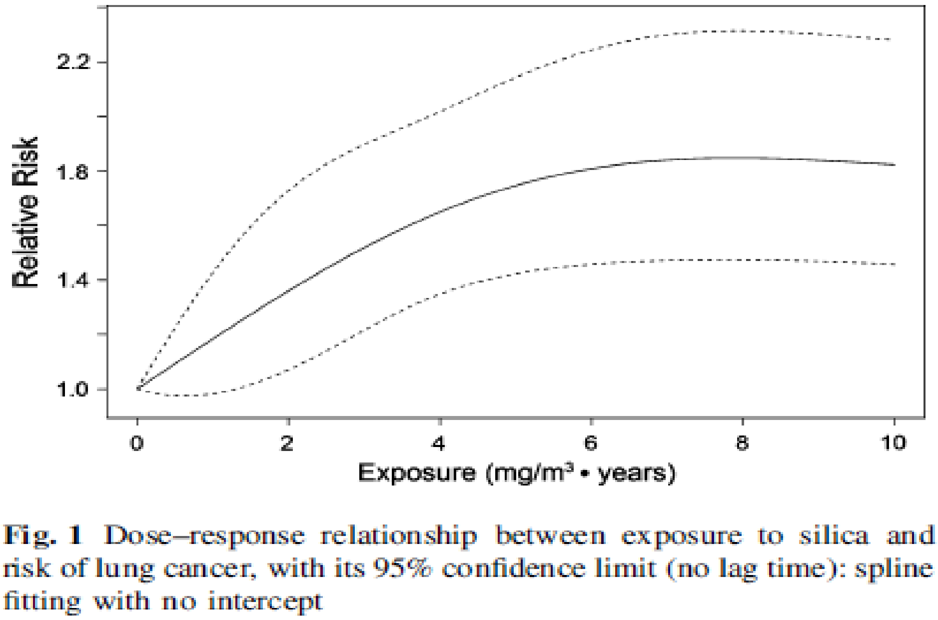

Figure 1 Dose response relationship (Lakhal and Lacasse, 2009).

3.4.2 Silicosis

Recent studies on silicosis in Dutch construction workers

The use of hand tools over the last decades in the construction industry has led to incidentally high exposure to silica containing dust and this was the reason to explore the risk for developing silicosis. In a cross-sectional study among 1335 Dutch construction workers radiological changes were observed in 2.9% of profusion ILO category ≥1/1. Silicosis (defined as the presence of small rounded opacities) was reported on 10 (0.8%) chest radiographs. The study showed an exposure response association between the prevalence of ILO ≥1/1 and cumulative exposure to quartz containing dust. However, in the minor profusion categories 0/1 and 1/0 a poor agreement between the three certified 'B' readers (κ between 0.21 and 0.4) was reported. Identification of pneumoconiosis (silicosis) at population level in workers exposed to silica containing dust has up to recently been done by conventional chest radiographs, classified according to the International Labour Office (ILO) guidelines. In a follow-up study among a sample of construction workers from the source population, more advanced imaging techniques were used. High-resolution computed tomography (HRCT) has been shown to be superior to chest radiography for the detection of small opacities, interstitial fibrosis, and emphysema especially in low grade pneumoconiosis and a low radiation HRCT protocol was used to evaluate cases and controls in greater detail. Posterior-anterior chest radiographs, dynamic and static lung volumes and gas diffusion parameters were measured in all participating individuals as well. The study gives evidence that in workers with normal chest radiography (ILO 0/0) the presence of low grade silicosis cannot be excluded. In relatively high exposed construction workers a seven times higher risk of simple (nodular) silicosis was found. Emphysema on HRCT was associated with current or former smokers, but not with exposure, and contributed to a reduction in diffusion capacity. Airflow limitation was mainly determined by current smoking and was not associated with simple (nodular) silicosis.

Recently, a diagnostic rule has been developed on the basis of which the likelihood that an individual worker has silicosis can be predicted on the basis of cumulative exposure, lung function and self-experienced health status. Workers with a high probability are referred to a specialized clinic. Approximately 150 workers with high scores have been referred and evaluated (Mets et al., 2010). The prevalence of silicosis in this group is again clearly elevated as expected. Many workers also experience COPD and emphysema. These studies together indicate that workers in the Dutch construction industry are at risk for developing silicosis. However, the cross-sectional data available is not optimal as a basis for risk or health impact assessment. Therefore, the literature was explored to identify studies which made use of either incidence or mortality data for silicosis.

Exposure response relations for silicosis

Silicosis exposure response relations have been evaluated in only a few studies. Exposure response relationships have been described for six cohort studies with silica exposure ranging from diatomaceous earth workers, granite workers, sand workers and gold miners using mortality data ('t Mannetje et al., 2002). Data from six occupational cohorts were pooled with good retrospective exposure data in which 170 deaths from silicosis were reported. The rate of silicosis mortality in the combined data was 28/100 000 person years (py), increasing in nearly monotonic fashion from 4.7/100 000 for exposure of 0-0.99 mg/(m^3.year) to 233/100000 for exposure of >28.1 mg/(m^3.year). The estimated risk of death up to age 65 from silicosis after 45 years of exposure at 0.1 mg/m^3 silica (the current standard in many countries) was 13 per 1000, while the estimated risk at an exposure of 0.05 mg/m^3 was 6 per 1000. Both of these risks are above the risk of 1 per 1000 typically deemed acceptable by the US OSHA. If on the basis of this study the rates are converted to a lifetime risk, (risk=1-exp (-Σ time. rate)), the estimated risk of death by age 75 due to silicosis was 1.9% after a lifetime of work (age 20–65) at the current standard for silica in the US (0.1 mg/m^3).

Other relatively recent studies made use of radiological data collected in a very similar way and were able to estimate the incidence of silicosis because of the cohort design of the studies (Chen et al., 2001; Kreiss and Zhen, 1996; Hnizdo et al., 1993; Steenland and Brown, 1995). Older studies are available (reviewed in Chen et al,. (2001) and Steenland (2005)) but these have no or limited follow up after the end of employment. As a result, the estimated lifetime risk is more than an order of magnitude lower and these studies are not of sufficient quality to be used for risk assessments. More specifically, the lifetime risk of exposure at 0.1 mg/m^3 for 45 years varied between 2 and 92%, with the higher risks for studies which had extended follow-up till after the end of employment. In these studies, the risk varied less, but still close to a factor 2, between 47 and 92%.

Incidence data is preferred over mortality data because it can be expected that silicosis as underlying cause of death will be poorly documented in most cases. The four studies which have made use of incidence data have closely resembling exposure response relationships for cumulative respirable silica exposure and cumulative risk of silicosis (Chen et al., 2001). This analysis was based on ILO category 1/1or higher (small opacities on radiograph) for most of the studies, similarly to the criterion used in the cross sectional study by Tjoe Nij et al (2003). The four studies with longer follow-up and comparable methodology have remarkably similar exposure response relationships.

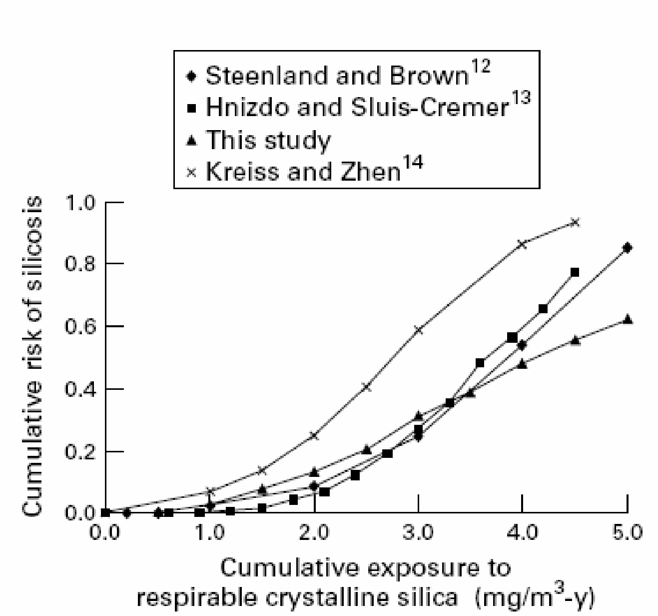

Figure 2 Cumulative risk for silicosis by cumulative exposure to respirable silica from Chen et al. (2001).

Exposure response relationship used
The comparison of incidence and mortality data indicates that probably a minority of the workers die of silicosis, although the incidence is high in many studies. The difference between a silicosis risk (ILO 1/1) and the mortality risk varies between a factor 23.5 and 46. Although a direct comparison is not possible, and follow-up is not available in the Tjoe Nij et al. study, results indicate, given the excessively high levels above existing exposure standards, that the risk for developing silicosis may be low in the construction industry in comparison to other industries. Such observations have more extensively analyzed for tin and tungsten and pottery workers (Chen et al., 2005). At a given exposure level, the risk of silicosis was higher for the tin and tungsten than for the pottery workers. The observed differences in the risk of silicosis among the three cohorts suggest that silica dust characteristics, in addition to cumulative respirable silica dust exposure, may affect the risk of silicosis. This could potentially be associated with the specific toxicological properties of the silica dust, which does not originate from fresh cut stone, as in most of the mining studies. At this time, there is not sufficient reliable exposure information available for the construction industry to estimate potential differences in potency. This could be an area of more extensive research for the near future because these differences might be of relevance for the estimation of the burden of disease.

The exposure response relationship was obtained by fitting an exposure response relationship for silicosis risk (ILO classification >1/1) with cumulative exposure using the data described by Chen et al. (2001). The obtained dose response relationships between exposure to silica (mg/(m^3.years)) and silicosis rate can be seen in Figure 3 for a quadratic and a log-model.

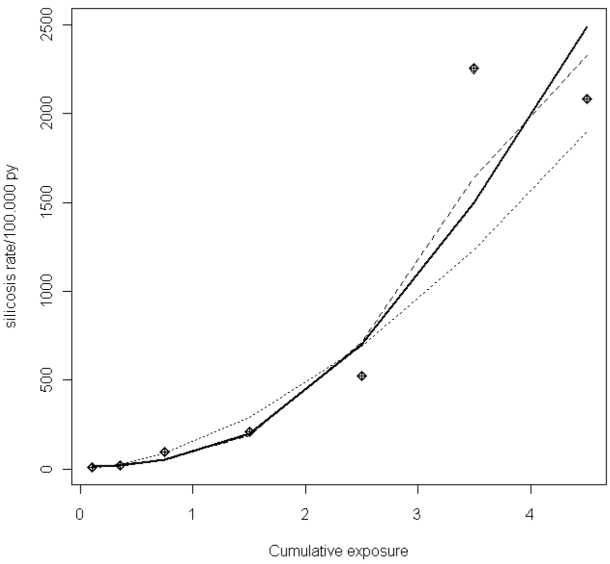

Figure 3 Dose response relationship between exposure to silica (mg/(m^3.years)) and silicosis rate (spline: black line, quadratic model: striped, and log-model: dotted line).

3.5 Results

3.5.1 Lung cancer

Figure 4 and Table 6 provide DALY associated with various silica exposure scenarios: i.e., unexposed, no intervention, intervention 1, and intervention 2. Impact assessments are conducted with two distinct cohort assumptions: i.e., 'cohort age 20 at onset' and 'cohort normal age distribution at onset'. A distinct impact is depicted for the two types of cohorts, with the cohort of age 20 showing much more differentiation among the different exposure scenarios. This is especially the case for the jobs with very high exposure. For life tables assuming a normal age distribution at onset the cumulative exposure among workers in these jobs is already high before the start of the intervention. Hence risks are already approximating a maximum level before intervention which is irreversible. This is less the case for low exposed workers (e.g., carpenters). Both assumptions with respect to age distribution do not provide a sound reflection of reality of a dynamic population with continuous in and outflow of workers. For the high exposed jobs the number of DALY increased from 11,318 (unexposed) to approximately 19,500 (no intervention). For carpenters only a slight increase of DALY was observed.

Table 6 Lung cancer deaths and DALY associated with silica exposure for four job titles in the construction industry.

	Cohort age 20	Cohort normal distribution
Unexposed		
Deaths	997	1012
DALY	11318	11251
Concrete drilling/sawing		
Deaths - no intervention	1695	1721
Deaths - intervention 1	1460	1721
Deaths - intervention 2	1694	1721
DALY - no intervention	19621	19501
DALY - intervention 1	16551	19499
DALY - intervention 2	19598	19501
Road paving		
Deaths - no intervention	1694	1721
Deaths - intervention 1	1460	1716
Deaths - intervention 2	1310	1703
DALY - no intervention	19604	19497
DALY - intervention 1	16551	19407
DALY - intervention 2	14833	19248
Tile setting		
Deaths - no intervention	1559	1585
Deaths - intervention 1	1460	1538
Deaths - intervention 2	1105	1371
DALY - no intervention	17680	17654
DALY - intervention 1	16551	17137
DALY - intervention 2	12524	15314
Carpenter		
Deaths - no intervention	1036	1051
Deaths - intervention 1	1036	1051
Deaths - intervention 2	1036	1051
DALY - no intervention	11746	11683
DALY - intervention 1	11746	11683
DALY - intervention 2	11746	11683

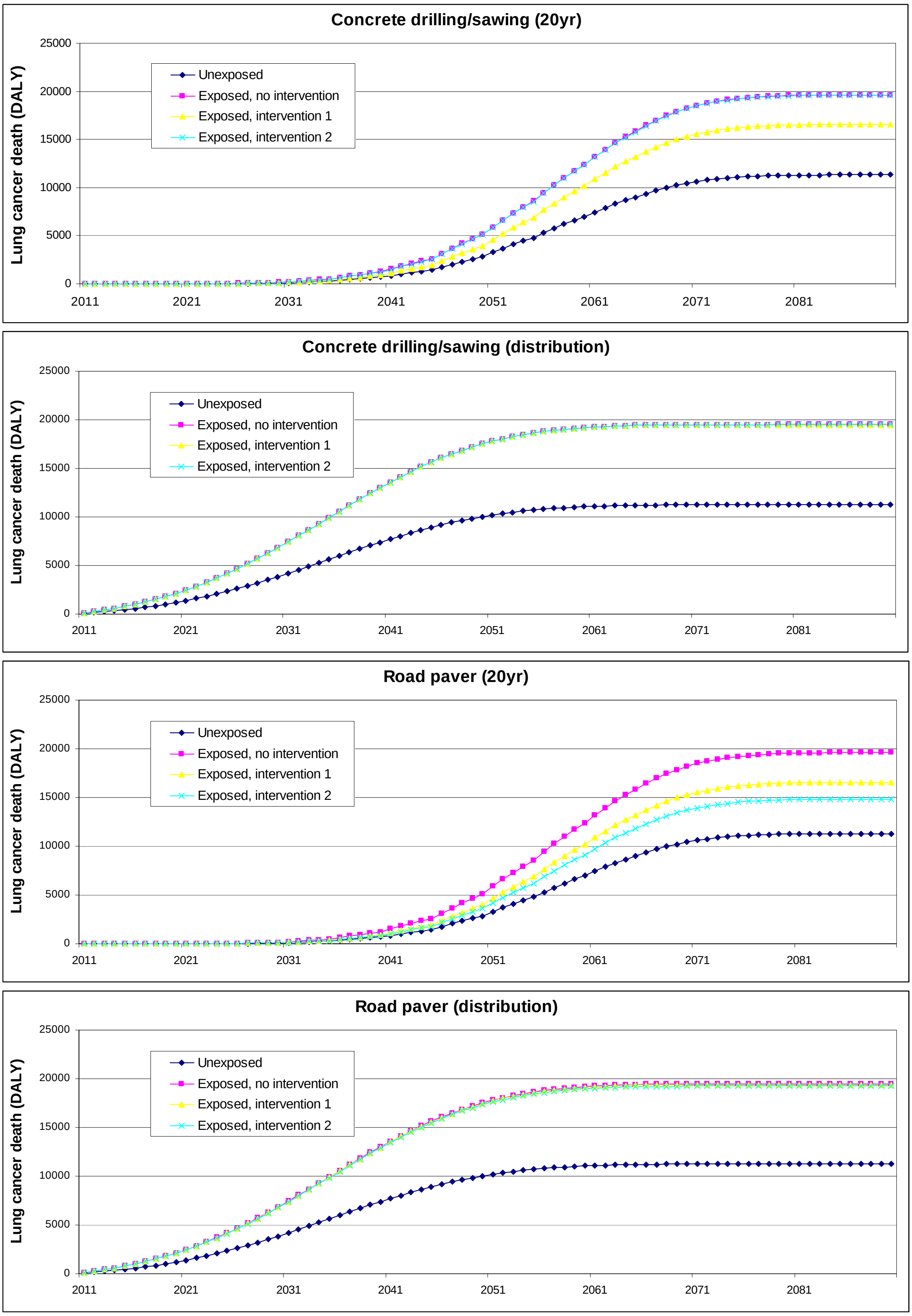

Figure 4 Lung cancer (DALY) associated with silica exposure for four job titles.

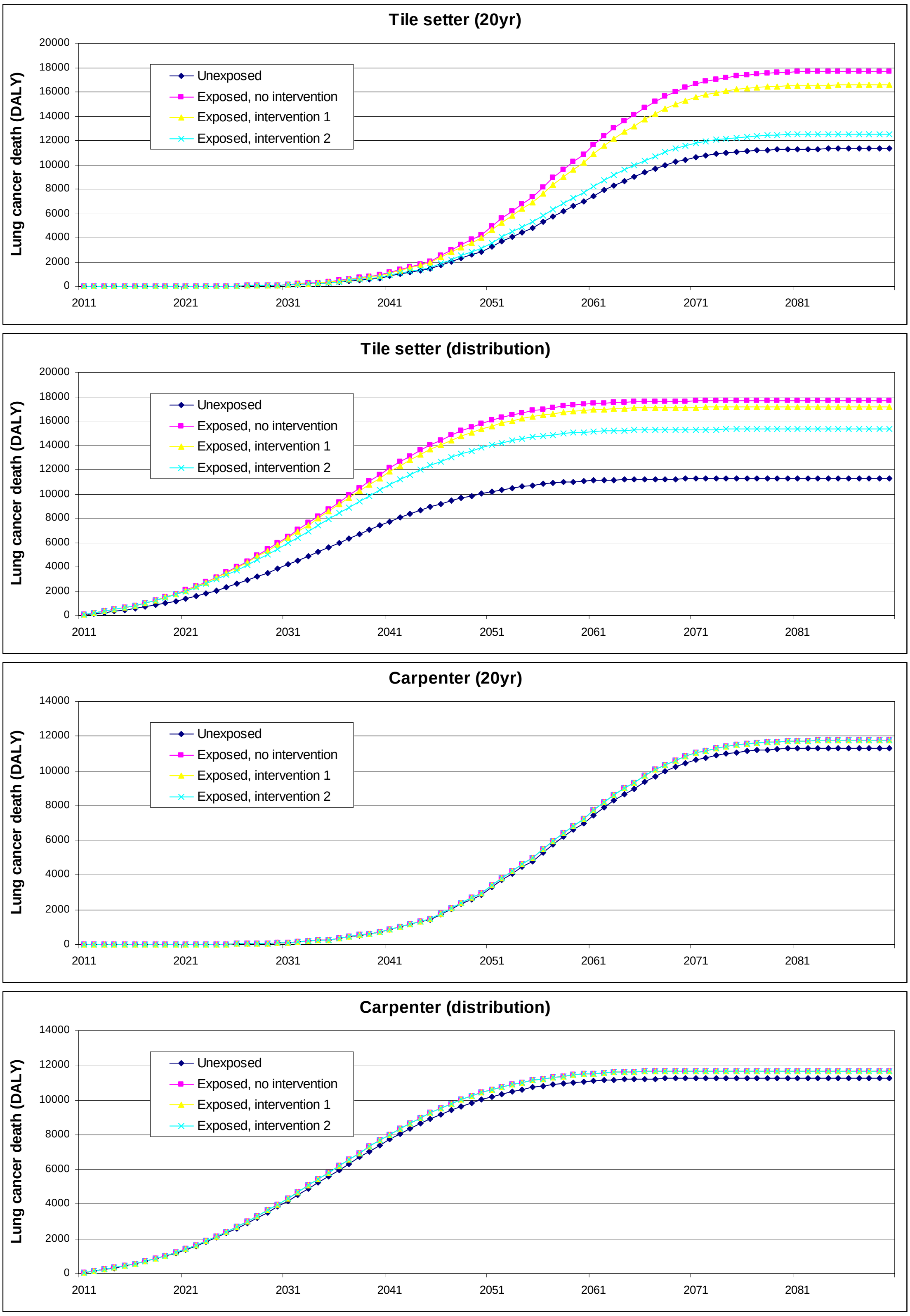

Figure 4 Lung cancer (DALY) associated with silica exposure for four job titles (continued).

3.5.2 Silicosis

Figure 5 and Table 7 show DALY associated with the development of silicosis. The same pattern emerges with more differentiation between exposure scenarios in the population of 20 years at onset. Total number of DALY is substantial for the high exposed concrete drillers and road pavers. Only a very limited number of DALY is lost due to ex-posure among carpenters. Note that silicosis does not occur among non-exposed workers as opposed to the background rate in the previous lung cancer example.

Table 7 Development of silicosis and DALY associated with silica exposure for four job titles in the construction industry.

	Cohort age 20	Cohort normal distribution
Unexposed		
Incidence	0	0
DALY	0	0
Concrete drilling/sawing		
Incidence - no intervention	6864	5211
Incidence - intervention 1	2909	5208
Incidence - intervention 2	6014	5210
DALY - no intervention	98840	49829
DALY - intervention 1	22162	49733
DALY - intervention 2	69884	49796
Road paving		
Incidence - no intervention	6072	5164
Incidence - intervention 1	2909	5075
Incidence - intervention 2	1186	4997
DALY - no intervention	71535	48373
DALY - intervention 1	22162	46495
DALY - intervention 2	8991	45503
Tile setting		
Incidence - no intervention	4009	3860
Incidence - intervention 1	2909	3457
Incidence - intervention 2	174	1796
DALY - no intervention	32349	28131
DALY - intervention 1	22162	24905
DALY - intervention 2	1699	13477
Carpenter		
Incidence - no intervention	85	59
Incidence - intervention 1	85	59
Incidence - intervention 2	85	59
DALY - no intervention	978	479
DALY - intervention 1	978	479
DALY - intervention 2	978	479

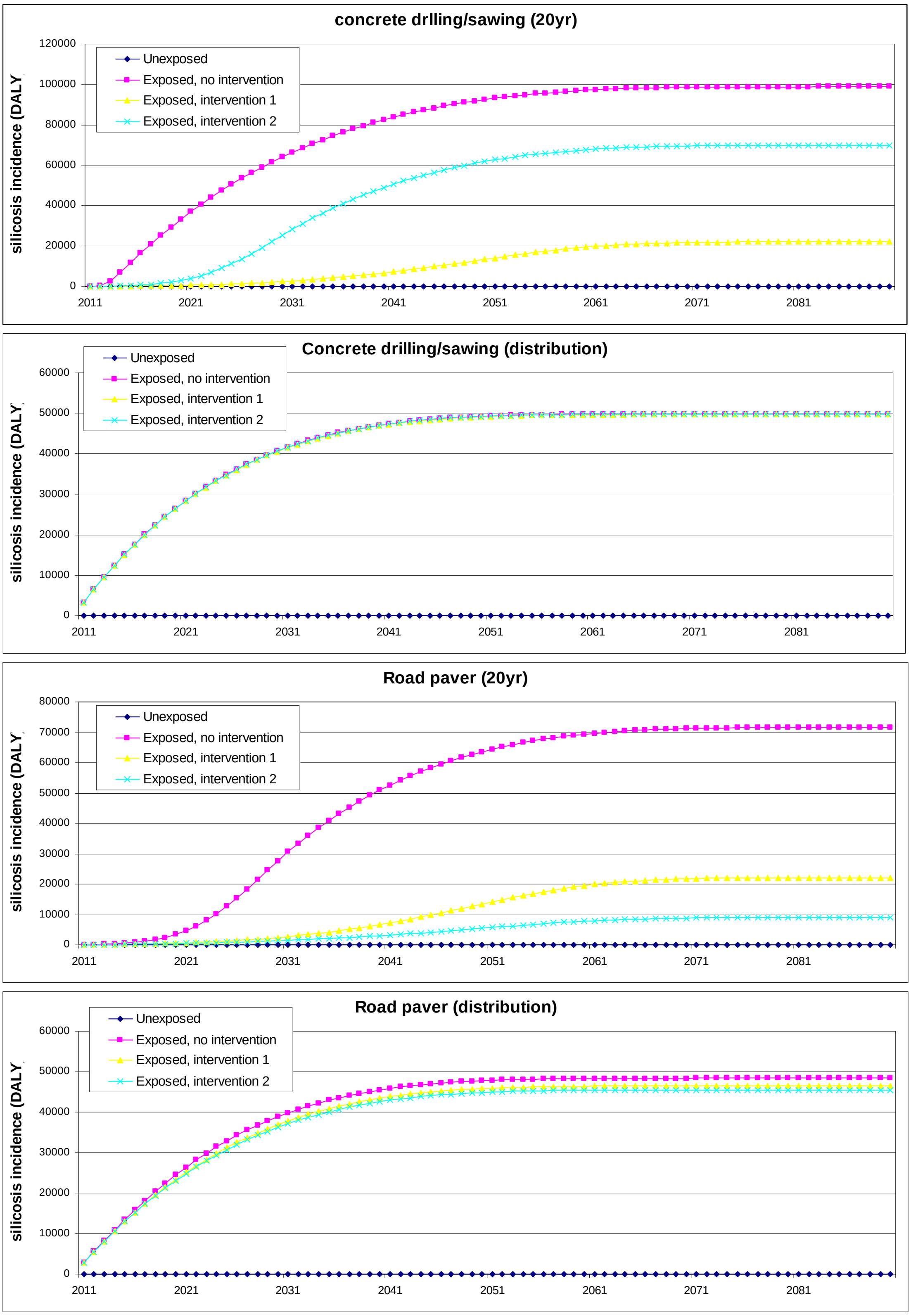

Figure 5 Silicosis (DALY) associated with silica exposure for four job titles.

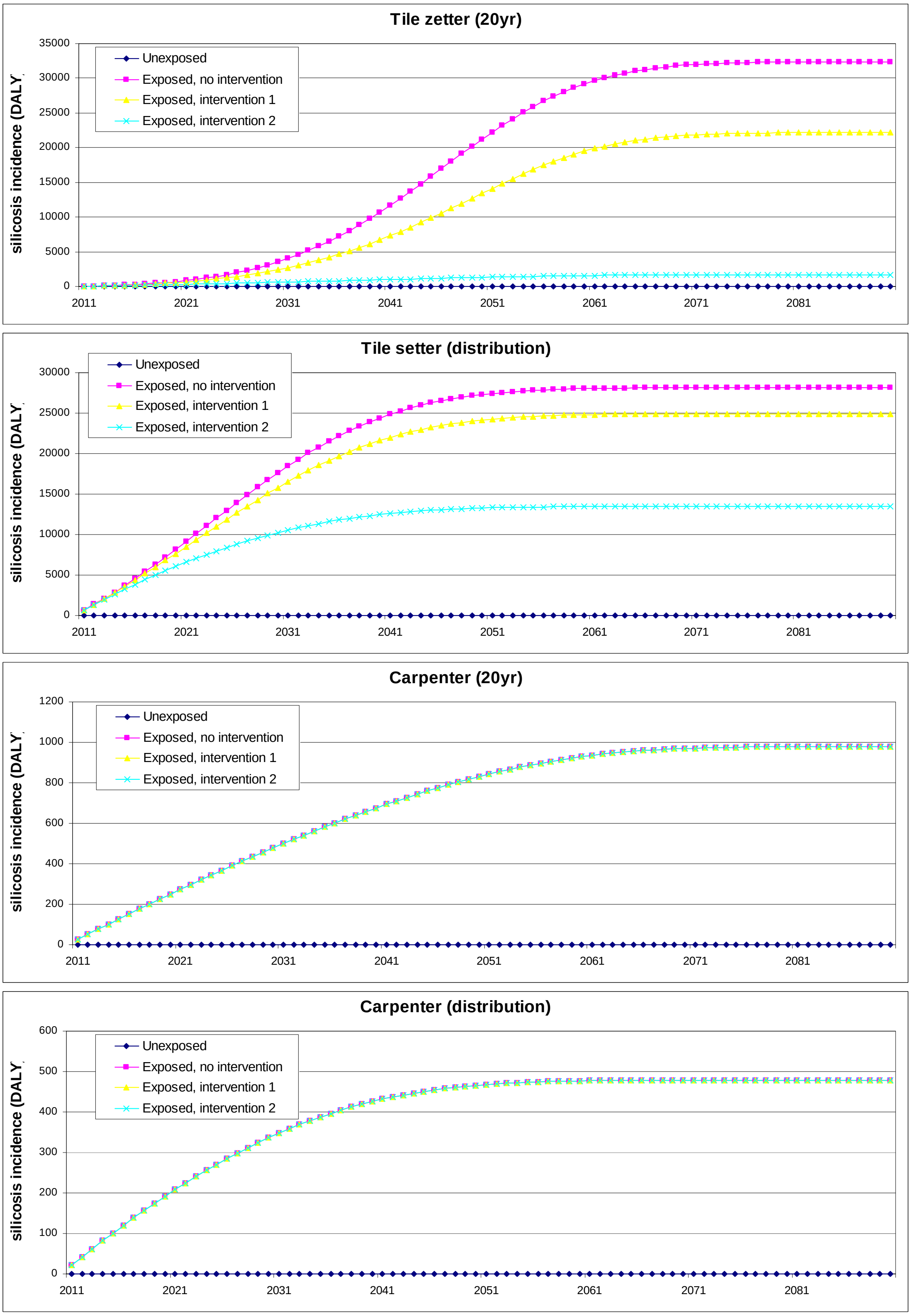

Figure 5 Silicosis (DALY) associated with silica exposure for four job titles (continued).

3.6 Limitations and further work

This worked example demonstrates how a relatively simple life table approach can be used to estimate the impact of an intervention with respect to the reduction lung cancer. The life table approach takes into account that the population is dying out from other causes and is therefore more accurate than the use of a conditional mortality proportion as proposed by Armstrong at al., 2007. By distinguishing between age and calendar year we were able to incorporate the age distribution and model a reduction in exposure in a certain year, irrespective of age.

However several aspects of the health impact assessment were simplified.

– First, no lag time was taken into account. In addition, the life table approach does not offer the possibility to take into account variability in exposure levels, start of employment (exposure), and exposure duration. These elements can be added and will make the model more realistic but this requires further development.

– Second, we did not model population dynamics (e.g. not disease related in- out flow of workers). Alternatively, we explored the influence of two static populations with different age distributions at onset.

– Third, we did not model different disease stages (lung cancer incidence was not modelled), or modification by silicosis, which has been mentioned in the literature. We also did not take into account recovery from disease (approx. 10% of people developing lung cancer survive in the Netherlands), the period of illness before dying, and did not take into account confounding or interaction effects (e.g. by smoking).

– Fourth, for silicosis we used dose-response information from one study in the mining industry. There are indications that the potency of this dust is higher as compared to exposure among workers in the construction industry. Sensitivity analyses and meta-analyses of available dose-response information should be done to provide a more reliable underpinning in the future.

A future step would be to develop a more realistic health impact model, for example a population based dynamic model. Such a model simulates a population of workers longitudinally through time and tracks the development of disease in each worker depended on their individual exposures. Such a model will have several advantages, for instance, an important benefit is that this approach will enable us to incorporate population characteristics and dynamics that possibly have a large influence on disease outcome. Furthermore since the full population exposure distribution is taken into account in such a model, the effect of more subtle exposure reductions can be explored, for example an overall shift of the distribution or cutting down the tail of a distribution, or limited compliance in subpopulations with newly introduced exposure control or personal protective equipment. Thus, such a model can deal with considerable heterogeneity in exposure distributions due to various underlying causes and can subtly model changes in exposure over time. Moreover, such a model also allows simulating other preventive strategies such as screening, health surveillance or other approaches.

4 Accidents

4.1 General description of the model

A model for calculating occupational risk in the Netherlands was developed: Occupational Risk Calculator (ORCA) (Aneziris et al., 2008). ORCA can calculate the occupational risk that workers have on dying or being injured in their daily jobs. Measures aimed at reducing the risk can be entered in ORCA to influence the risk calculation. 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, ORCA can be used to work out an optimal balance between the cost and the benefits of implementing risk-reducing measures.

For ORCA the risk rate has been determined for 63 hazards. The risk rate is defined as the probability of an accident with a given consequence per unit of time of exposure to a hazard. Examples of hazards are: 'Fall from height – placement ladder' and 'Contact with moving parts of a machine – cleaning'. For these hazards the risk rates per hour of activity are given in Table 8.

Table 8 The risk rates per hour for injury or death as a result of an activity.

Hazard type	**Fatality Risk rate [/hr]**	**Permanent injury risk rate [/hr]**	**Recoverable injury risk rate [/hr]**
Fall from height – placement ladder	2.37E-08	2.10E-07	8.28E-07
Contact with moving parts of a machine – cleaning	6.73E-09	5.40E-07	1.33E-07

In the table three possible outcomes/consequences are mentioned: death, permanent injury and recoverable injury. These are the consequences as they are described in accident reports of the labour inspectorate. Not all injuries are investigated by the labour inspectorate, only those where 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.

From Table 8 it can be seen that the risk of dying due to falling from a placement ladder is 2.37 × 10-8 for each hour worked on a placement ladder, or in other words: once every 42 million hours of working on a replacement ladder a fatal accident occurs. This can be used to predict the number of deaths and injuries that will occur in a working population. As an example: it is known from the surveys done for the ORCA project that the average construction worker spends 10% of the time on placement ladders. With an average year of 1680 hours (= 42 weeks × 40 hours), ORCA would then predict that 222,059 (from section 2.4.2) × 1680 × 0.1 × 2.37 × 10^{-8} = 0.88 persons would die from the hazard 'Fall from height – placement ladder' in the construction industry per year. Equally the model would predict 7.8 permanent injuries and 31 recoverable injuries per year. As explained above the number of recoverable injuries is only the fraction that results in hospitalisation within 24 hours. This number will be lower than the total number of injuries within a specific job where lost time due to injuries occurs as not all accidents are severe enough to be reported to the labour inspectorate. This will have an impact on the calculation of DALY.

In a separate study the whole of the sector 'Construction Industry' ('Bouwnijverheid') was analysed on all their activities and the associated risks (Bellamy et al., 2008). With ORCA it was predicted that 21 workers would die. From CBS statistics a number of 20 deaths was known. This shows that the model in general can give good predictions. For smaller industry sectors the numbers might vary more due to statistics.

4.2 Job descriptions

As described in section 2.3 calculations will be done for four jobs:
- Carpenter
- Road paver
- Tiler
- Concrete driller

As shown in the description of the model above, the risk calculation can be done if the exposure of these jobs to the 63 defined hazards is known. This is described in the next section.

4.3 Exposure data

From surveys the exposure of all workers in the construction industry as a whole is known. In Table 9 the calculated Individual Risk (IR = risk rate × exposure time) for this average construction worker for the 63 hazard types are given. The total calculated IR per average construction worker per year for all 63 hazards combined is given in the last row. This is the total IR of dying or being injured at work per average worker due to the different activities being done during a typical working year. As can be seen from the percentages of time exposed to hazards this sums to more than 100% as the average worker can be exposed to multiple hazards at one time. For example: falling at the same level (tripping etc.) can occur while walking on a site and being hit by a falling object. The data in Table 9 is divided into workers of 50 years or younger or workers older than 50 as it is known that the risk rates differ for these age groups and a distinction in the analysis of the accidents was made.

The data from Table 9 shows that a cohort of 10,000 average construction workers with age 20 after 1 year would expect $10{,}000 \times 5.4 \times 10^{-5} = 0.54$ deaths. Also it would show 4.2 workers permanently injured and 8.2 workers injured recoverably. For a cohort of 10,000 construction workers of age 51 and above these numbers would be 1.3, 7.3 and 14 respectively indicating a greater vulnerability of older workers in the construction industry.

Thus, for the average construction worker the risk calculation to predict the number of deaths and (serious) injuries can be done. For the 4 different jobs picked this route cannot be followed as there are no known surveys with exposure data for the 63 hazard types (this would be recommended for a follow up to this project). Therefore a different route is followed, as described below.

Table 9 Individual risks of average construction workers.

Hazard type	perc time exp. to haz. [%]	IR death < 50 [/yr]	IR perm < 50 [/yr]	IR rec < 50 [/yr]	IR death > 50 [/yr]	IR perm > 50 [/yr]	IR rec > 50 [/yr]
1.1.1.1 Fall from height - placement ladder	9.9	2.3E-06	3.1E-05	1.4E-04	8.5E-06	4.5E-05	1.3E-04
1.1.1.2 Fall from height - fixed ladder	1.7	3.1E-07	1.5E-06	5.9E-06	1.1E-11	1.2E-07	5.3E-08
1.1.1.3 Fall from height - step ladder or steps	8.3	8.3E-07	7.9E-06	2.8E-05	1.3E-09	1.5E-05	4.4E-05
1.1.1.4 Fall from height - rope ladder	0.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1.1.2.1 Fall from height – working on mobile scaffold	3.0	2.0E-06	1.3E-05	5.7E-05	9.8E-06	4.4E-05	1.7E-04
1.1.2.2 Fall from height - working on fixed scaffold	11.2	2.7E-06	1.5E-05	8.0E-05	5.9E-06	3.1E-05	1.2E-04
1.1.2.3 Fall from height – (de-)Installing scaffold	7.2	1.0E-06	8.0E-06	2.4E-05	1.2E-05	1.4E-05	2.7E-05
1.1.3.1 Fall from height – roof	4.2	1.6E-05	3.3E-05	1.1E-04	1.6E-05	3.9E-05	1.0E-04
1.1.3.2 Fall from height – floor	5.0	5.6E-06	2.3E-05	9.0E-05	8.0E-06	3.3E-05	1.3E-04
1.1.3.3 Fall from height – fixed platform	3.0	1.8E-06	8.9E-06	2.5E-05	4.6E-06	2.3E-05	5.8E-05
1.1.4 Fall from height – hole in the ground	14.1	3.4E-07	2.4E-06	9.7E-06	7.0E-07	5.1E-06	2.1E-05
1.1.5.1 Fall from height - moveable platform	2.1	2.6E-06	8.9E-06	1.4E-05	3.5E-06	1.1E-05	1.7E-05
1.1.5.2 Fall from height - non-moving vehicle	0.3	2.0E-07	1.4E-06	4.4E-06	3.9E-07	2.7E-06	8.2E-06
1.1.5.3 Fall from height – other	2.0	7.1E-07	6.3E-06	2.1E-05	1.8E-09	7.2E-06	2.6E-05
1.2 Fall on same level	68.9	2.8E-08	3.3E-06	1.3E-05	6.3E-07	6.8E-06	2.3E-05
1.3 Fall down stairs or ramp	1.2	6.7E-08	7.3E-07	3.2E-06	1.1E-07	1.2E-06	5.3E-06
2. Struck by moving vehicle	11.6	2.0E-06	8.2E-06	1.4E-05	3.5E-06	1.4E-05	2.4E-05
3.1 Contact with falling object – crane or load	6.9	3.4E-06	1.8E-05	1.6E-05	7.2E-06	1.7E-05	1.3E-05
3.2 Contact with falling object - mechanical lifting	3.4	3.2E-07	4.6E-06	4.4E-06	4.1E-07	3.9E-06	4.1E-06
3.3 Contact with falling object – vehicle or load	1.9	5.0E-09	1.9E-06	2.0E-06	2.9E-08	7.4E-07	2.7E-07
3.4 Contact with falling object - manual handling	3.5	4.2E-18	4.1E-06	8.8E-06	4.0E-18	3.9E-06	8.2E-06
3.5 Contact with falling object – other	2.3	5.9E-06	2.5E-05	3.9E-05	8.2E-06	2.6E-05	4.7E-05
4.1 Contact with flying object – machine or handheld tool	17.8	2.4E-07	3.0E-05	1.4E-05	1.2E-06	2.5E-05	1.7E-05
4.2 Contact with flying object – object under pressure or tension	9.4	8.1E-07	1.1E-05	9.7E-06	1.5E-06	8.0E-06	8.4E-06
4.3 Contact with flying object – blown by wind	7.6	4.4E-09	8.6E-07	1.7E-06	2.1E-08	7.1E-07	2.1E-06
5 Hit by rolling/sliding object or person	11.2	2.6E-07	3.9E-06	6.0E-06	8.7E-07	6.0E-06	1.3E-05
6.1 Contact with object used or carried–hand held tool operated by other person	24.4	1.3E-10	1.9E-06	2.5E-06	7.5E-10	7.5E-10	1.8E-07
6.2 Contact with object used or carried - NOT handheld tool	12.1	9.7E-08	1.1E-05	6.1E-06	5.7E-10	1.5E-05	4.1E-06
7 Contact with hand held tools operated by self	47.2	4.9E-10	1.7E-05	2.0E-05	2.6E-09	6.0E-06	7.2E-06
8.1.1 Contact with moving parts of a machine – operating	25.7	2.6E-07	8.5E-05	1.7E-05	2.9E-09	1.2E-04	1.5E-05
8.1.2 Contact with moving parts of a machine – maintaining	1.0	1.1E-07	1.9E-06	6.5E-07	1.3E-09	3.2E-06	5.7E-07
8.1.3 Contact with moving parts of a machine – clearing	0.2	1.7E-07	3.0E-06	7.3E-07	5.8E-10	2.0E-06	6.2E-07
8.1.4 Contact with moving parts of a machine – cleaning	1.1	1.5E-07	1.0E-05	2.6E-06	4.0E-09	9.9E-06	2.0E-06
8.2 Contact with hanging/ swinging objects	9.2	6.9E-07	3.3E-06	3.8E-06	4.1E-06	4.9E-05	6.3E-05
8.3 Trapped between	4.6	3.6E-08	5.2E-07	3.7E-07	6.0E-06	8.0E-05	3.7E-05
9 Moving into object	28.1	3.2E-10	9.8E-07	4.4E-07	1.8E-09	2.7E-05	2.6E-05
10 Buried by bulk mass	4.0	9.0E-11	3.5E-07	5.7E-07	5.1E-10	1.3E-06	6.3E-06
11 In or on moving vehicle with loss of control	4.2	8.3E-07	4.3E-06	8.7E-06	1.7E-06	4.4E-06	8.5E-06
12.1 Contact with electricity – high voltage cable	1.0	4.3E-07	2.7E-07	8.8E-07	1.2E-09	5.0E-07	7.4E-07
12.2 Contact with electricity – tool	14.2	1.8E-07	2.7E-07	8.2E-07	8.6E-11	2.1E-07	5.0E-07
12.3 Contact with electricity – electrical work	3.9	5.5E-07	1.9E-06	5.4E-06	3.2E-07	1.4E-06	4.4E-06
13 Contact with hot or cold surfaces or open flame	2.5	2.8E-11	1.1E-07	1.6E-07	1.7E-10	1.7E-10	1.7E-07
14.1 Release of hazardous substance out of open containment	0.5	9.1E-11	3.0E-07	8.8E-07	4.4E-10	2.5E-07	1.0E-06
14.2 Exposure to hazardous substance without Loss of Containment	1.1	2.0E-08	3.8E-07	1.8E-06	9.8E-08	2.2E-07	1.6E-06
15.1 Release of a hazardous substance out of a closed containment – adding, removing or opening	0.3	1.3E-08	3.3E-07	1.0E-06	1.6E-08	1.9E-07	5.8E-07
15.2 Release of a hazardous substance out of a closed containment – transport	0.3	1.4E-10	7.8E-08	1.1E-06	1.6E-10	2.5E-07	6.7E-07
15.3 Release of a hazardous substance out of a closed containment-closing	0.1	2.6E-11	2.7E-07	3.1E-07	2.0E-11	1.9E-07	2.6E-07
15.4 Release of a hazardous substance out of a closed containment – working nearby	0.5	7.4E-08	4.2E-07	2.0E-06	4.5E-08	1.6E-07	6.4E-07
17.1 Fire - hot work	2.2	3.4E-08	4.8E-07	1.7E-06	1.8E-12	5.8E-07	3.3E-06
17.2 Fire - working near flammables/ combustibles	1.0	1.9E-08	3.2E-07	6.8E-07	9.1E-08	1.4E-07	7.3E-07
17.3 Fire - fire fighting	0.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
20.1 Human aggression	4.2	1.3E-08	4.5E-07	2.6E-07	1.2E-07	4.6E-07	4.5E-07
20.2 Animal behaviour	0.6	4.4E-11	9.7E-09	2.9E-08	2.4E-07	1.5E-06	1.8E-06
22.1 Hazardous atmosphere in confined space	0.0	9.6E-09	4.3E-09	3.1E-08	1.7E-08	8.7E-09	4.1E-08
22.2 Hazardous atmosphere through breathing apparatus	0.1	2.8E-08	7.0E-09	7.7E-08	1.2E-10	1.2E-10	5.6E-08
23.1 Impact by immersion in liquid – working in or under	0.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
23.2 Impact by immersion in liquid – working nearby	0.2	2.0E-07	1.2E-08	6.2E-08	2.4E-07	3.1E-08	3.1E-08
25.1 Extreme muscular exertion – handling objects	26.6	3.2E-11	6.0E-07	4.0E-07	2.6E-05	2.9E-05	2.2E-04
25.2 Extreme muscular exertion – moving around	8.0	1.6E-11	5.3E-07	1.4E-06	8.3E-11	2.6E-07	1.4E-06
27.1 Physical explosion	2.7	7.9E-08	4.1E-07	1.0E-06	2.1E-07	7.8E-08	5.6E-07
27.2 Chemical explosions	1.9	3.3E-07	1.4E-06	2.1E-06	3.1E-07	5.4E-07	1.3E-06
Total		5.4E-05	4.2E-04	8.2E-04	1.3E-04	7.3E-04	1.4E-03

In the database that is part of the ORCA model about 12,000 accidents are recorded from 1998 – 2004 (6.17 years). After querying the database the accidents that occurred with the four job types are given. A summary of the numbers of accidents is shown in Table 10.

Table 10 Number of accidents occurring to the four job descriptions.

Job	Deaths	Perm inj	Rec inj	Unknown	Total
Tile setter	1	0	4	2	7
Road paver	1	2	5	6	14
Carpenter	15	184	280	166	645
Concrete driller	0	11	10	10	31

With these numbers and the number of workers in this job the exposure time can now be calculated because the risk rate for all workers for specific hazards is known:

$RR_{hazard} = N_{deaths\ or\ injuries\ for\ a\ hazard} / (N_{exposed} \times t_{exposed})$. =>

$t_{exposed} = N_{deaths\ or\ injuries\ for\ a\ hazard} / (N_{exposed} \times RR_{hazard})$

The number of exposed workers was given in Table 3. To simplify the calculations, these numbers were used although the numbers of workers in the four jobs vary over time and the accidents occurred between 1998 and 2004. Thus the number of exposed workers might differ from the numbers mentioned in Table 3.

The Individual Risk can now be calculated for the 4 jobs in the same way as for the average construction worker, as in the following example on how the risk of dying of the hazard 'Fall from height - floor' was determined for a carpenter. There were 2 recorded deadly accidents in the database with a carpenter for this hazard in 6.17 years. The risk rate for dying of an accident in this hazard in the ORCA model is 7.1×10^{-8} per hour. Thus the exposure time for an average carpenter would be: $2 / 6.17 \times 80,000 \times 7.1\times10^{-8}$ hour = 57 hours in a year. From the 4 permanently injured accidents and the 42 recoverably injured the exposure times are calculated as 27 and 75 hour / year. The number of hours would have to be the same and represent the uncertainty arising from this method which is also caused by 28 accidents where the consequence is recorded as 'unknown'. For the calculations the unknowns will be added as recoverable accidents as it is expected that the more serious consequences of death and permanently injured will be described better in the accident reports.

With the 57 hours of exposure to a deadly accident in the hazard 'Fall from height - floor' the risk for a worker of age < 50 can now be calculated as:

Individual Risk = $t_{exposure} \times RR_{hazard,\ age < 50} = 57$ hr/yr $\times 6.63\times10^{-8}$ hr^{-1} = 3.78×10^{-6} yr^{-1}

$RR_{hazard,\ age < 50}$ is the risk rate per hour for 'Fall from height - floor', known from ORCA (It was used for calculating the Individual Risk in Table 9: $IR_{hazard,\ age < 50} = RR_{hazard,\ age < 50}$ hr-1 × 5.0% × 1680 hr/yr).

Now the total risk of the different jobs can be calculated in the same way as was done for the average worker in the construction industry as in Table 9. The results are given in Table 11.

Table 11 Individual risks of the 4 job descriptions and the average construction worker.

Job description	IR death < 50 [yr-1]	IR perm < 50 [yr-1]	IR rec < 50 [yr-1]	IR death > 50 [yr-1]	IR perm > 50 [yr-1]	IR rec > 50 [yr-1]
Average construction worker	5.4E-05	4.2E-04	8.2E-04	1.3E-04	7.3E-04	1.4E-03
Carpenter	2.7E-05	3.6E-04	8.4E-04	4.8E-05	4.5E-04	1.2E-03
Road paver	3.3E-05	6.5E-05	4.0E-04	5.8E-05	1.3E-04	5.0E-04
Tiler	4.7E-05	0*	2.8E-04	6.7E-05	0*	4.1E-04
Concrete driller	0*	9.3E-04	1.6E-03	0*	9.6E-04	2.2E-03

** Due to the small number of tilers and drillers, no accidents with deadly or permanent injury were found in the ORCA database for their profession and thus the risk is calculated here as 0. If the ORCA database was based on a larger number of years it is probable that some accidents would occur and the risk would not be 0. This is addressed in section 4.7.*

With these numbers a prediction can be made of the number of deaths occurring in a group of workers with that job description. A cohort of 10,000 carpenters with age 20 for example would suffer $10{,}000 \times 2.7 \times 10^{-5} = 0.27$ deaths in one year.

4.4 Intervention measure

The intervention strategies described in Chapter 3 will have an effect on the exposure of workers to concentrations of silica levels. This will have no effect on the number of occupational accidents as these are generally acute, while silica levels will have no immediate effect on the workers. The use of a hand saw as opposed to using a circular saw will have an effect though. If the average construction worker were to use only man powered hand tools instead of electrical powered tools the risk for this hazard would decrease by a factor of 3. Since this hazard is only one of the hazards the total reduction of the risk can differ for the different effects. The result is given in Table 12.

Table 12 Individual risk of the average construction worker, when using self-powered tools instead of electrical power tools.

Job description	IR death < 50 [yr-1]	IR perm < 50 [yr-1]	IR rec < 50 [yr-1]	IR death > 50 [yr-1]	IR perm > 50 [yr-1]	IR rec > 50 [yr-1]
Average construction worker	5.4E-05	4.1E-04	8.1E-04	1.3E-04	7.3E-04	1.4E-03

From Table 12 it can be seen that only the risks on permanent and recoverable injury for workers of age < 50 are affected slightly. With ORCA many measures can be introduced to calculate the effect on the risks. When the risk numbers are known those can be used for the calculations as used in the subsequent sections. For this proof of principle project the calculations have not been done, but it is not a problem to introduce the measures and draw conclusions on them in future studies.

4.5 Risk calculation

As explained in the previous sections, a prediction of the number of deaths and serious injuries can be made with the number of exposed workers and the individual risk.

In the life table calculations two cohorts of 10,000 workers are defined:
- with an average age of 42 and a standard deviation of 7.8 years;
- all with age 20.

Calculation of number of deaths
With the average age group the number of exposed workers of age 20 is 9.61701 as calculated with a normal distribution and cutting off at ages under 20 and over 65. For the group of carpenters after onde year this would result in $9.61701 \times 2.7 \times 10^{-5} = 2.6 \times 10^{-4}$ deaths. The number of deaths that would occur due to 'all causes' is the number of exposed workers of age 20 multiplied by (1 – the survival probability) = $9.61701 \times (1 - 0.9993073) = 9.61701 \times 6.9 \times 10^{-4} = 6.6 \times 10^{-3}$. Thus the percentage of deaths due to occupational accidents in the age group of 20 would be $2.7 \times 10^{-5} / 6.9 \times 10^{-4} = 4\%$. This means that 4% of the deaths occurring in a group of carpenters of age 20 would be attributable to occupational hazards. For the Netherlands as a whole with about 6 million workers (CBS, 2004) and around 80 occupational deaths per year (Arboportaal.nl) the average risk of dying at work would be in the order of $80/6\times10^{6} = 1.3 \times 10^{-5}$ yr^{-1}. Thus the risk of the carpenters would be around two times higher than for the average worker, which does not seem unreasonable as the construction industry has higher risks than other sectors.

The calculation of the number of deaths is done in Excel with the following steps:
1. For the two cohorts defined, for each age the surviving population for the next year is calculated with the survival probability (calculated from a given list of all cause mortalities, see Appendix B). This results in a gradually declining population over the years, until in 2090 most of the population has died out (0.4% of the population remains with the youngest being 100 years of age).
2. After each year the number of occupational deaths is calculated with the calculating rules given above, using two different risk rates for the groups < 50 and > 50. Those that are 65 are assumed to have retired and no longer have a risk of dying due to occupational risks. Note that this last calculating rule is markedly different than for diseases such as lung cancer, where the effect might surface years after the last working day. For the accident model the risks stop as soon as retirement. It is assumed that the occupational deaths are part of the all cause mortality and do not influence the decline in the population due to all causes.

Calculation of DALY from deaths
The number of DALY resulting from the occupational deaths is calculated as follows:
1. First the life expectancy for an age group is calculated with the sum of the remaining cumulative survival probabilities at age ×.
2. The number of DALY for a certain age group is now calculated by subtracting the age at which the death occurs from the life expectancy and is multiplied by the number of deaths. In the example given above, in the group of 9.61701 carpenters with age 20, 2.6×10^{-4} deaths occurred. As the life expectancy at age 21 is 74.20 years, the number of DALY would be $2.6 \times 10^{-4} \times (74.2 - 21) = 0.014$ DALY. This is then repeated for all age groups after one year and summed over all years.

rivm

Calculation of number of injuries

The number of injured workers can also be calculated with the risk rates, similar to deaths, described above. The injured will be able to return to work, except for those cases where a severe permanent injury prohibits this.

Calculation of DALY from injuries

For permanent injuries it is assumed that the injury will last the rest of the workers life (the remaining life expectancy). This is multiplied by the weighing factor 0.15. In appendix C the derivation of this weighing factor is explained in detail. As an example: in the group of 9.61701 carpenters with age 20, $9.61701 \times 3.6 \times 10^{-4} = 3.5 \times 10^{-3}$ permanent injuries would occur before reaching the age of 21. This would lead to $3.5 \times 10^{-3} \times 0.15 \times (74.2 - 21) = 2.8 \times 10^{-2}$ DALY due to permanent injury. This is then repeated for all age groups after one year and summed over all years.

For recoverable injuries it is assumed that the injury will recover in the time of absence from work. The time of absence from work is known from the accidents in the 4 job descriptions. As explained in appendix C, the average factor after multiplying the weighing factor with the absence times is 0.1 year. To simplify the calculations this is used for all the job descriptions. As an example: in the group of 9.61701 carpenters with age 20, $9.61701 \times 4.5\times10^{-4} = 4.3 \times 10^{-3}$ recoverable injuries would occur before reaching the age of 21. This would lead to $4.5\times10^{-3} \times 0.1 = 4.5 \times 10^{-4}$ DALY due to recoverable injury. This is then repeated for all age groups after one year and summed over all years.

4.6 Results

The predicted number of deaths due to occupational accidents is given for the two different cohorts in Figure 6 and Figure 7.

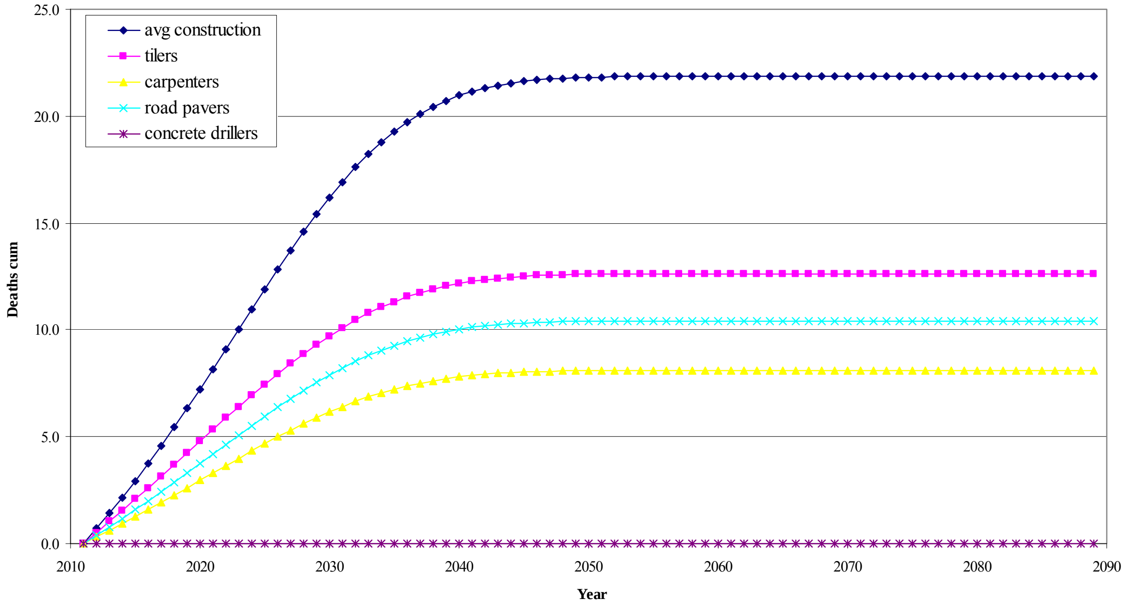

Figure 6 Predicted occupational deaths (cum) per job for the cohort with average age 42 s.d. 7.8.

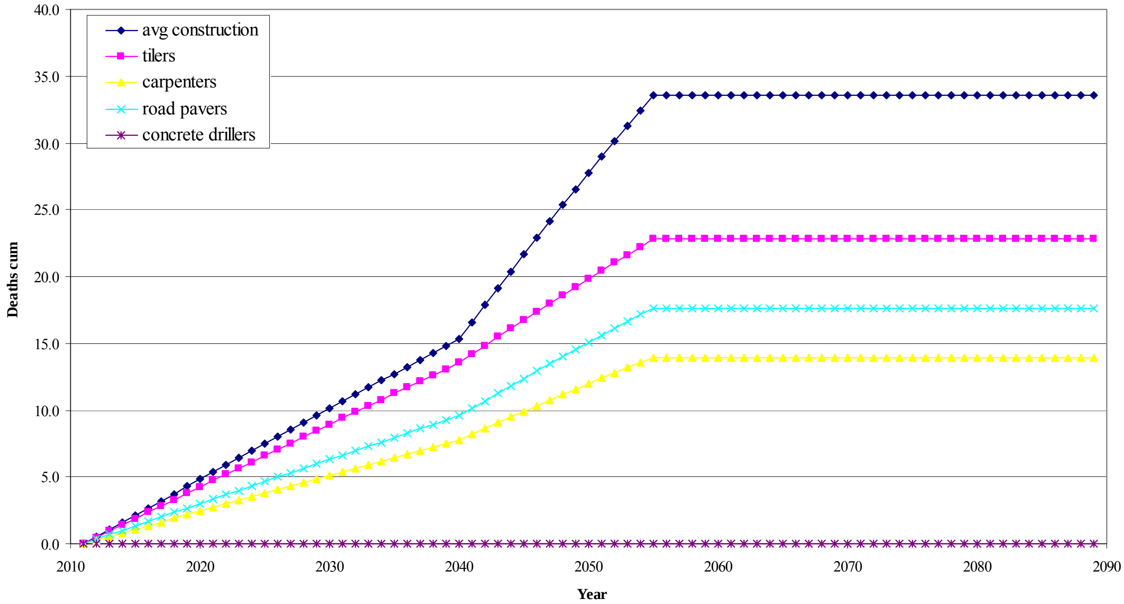

Figure 7 Predicted occupational deaths (cum) per job for the cohort with age 20.

The predicted number of DALY due to occupational deaths is given for the two different cohorts in Figure 8 and Figure 9.

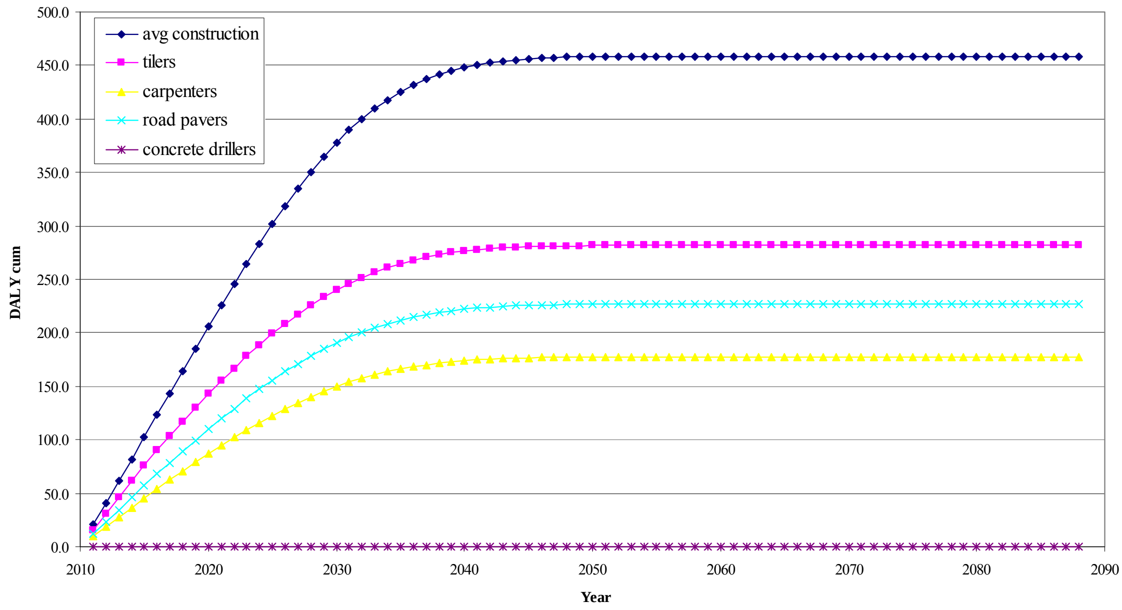

Figure 8 Predicted DALY due to occupational deaths per job for the cohort with average age.

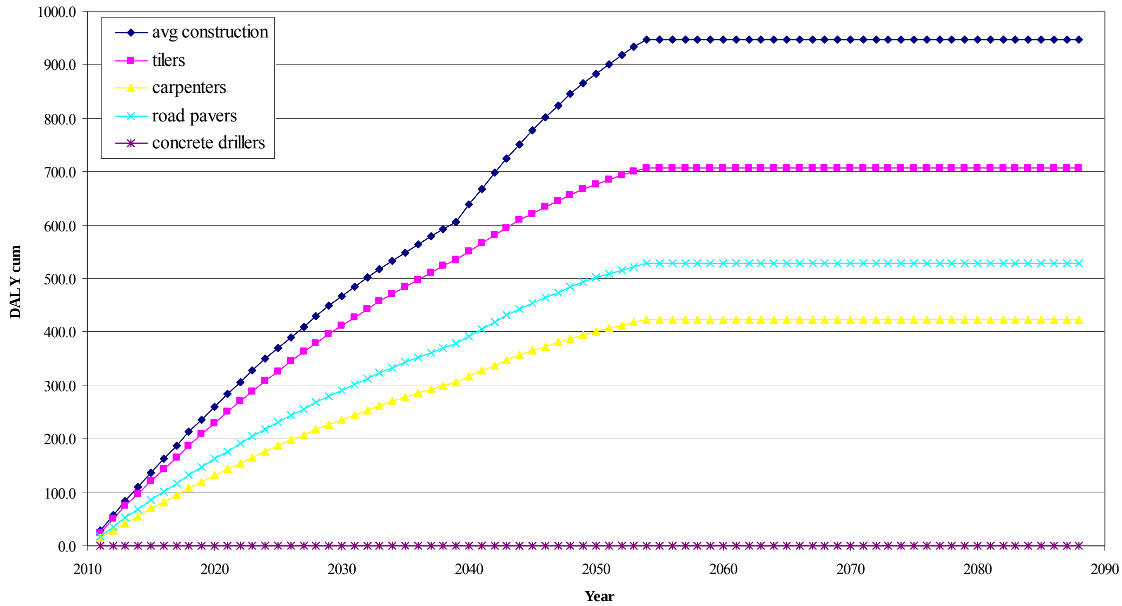

Figure 9 Predicted DALY due to occupational deaths per job for the cohort with age 20.

The predicted number of DALY due to occupational injuries is given for the two different cohorts in Figure 10 and Figure 11.

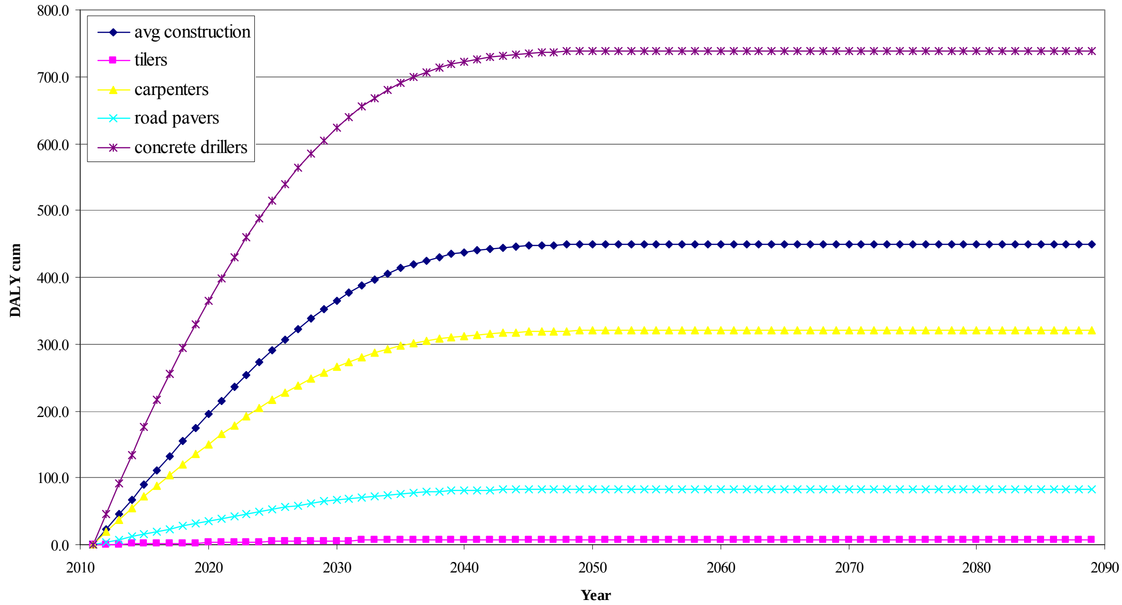

Figure 10 Predicted DALY due to occupational injuries per job for the cohort with average age 42 s.d. 7.8.

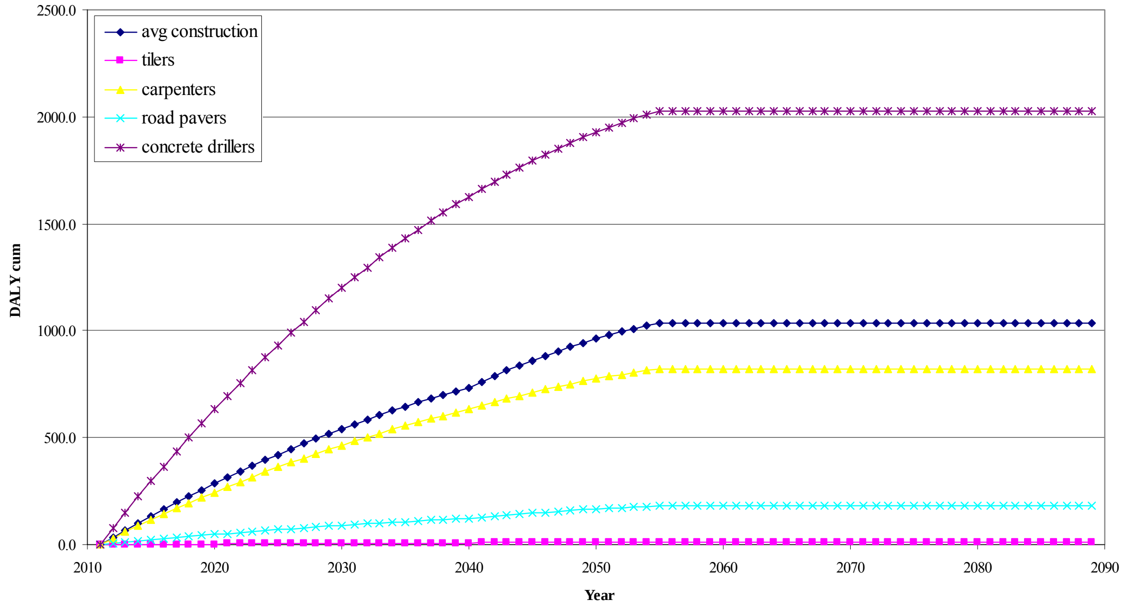

Figure 11 Predicted DALY due to occupational injuries per job for the cohort with age 20.

In the figures there is a marked dent in the curves for the cohort with age 20. This is the result of using two different risk rates for ages < 50 and > 50 year. As soon as the cohort of age 20 reaches the age of 51 a different rate is used and the steepness of the curves increases mostly. This also happens for the cohort with the normal distribution, but here the steepness first increases as more of the working population reach the age of 51 and then declines as more of the working population are retired.

As explained under Table 11 the graphs show no deaths for concrete drillers and thus no DALY. For tilers only a small number of DALY result as there were no recorded accidents with permanent injury and these account for the largest part in the DALY calculations. The results from the graphs are summarised in Table 13.

Table 13 Occupational deaths and DALY associated with occupational deaths and injuries for the four job descriptions and the average construction worker.

	Cohort normal distribution	**Cohort age 20**
Deaths		
Average construction worker	22	34
Carpenter	8	14
Road paver	10	18
Tiler	12	23
Concrete driller	0	0
DALY due to deaths		
Average construction worker	458	947
Carpenter	177	423
Road paver	227	529
Tiler	282	708
Concrete driller	0	0
DALY due to injuries		
Average construction worker	450	1036
Carpenter	320	821
Road paver	83	181
Tiler	8	14
Concrete driller	740	2027

4.7 Limitations and further work

As mentioned in the text above there are some limitations to this part of the project:

– Not all accidents are reported to the Labour Inspectorate, only those where 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. When calculating the number of deaths and the number of DALY resulting from deaths these will be quite accurate. The number of injuries and the DALY resulting from that are less accurate as it is known that some underreporting occurs for these accidents as well as a lot of injuries are not severe enough to be inspected. The ORCA model is quantified with the data from the accident reports and thus cannot make a prediction of these less severe injuries and the underreported injuries and delivers the risk for the reportable injuries only. However, it might be corrected by constructing predictions for these less serious accidents, probably per hazard type. This could be researched through further surveys and comparing the accident numbers to hospital records or other records, from institutes such as TNO, the Coronel Instituut voor Arbeid en Gezondheid and Consument en Veiligheid. First it is probably best to estimate what would be the impact of such refinements over the data and methods already used (for instance for determining a weighing factor for injuries as used in Appendix C) through a sensitivity analysis.

– Apart from the fact that not all accidents are reported to the Labour Inspectorate, there are some accidents that are work related but are not reported to the Labour Inspectorate. Traffic accidents for instance are handled by the police. For a better prediction of the number of DALY it would help if predictions could be constructed for these accidents as well.

– The risk for the four job titles was calculated by analyzing the recorded accidents and calculating back to the exposure times. This leads to a number of occurrences of zero accidents resulting in deaths or injuries for the job descriptions with few workers in them. This is caused by the small population and the limited time period of the accident database of around six years. When accidents are analysed over a larger time interval it is probable that one or more occurrences will be found and the numbers would improve in reliability. Alternatively, the calculation could be improved by determining the exposure times to hazards directly with surveys. That would also deal with errors introduced by the 'unknowns' in the accidents, the uncertainty about the number of workers in a specific job description and the fact that the number of workers may have varied over time, while it was assumed constant for these calculations.

– For this part the same statement about using static populations for the calculations can be made as for the lung cancer/silicosis and lifting part.

5 Lifting

5.1 General description of the model

The OHIA model for lifting has the following components:

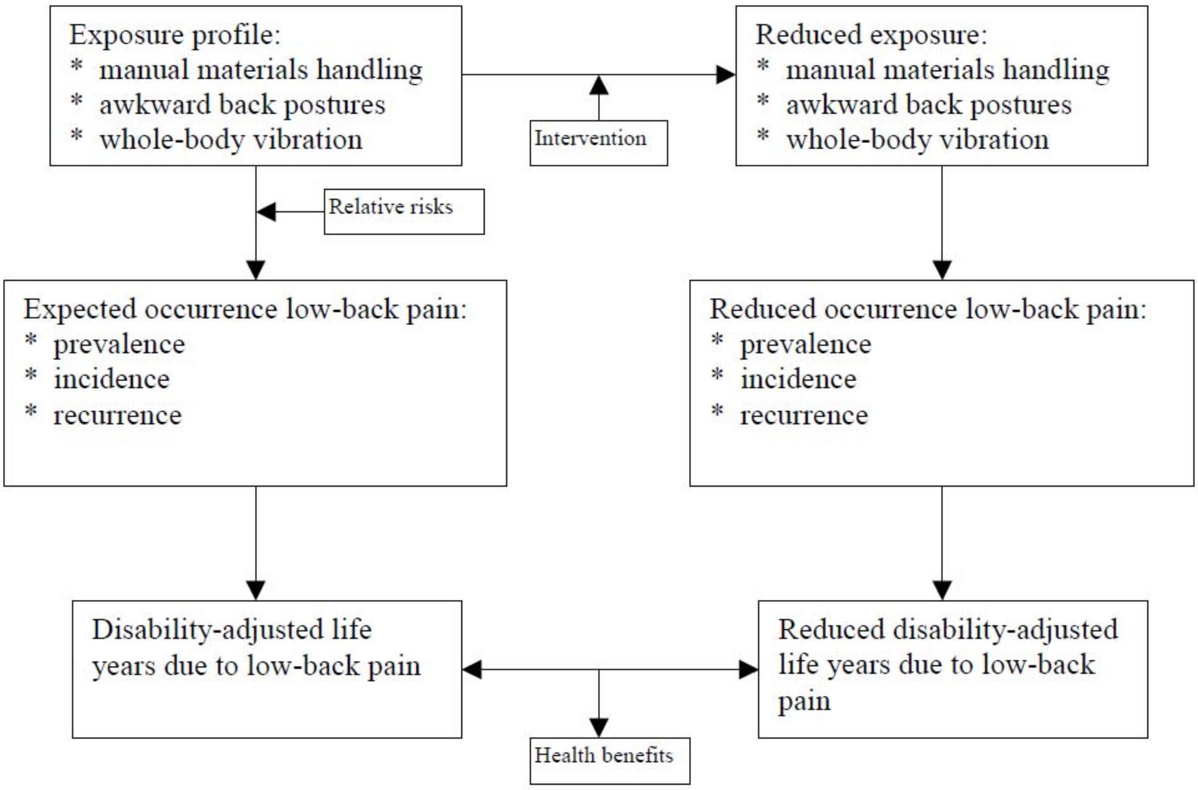

Figure 12 Schematic approach for the health impact assessment for low back pain.

The OHIA model for lifting consists of six steps:
1. Description of the exposure profile in the occupation of interest.
2. Estimation of the expected occurrence of low back pain based on the exposure profile.
3. Assessment of the disability-adjusted life years due to low back pain.
4. Evaluation of the effect of the intervention on the exposure profile in the occupation of interest.
5. Estimation of the adjusted occurrence of low back pain based on the reduced exposure due to the intervention.
6. Assessment of the disability-adjusted life years due the adjusted occurrence of low back pain.

Step 1 requires occupation-specific input information, i.e. the exposure profile of the occupational group of interest. Step 4 requires information on the effects of the intervention on the specific exposure profile. All other steps include general information that is assumed to be constant across all occupations. The difference between step 3 and step 6 will present the health benefits due to the implementation of the intervention.

Mathematical model
The basic OHIA model for lifting is based on a Markov approach whereby a simulation was carried out on a hypothetical cohort of workers with prolonged exposure to physical, all aged 20 at start, who were free of low back pain (LBP) in the previous 12 months, with a follow-up period of 40 years. A Markov chain approach was used with one year increments of time during which a subject may make a transition from one health state to another (Sonnenberg et al 1993). In this analysis, three health states were defined: no LBP, LBP in the past 12 months, and permanent work disability due to low back pain. The latter health state was based on the definition in the legal system of the Netherlands. This health state was considered an absorbing state, i.e. transition to another state from within this state is regarded to be impossible. The transition probabilities were assumed to be constant over time, i.e. the transition from one health state to another health state in a given year is independent from the health status in earlier one year cycles. The transition probabilities and duration of LBP episodes were derived from the analysis presented above. The cohort simulation with the Markov chain approach (a Monte Carlo simulation) was conducted with a simple spreadsheet application. The cohort simulation started with healthy subjects at age 20, who were followed up for a 40 year career in the same job with a constant level of physical load. The total burden of low back disease was calculated during this 40 year working life, expressed by DALY for acute, sub acute, and chronic LBP. For the absorbing state, the permanent disability (WAO), information was used from the annual enrolment into the WAO, approximately 5000 persons in 2009 from a workforce of 7.3 million workers. Given the fact that LBP is an important cause of permanent disability, it was assumed that workers with LBP had a fourfold risk on WAO than workers without LBP. The model calculates for a defined occupational population the development of LBP over time, and expressed the total burden of disease due to LBP in DALY cumulated over a 40-year working career.

5.2 Job descriptions

The health impact assessment of reduction of manual materials handling is conducted for:
- straatmaker/road layer (job code Arbouw 9514);
- timmerman/carpenter (job code Arbouw 9546);
- tegelzetter/tiler (job code Arbouw 9513);
- betonboorder/concrete finisher (job code Arbouw 9521).

Since for scaffolders (steigerbouwers, job code Arbouw 9593) very detailed information is available, the health impact assessment was also conducted for this job title.

5.3 Exposure

5.3.1 Step 1 The exposure profile

Definition of risk factors
The exposure profile consists of the three main risk factors that determine the work-relatedness of low back pain (Lötters et al. 2003). These three risk factors are incorporated in the decision scheme whether low back pain should be registered as an occupational disease (NCVB, 2010). This exposure profile is presented in Table 14.

Table 14 Profile of risk factors in physical load for the occurrence of low back pain.

Risk factor	Definition	Risk (OR)	Code
Manual materials handling	Frequent lifting of 5 kg or lifting > 25 kg more than once a day	1.51	RF1
	Frequent lifting > 15 kg at least 10% of work time	1.91	RF2
Awkward back postures	Frequent bending/twisting of trunk over 20 degrees for > 2 hours per day	1.68	RF3
	Frequent bending/twisting of trunk over 30 degrees for at least 10% work time	1.93	RF4
Whole-body vibration	Magnitude > 0.5 m/s^2 during 8 hr workday	1.39	RF5
	Magnitude > 1.0 m/s^2 during 8 hr workday	1.63	RF6

OR = odds ratio = the ratio of the likelihood (= odds) of an event occurring in one group to the likelihood of it occurring in another group.

This profile has two levels of exposure magnitude for each risk factor and, thus, enables categorization of exposure for each risk factor across all occupations into three levels: no exposure, moderate exposure, and high exposure. Thus, within each risk factor only one risk can be chosen. The exposure assessment in the occupations of interest may be based on direct measurements, observational methods, expert judgement, or self-reports. In general, for manual materials handling self-reports seem to have sufficient validity the assess exposure. For awkward back postures direct measurements or observational methods are required for the valid assessment. Whole-body vibration can be measured directly quite easily and also expert judgement is reliable when using published information on vibration levels in different ve-hicles (Burdorf et al 1999).

Exposure profile in selected occupations
In Table 15 the results of the literature review of studies on physical load among construction workers in the five selected occupations are presented. A literature search in Pubmed and Web of Science on physical load in all occupations in the construction industry identified a limited number of studies on the selected occupations. The studies on the same occupation have used slightly different definitions of manual materials handling and awkward postures and an expert judgement is required to translate the reported exposure profile into the presence of risk factors required for the model.

Table 15 Exposure profile of physical load in selected occupations.

Author	Occupation	Definition	Risk factor
Hartmann et al, 2005	Carpenter	Frequent lifting > 10 kg during 6.7% of work time	RF1
		Bending/twisting of trunk over 30 degrees for at least 10% work time	RF4
	Scaffolder	Frequent lifting > 10 kg during 13.7% of work time	RF2
Dawson et al 1999 Van der Beek et al, 2005	Scaffolder	Frequent lifting > 10 kg during 14% of work time and lifting > 25 kg during 3% work time	RF2
		Bending/twisting of trunk over 45 degrees for at least 8% work time	RF4
Saurin et al 2008	Scaffolder	Frequent bending/twisting of trunk over 20 degrees for > 24% work time Manual materials handling not evaluated separately	RF3
Hsiao et al 1996	Scaffolder	Regularly manual materials handling > 10 kg Bending and twisting not evaluated	RF2
Spielholz et al 1998	Carpenter (concrete formwork)	Frequent bending/twisting of trunk over 20 degrees for > 40% work time Manual materials handling not reported	RF4
Paquet et al 1999 Paquet et al 2005	Carpenter (concrete formwork)	Frequent lifting > 5 kg during the day Frequent bending/twisting of trunk over 20 degrees for > 45% work time	RF1 RF4
Burdorf et al 2007	Road layer	Frequent lifting of 10 kg during 16% of work time and lifting > 25 kg during 4% work time	RF2
		Frequent bending/twisting of trunk over 30 degrees for at least 13% work time	RF4

5.3.2 Step 2 Expected occurrence of low back pain

The expected occurrence of low back pain is a combination of occurrence of low back pain in unexposed populations and the specific exposure profile. The estimated 12-months prevalence of 30% in unexposed workers aged between 35-45 years is based on a meta-analysis of international studies (see Table 16). This figure is currently used in the registration guideline for LBP as occupational disease (Lötters et al 2003). In the general Dutch population (men and women in paid employment as well as outside the workforce) the 12-month prevalence of LBP was estimated around 27% (Picavet et al. 2003). Thus, the estimated occurrence of LBP of 30% in the working population seems a reasonable assumption.

In a large cohort study with three years follow-up among 1192 workers in various companies in the Netherlands the observed incidence of low back pain was 12,6% per year (Hoogendoorn et al. 2002). This study provides a reasonable assumption for the annual incidence of 13% among unexposed populations.
The recurrence of LBP in the unexposed working population is unclear. Few studies have reported on recurrence of LBP, but do not present stratified information according to magnitude of physical load. Based on secondary analysis of own datasets in working populations a conservative estimate for recurrence of low back pain of 65% is used. An important assumption in the HIA-model is that the recurrence of LBP will not be affected by the magnitude of physical load. This assumption will have a modest impact on the overall estimated burden of disease due to LBP, since this burden of disease is more strongly influenced by the incidence than by the recurrence of LBP.

Table 16 Assumptions on incidence, recurrence, and prevalence of low back pain among working populations without any relevant exposure to low back pain.

Assumptions	Estimate	Source
Prevalence of 12 months LBP in unexposed population	30%	Lötters et al 2003
(no LBP to LBP & LBP to LBP)	27%	Picavet et al 2003
Incidence of 12 months LBP in unexposed population (no LBP to LBP)	13%	Hoogendoorn et al 2002
Recurrence of 12 months LBP in unexposed population (LBP to LBP)	65%	This report

Based on the occurrence of LBP in an unexposed population, the presence of a risk factor will increase the likelihood of LBP. The OHIA model for lifting has used the following assumptions:
– The risk of physical load will affect the incidence of LBP, but not the recurrence. Through a change in incidence, the prevalence will change;
– The risk of physical load is expressed as odds ratio and, thus, a logistic linear model is used whereby the estimated incidence of LBP is a linear function of an intercept (β_0) based on the incidence in unexposed workers (expressed by the likelihood p = 0.13) and regression coefficients β_i for each risk factor present. The odds ratio for a risk factor is expressed by $\exp(\beta_i)$. The mathematical formula is:

$$\text{Incidence (likelihood)} = \frac{\exp(-\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3)}{1 + \exp(-\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3)}$$

whereby $\beta_0 = 1.901$, β_1= logOR1 (either OR of RF1 or OR of RF2), β_2= logOR2 (either OR of RF3 or OR of RF4), and β_3 = logOR3 (either OR of RF5 or OR of RF6).

The expected occurrence of LBP, defined by the classical epidemiological measures prevalence, incidence, and recurrence, can be expressed in related transitional probabilities:
– prevalence: the proportion of workers with LBP in the past 12 months (combination of transition from no LBP to LBP and from LBP to LBP);
– incidence: the proportion of workers with LBP in the past 12 months among those workers without LBP the previous year (transition from no LBP to LBP);
– recurrence: the proportion of workers with LBP in the past 12 months among those workers with LBP in the previous year (transition from LBP to LBP).

Please note that estimates of prevalence, incidence, and recurrence do not provide sufficient information to calculate the transition probabilities, which requires additional information on number of subjects involved in incidence and in recurrence.

Table 17 presents the transitional probabilities for the unexposed group and an occupational group exposed to two risk factors: frequent lifting > 15 kg at least 10% of the work time, and frequent bending and twisting of the trunk over 30 degrees for at least 10% of the work time (i.e. scaffolders). In the unexposed group the incidence of 12 months LBP was estimated as 13%, which implies of transitional probability of 0.13 (see Table 16). In the exposed group with two risk factors the formula presented above is applied to calculate the expected incidence of 12 months LBP, which results in a transitional probability of 0.21. Based on the incidence of LBP, in both occupational groups the prevalence was estimated and subsequently the recurrence of LBP. The estimated annual transitional probabilities will be used in the HIA-model to simulate the effects on DALY due to LBP during a working life of 40 years.

Table 17 Estimates of the annual transitional probabilities for low back pain.

	Annual probability	
	Unexposed	**Scaffolders**
no LBP to no LBP	0.87	0.79
no LBP to LBP	0.13	0.21
LBP to no LBP	0.35	0.35
LBP to LBP	0.65	0.65

5.3.3 Step 3 Disability-adjusted life years due to low back pain

The assessment of the disability-adjusted life years due to low back pain consists of three parts: (1) appreciation of LBP with respect to DALY, (2) distribution of duration of episodes of LBP, and (3) the application of the model in a cohort of construction workers with a particular exposure to physical load.

Appreciation of low back pain with respect to DALY
In a Dutch study the occurrence of low back pain (LBP) has been allocated a weighing factor of 0.06 (Gommer et al, 2010), equalling a DALY of 0.06 for each year with daily presence of low back pain. Since low back pain is not regarded as a relevant cause of deaths, this DALY estimation only covers morbidity due to LBP. There is no distinction in DALY as to the severity of low back pain, characterised by specific diagnosis (hernia nuclei pulposi, radicular syndrome), pain severity, or level of functional limitations. In Dutch guidelines for general practitioners and occupational physicians LBP is often divided into acute (less than 6 weeks), sub acute (6 weeks to 3 months), and chronic low back pain (3 months and more). This distinction is only relevant for DALY attribution with respect to the duration of the presence of complaints. For each day of LBP in a given year the corresponding DALY is 0.06/365 = 0.00016.

Distribution of duration of episodes of LBP
In order to determine the distribution of duration of LBP and distinguish acute episodes from chronic episodes a secondary data analysis was conducted on a three-year follow-up study among Dutch scaffolders (Elders et al 2004). The available information on duration on LBP in the past 12 months consisted of 5 categories (see Table 18). All questionnaires collected

throughout the study were used to estimate the overall distribution among scaffolders and supervisors separately. The available cohort was too small to analyse whether over the years the shift towards more chronic low back pain occurred faster among scaffolders than supervisors. Thus, in the current model the overall distribution of duration of LBP remains constant over the years.

Table 18 Distribution of duration of episodes of low back pain.

		Distribution of total days of LBP in a given year				
	Number of episodes	1-7 days	8-28 days	29-42 days	43-90 days	91-365 days
Scaffolders (n=222)	304	17%	27%	13%	18%	25%
Supervisors (n=66)	99	24%	28%	16%	10%	22%

Based on this information the occurrence of LBP was divided into acute, sub acute, and chronic LBP with an average duration of each episode in days. This distributional information can be converted into DALY in order to estimate the burden of disease (see Table 19).

Table 19 Duration of episodes of low back pain and associated DALY.

	Mean number of days	**DALY allocation**	**Distribution across job title**	
LBP episodes			Scaffolder	Supervisor
Acute LBP	17.0	0.003	57%	68%
Sub acute LBP	66.5	0.011	18%	10%
Chronic LBP	365	0.06	25%	22%

Given the rather small differences in the duration distribution between scaffolders and supervisors the health impact assessment model will assume an equal distribution of duration of episodes across all occupations.

Application of the model in a cohort of construction workers
In the unexposed population the incidence of LBP is 13% each year. During a 40 year period in a cohort of 10,000 workers this will result in a total burden of disease due to LBP of 1864 DALY, which equates to 0.48 DALY per 100 person years. Among 10,000 scaffolders, as example of a group with two risk factors (high manual materials handling, high frequent bending & twisting of the trunk) the total burden of disease due to LBP will amount to 2820 DALY, which is about 0.73 DALY per 100 person years. Hence, the high exposure to physical load will result in an additional burden of disease due to LBP of 956 DALY in the total cohort, which is 0.25 DALY per 100 person years (see Figure 13).
In this estimation no additional DALY are attributed to sickness absence and permanent disability. In this model permanent disability among construction workers is very low, currently estimated at 0.0028 per worker per year. It is expected that chronic LBP will also increase unemployment (when loss in earnings capacity is too low to qualify for permanent disability payment). A slight adjustment of the likelihood of becoming permanently disabled due to LBP will substantially influence the estimated DALY.

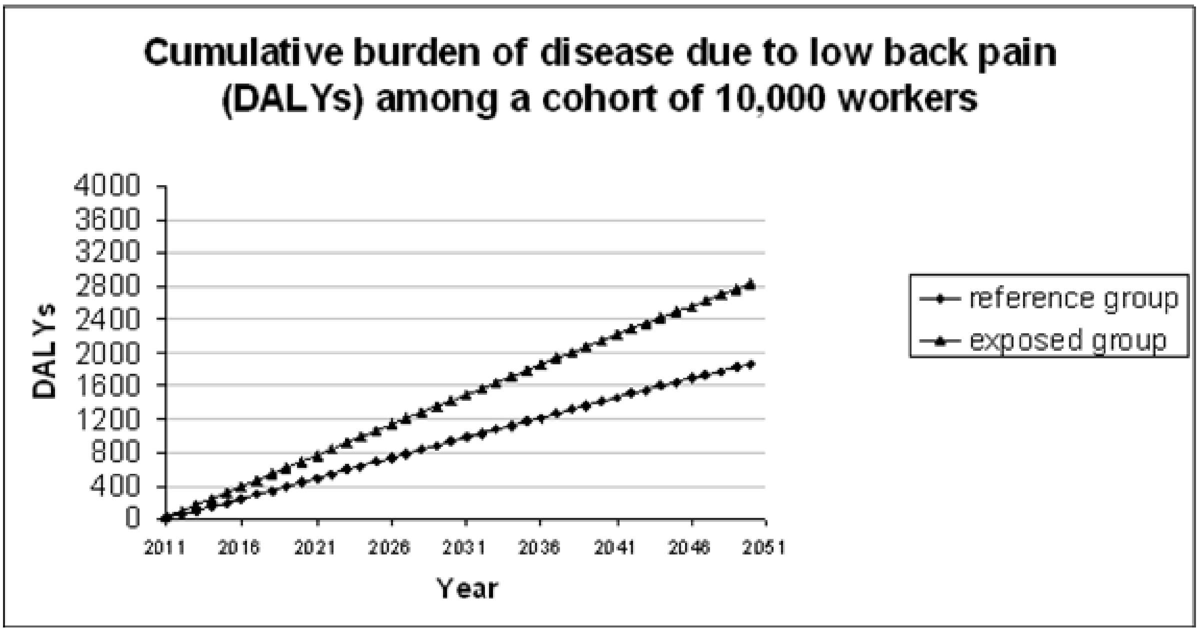

Figure 13 Estimated DALY in an occupational group with high exposure to manual materials handling and frequent bending and twisting of the trunk (exposed group) relative to an unexposed group (reference group).

For three occupations the information to assess their exposure profile was available and the estimated burden of disease varied from 0.71 to 0.75 DALY per 100 person years (see Table 20).

Table 20 Estimated burden of disease due to low back pain in selected occupations.

Occupation	Risk factors present	DALY per 100 person years
Carpenter	RF1 and RF4	0.70
Road layer	RF2 and RF4	0.73
Scaffolder	RF2 and RF4	0.73
Unexposed workers	none	0.48

5.3.4 Step 4 Effect of the intervention on the exposure profile

For specific occupations detailed information is available on the effects of several ergonomic interventions on reduction in manual materials handling, awkward postures, or whole-body vibration.
The effects of seat suspension, smoothness of terrain, and driving speed on reduction in magnitude of whole-body vibration for a large number of vehicles and equipment are well-established in the scientific literature (Burdorf et al 1993). Hence, the potential effects on burden of disease of these control measures can be assessed with sufficient certainty.
The influence of ergonomic interventions on manual materials handling or awkward postures is described for a limited number of occupations. For the selected occupations only information is available for road layers and scaffolders (see Table 21). For road layers the exposure profile changed for manual materials handling from high exposure to moderate exposure, but for awkward postures the high exposure remained unchanged. For scaffolders the exposure

profile reduced manual materials handling from high to moderate exposure and for awkward postures from high to no exposure.

Table 21 Influence of ergonomic interventions on manual materials handling, awkward postures, and whole-body vibration in the construction industry.

Author	Occupation	Estimated effect on exposure
Vink et al 1997	Scaffolders	Reduction in % work time while manually handling materials > 20 kg from 52% to 6% (roughly 90% reduction): RF2 reduces to RF1 Less time spent with bended or twisted trunk: RF4 is eliminated
Burdorf et al 2007	Road layers	Reduction in frequency of lifting load above 15 kg above 80%: RF2 reduces to RF1. More time spent with bended or twisted trunk: RF4 remains present

5.3.5 Step 5 Expected occurrence of low back pain after intervention

The expected occurrence of low back pain after the implementation of the ergonomic intervention is again a combination of occurrence of low back pain in unexposed populations and the specific exposure profile with a reduced exposure. In the OHIA model for lifting the presence of risk factors of physical load is adjusted and, subsequently, the new incidence, prevalence, and recurrence of low back pain is estimated.

5.3.6 Step 6 Disability-adjusted life years due to low back pain after the intervention

Table 22 presents the disability-adjusted life years before and after the intervention. The difference is a determined by the change in exposure profile. For road layers exposure to manual materials handling is reduced and the associated gain in DALY is 0.04 DALY per 100 person years, which is a 5% reduction in burden of disease due to low back pain. For scaffolders exposure to manual materials handling and awkward postures is reduced, resulting in a gain of 0.14 DALY per 100 person years, which is a 23% reduction in burden of disease due to low back pain.

Table 22 Estimated burden of disease due to low back pain in selected occupations before and after the intervention.

Occupation	DALY per 100 person years before the intervention	DALY per 100 person years after the intervention
Carpenter	0.70	Not applicable
Road layer	0.73	0.69
Scaffolder	0.73	0.59
Unexposed workers	0.48	0.48

5.4 Considerations for the general OHIA-model in the occupational population

Available information on exposure to physical load

The information on exposure to physical load will not be available across all possible jobs in the workforce, since for most jobs reports or publications are lacking. This is largely explained by the lack of measurement devices that can capture all relevant exposure information, the lack of a generally accepted definition of exposure with common metrics, and the large effort required to measure physical load in a job.

For the construction industry self-reported exposure to physical load is available, but the translation of this information into the relevant risk factors for the exposure profile is not straightforward. A possible avenue would be to develop a job-exposure matrix across all relevant jobs in the construction industry, based on the prevalence of self-reported risk factors and calibration of the distribution of prevalence of risk factors with objective exposure assessments in specific jobs. A similar approach could be adopted for relevant jobs outside the construction industry.

Available information on effects of ergonomic interventions

In general, information on the effects of ergonomic intervention on physical load is sparse. The effects of seat suspension, smoothness of terrain, and driving speed on whole-body vibration are well-established and, thus, the reduction in burden of disease due to low back pain can be assessed with sufficient certainty. However, the literature search for ergonomic interventions in the construction industry demonstrated that a quantitative description of interventions on manual materials handling or awkward postures is lacking for most potential interventions and jobs. Existing databases on control measures, such as Solbase, do not contain sufficiently detailed information to allow the use of the OHIA-model.

Existing cohort versus new cohort

The calculations were performed for a new cohort of construction workers starting at the age of 20 years in a particular occupation and continuing until the age of 60 years. It is possible to adopt the model to the age distribution of the current workforce, but specific assumptions are required to make this a meaningful exercise:

– is the working career of a worker before his current age considered as a non-exposed situation?

In construction industry many occupations will have some exposure to physical load, hence, this seems not a realistic assumption.

– is working experience in the given job a better source of information than age of the worker?

The history of workers in strenuous jobs could be included in the HIA-model, but this requires additional information that may not be easily available in companies.

– what is the starting time for estimating the burden of disease?

In an existing cohort, workers have already an exposure history that may have an impact on their future morbidity (and mortality for other diseases than low back pain). Should this be taken into account?

In the current model the high incidence of low back pain ensures that in a relatively short period of 5 years the occurrence of low back pain reaches an equilibrium. This implies that from thereon each additional year of exposure will contribute a constant burden of disease. For an existing cohort whereby the average duration of exposure was approximately 20 years, the total burden of disease of an existing cohort will be approximately 50% of the burden of disease of a new cohort.

Sensitivity of the HIA-model

The HIA-model does not incorporate additional DALY attributed to sickness absence and permanent disability. In the HIA-model sickness absence is not included at all. Permanent disability is included as absorbing state and only the year in which permanent disability is granted, contributes to the estimated DALY (scenario baseline). Thus, the duration of permanent disability due to LBP after entering the disability pension scheme is not included in the estimated DALY, which reflects the burden of disease among those workers who will remain in the workforce. When assuming that workers who have entered permanent disability due to low back pain will remain disabled for their entire working career due to low back pain, the total DALY will increase sharply (scenario peak). This scenario reflects the burden of disease among persons who have started in paid employment and who are still employed or without paid employment. Table 23 presents both scenarios, demonstrating the profound influence of the choice of valuation of permanent disability.

Table 23 Sensitivity of the HIA-model for assumptions about remaining permanently disabled due to low back pain.

Occupation	DALY per 100 person years among a cohort of workers who started in their job aged 20		DALY per 100 person years among persons who started in their job aged 20, including both those workers remaining in the job and those becoming permanently disabled	
Carpenter	0.70	(2,676 DALY)	2.43	(9,293 DALY)
Road layer	0.73	(2,820 DALY)	2.56	(9,789 DALY)
Scaffolder	0.73	(2,820 DALY)	2.56	(9,789 DALY)
Unexposed workers	0.48	(1,864 DALY)	1.69	(6,480 DALY)

6 Comparison of the results

We calculated the occupational burden of disease for different combinations of agents and diseases, namely lung cancer and silicosis due to silica exposure, lower back pain due to lifting and death and injury due to incidents. The results of the calculations are summarized in Table 24 for a cohort of age 20 (10,000 employees) and after correction for the actual number of workers per job, using the work force as given in Table 3.

Table 24 Occupational burden of disease (DALY) for different job titles, cohorts and agents/diseases.

	Cohort age 20[a]	Actual workforce
Concrete drillers/sawyers	**109,000**	**21,000**
Exposure to silica		*98%*
– Silicosis	99,000	
– Lung cancer	8,300	
Lifting		-
– Lower Back Pain	Not available	
Incidents		*2%*
– Deaths	0	
– Injury	2000	
Road pavers	**81,000**	**35,000**
Exposure to silica		*98%*
– Silicosis	72,000	
– Lung cancer	8300	
Lifting		*1%*
– Lower Back Pain	956	
Incidents		*1%*
– Deaths	530	
– Injury	180	
Tilers	**39,000**	**13,000**
Exposure to silica		98%
– Silicosis	32,000	
– Lung cancer	6,400	
Lifting		-
– Lower Back Pain	Not available	
Incidents		*2%*
– Deaths	700	
– Injury	14	
Carpenters	**3500**	**28,000**
Exposure to silica		*41%*
– Silicosis	980	
– Lung cancer	430	
Lifting		*23%*
– Lower Back Pain	810	
Incidents		*36%*
– Deaths	423	
– Injury	821	

[a] The occupational burden of disease is calculated as the difference between the exposed employee and the unexposed employee.

The results show that the occupational burden of disease per employee is highest for the concrete drillers/sawyers, followed by road pavers, tilers and carpenters. However, corrected for the actual number of employees, the highest occupational burden of disease is found for the group of road pavers, followed by carpenters, concrete drillers/sawyers and tilers.

The exposure to silica gives by far the largest contribution to the occupational burden of disease for road pavers, concrete drillers and tilers. For carpenters, exposure to silica is much less and lifting and incidents become equally important.

7 Discussion

An Occupational Health Impact Assessment (OHIA) model is developed to evaluate the impact of both incidents and exposure to substances and physical load. For the feasibility study, a limited number of agents, diseases and job titles in the construction industry were selected, based on the importance for the total occupational burden of disease and the availability of data. The study demonstrated that it is possible to evaluate different exposures and diseases in one model:

– *Integrated health impact assessment using existing data*
The study demonstrated that it is possible to integrate different jobs, exposures and diseases into one model. The integrated model allows to calculate the combined occupational burden of disease, as demonstrated in Table 24. In this calculation, existing data are used, namely detailed population and exposure data on the level of job titles. The project is the first demonstration of such an integrated model.

– *Comparison of different exposures/diseases on a job level is possible*
It is possible to combine different exposures for single job titles in one health impact measure, the DALY, and to determine the relative contribution of different exposures and diseases per job title. This allows the evaluation of the most important exposures both on the level of a sector as well as on the level of an 'average' employee. Furthermore, within the sector the relative contribution of different job titles and different exposures can be determined.

– *Priority setting and interventions*
The relative contribution of different exposures and diseases in the integrated health impact assessment allows setting the right priorities for interventions. Furthermore, it is demonstrated that the model is useful for calculating the effect of an intervention for an exposure. The interventions chosen in this feasibility study are very specific to one exposure, and there is no combined effect calculated. For instance, the intervention 'wet suppression' reduces the exposure to silica, but will not influence the probability or effect of either incidents or lower back pain. The model, however, makes it possible to calculate the effect of interventions on all exposures.

– *Perspective to real model*
The feasibility study demonstrated the possibilities of an integrated OHIA model and identified the gaps and limitations. This gives the opportunity to determine the necessary steps to come to a realistic integrated model.

The study identified also a number of discussion points, gaps, limitations and improvement:

– *The use of cohorts*
In the study, two different cohorts were used, namely a fixed cohort of employees at age 20 just starting employment ('cohort age 20') and a fixed cohort of employees with a mean age of 42 (standard deviation 7.8) who had all worked in the construction industry since age 20 ('normal cohort'). The differences between the two cohorts depend on the type of exposure and type of effect. For exposure to silica, interventions appear much more effective in cohort age 20 than in the normal cohort. This effect is the most significant for the development of lung cancer. The explanation is that the employees in the normal cohort have already been exposed to a significant dose before intervention, and the effect of a reduction of the remainder dose is small (see the dose-response relationship, Figure 1). Employees in the

cohort age 20 have not been exposed before intervention, and thus an intervention is more successful. For low back pain and incidents, the effect is not determined by the cumulative dose over the years, and interventions appear equally successful in both cohorts.
Both cohorts do not represent the actual workforce and its development in time. For a realistic estimate of the occupational burden of disease, population dynamics needs to be modelled, e.g. the in- and outflow of employees due to job changes and including their history of exposure. However, since these data are not available, modelling of a dynamic cohort is not possible. Various alternative cohorts are also possible, describing the workforce more or less realistically. For example, one can start with a cohort with a normal distribution and keep the number of employees fixed by replacing the persons leaving the cohort due to illness or retirement by new employees of age 20. In this way, a more realistic workforce is modelled, but the in- and outflow due to job changes is still missing. For simplicity, it is therefore recommended to use a fixed cohort.
For exposure to harmful substances, the exposure before intervention may be dominant in the burden of disease. The use of a fixed cohort with a normal distribution may then underestimate the effect of an intervention. It is therefore recommended to compare the effect of interventions using the fixed cohort of age 20. In this way, the long-term benefit of the intervention is more pronounced. This approach is also in line with the use of occupational health limits for the protection of employees: the concentration limits for harmful substances are derived on the basis that a continued exposure of an employee during the whole active life should not lead to any negative health effects.

– *Variability in exposure*
In the calculations, use is made of data on average exposure. In reality, exposure differs per employee and the use of an exposure distribution is more realistic.

– *Simplified modelling*
In the modelling of the exposure and disease, simplifications were made. For example, we did not model a lag time or the different disease stages for lung cancer and silicosis, absence and/or recovery from disease or confounding or interaction effects. In the next phase, it is recommended to do a sensitivity analysis to determine the most important factors in the OHIA model and to give guidance to further improvements.

– *Job titles*
The Arbouw code was used to classify the jobs. It should be noted that one Arbouw code covers a large variety of jobs and therefore large variety of exposure. For example, the job title 'road paver' may include working with asphalt, concrete or cobble stones, having very different types of exposure. In the next phase, the Arbouw codes and alternatives need to be studied in order to have job descriptions that match the exposure data.

– *Missing data*
Not for all job titles exposure data are available. For example, data on lower back pain due to lifting was not available for tilers and concrete drillers/sawyers. Also data on the effect of interventions were missing and rough estimates had to be made.

– *Fraction of the occupational burden of disease*
The study covered four job titles and three types of exposure. To have an indication of the total burden of disease for the construction sector covered in the study, the following rough estimation is made:

o The number of employees in the four job titles having a periodic medical examination is equal to 13721, whereas the total number of employees having a periodic medical examination is equal to 36741 (see Section 2.3). This means that we cover about 37% of the number of employees in the construction industry.

o The contribution of diseases to the total occupational burden in the Netherlands is estimated to be 6.6% for accidents, 10% for lung cancer and 5.5% for lower back pain complaints (Eysink et al, 2007). Assuming that exposure to silica is the most important cause for lung cancer, and assuming that the relative contribution of diseases in the construction industry is similar to the relative contribution in the total Dutch workforce, we would cover about 20% of the diseases in the total burden of disease. However, we may expect that ex-posure to silica is more important in the job titles selected than in the average Dutch workforce. This is also shown in the OHIA model, where the burden of disease to silica exposure is dominant compared to accidents and lower back pain. It should however be noted that the largest burden of disease due to the exposure of silica is caused by silicosis instead of lung cancer.

The study is therefore expected to cover an important part of the construction industry, but is far from complete. It is therefore recommended for the next phase to have a better assessment of the dominant exposures and diseases in the construction industry and extend the study to all employees in the construction industry and the most important agents.

– *The use of DALY as measure*

The study used the DALY as measure to compare the different exposures and diseases. The use of DALY means that we compare the health effects over the entire life of an employee, including after retirement. Alternative measures are possible, focussing on the loss of productivity of employees, e.g. the health-related loss of working years (DAWY, Disease-adjusted Working Years, Eysink et al, 2010) or days of absence of work.

8 Conclusions and recommendations

A comparison of the scope of the OHIA model, as described in Section 1.2, and the results of the feasibility study demonstrates that:

– The OHIA model calculates the occupational burden of disease for a selection of important agents, diseases and occupational groups within one sector, and can be extended to other agents, diseases, jobs and sectors.

– The OHIA model allows the comparison of the occupational burden of disease for a selection of important agents and diseases on the level of agent and disease and can be extended to other agents, diseases, jobs and sectors.

– The OHIA model allows the comparison between the risk of incidents and the impact of chronic exposure.

– The OHIA model facilitates to determine an effective impact reduction strategy per sector.

We therefore conclude that it is possible to construct an integrated health impact assessment model that allows setting the right priorities for interventions and is useful for calculating the effect of an intervention for an exposure.

To build a complete integrated health impact assessment model, we recommend for the next phase of the project:

– To limit the research in the next phase to one industry sector. Based on the availability of data, the construction industry is preferred.

– To extend the model to all job titles in the construction industry, allowing a complete description of one sector.

– To consider other end-points than the DALY for the comparison of the occupational burden of disease.

– To extend the model to the most important agents and diseases in the construction sector.

– To involve the stakeholders in the construction industry. In this way, the practical applicability of the model and its use in reducing health impacts is better ensured.

– To do an uncertainty and sensitivity analysis of the existing model. The results of this analysis will provide insight in the uncertainties of the results, and hence the practicability. Furthermore, it will focus the research into the areas where it is most effective. The study showed a number of gaps, limitations and improvements, like dynamic modelling and the use of exposure distributions. It is recommended to reconsider these flaws again after the uncertainty and sensitivity analysis, in order to determine the most important ones for further research.

– To use a fixed cohort, age 20, for the comparison of health impacts and the effect of interventions.
– To make a mock-up of the final model. In the construction of the mock-up, all decisions should be made and recorded, e.g. on the level of input data needed, how to deal with missing data, the end results of the OHIA model, etc. This mock-up will therefore much clearer present the usefulness of the final model and will guide the development of the model. Furthermore, the mock-up will facilitate the discussions with stakeholders.

References

Aneziris O, Baedts E de, Baksteen J, Bellamy LJ, Bloemhoff A, Damen M, Eijk V van, Kuiper JI, Leidelmeijer K, Mud M, Mulder S, Oh JIH, Papazoglou IA, Post JG, Sol VM, Uijt de Haag PAM, Whitehouse MA, 2008. The quantification of occupational risk. The development of a risk assessment model and software. RIVM report 620801001.

Armstrong BG, Darnton A. Estimating Reduction in Occupational Disease Burden Following Reduction in Exposure. Occup Environ Med. 2007.

Baars AJ, Pelgrom SMGJ, Hoeymans FHGM, Raaij MTM van. Health effects and burden of disease due to exposure to chemicals at the workplace - an exploratory study, 2005. RIVM report 320100001 (in Dutch).

Beek AJ van der, Mathiassen SE, Windhorst J, Burdorf A. Strategies to assess physical demands of manual lifting in scaffolding. Appl Ergonomics 2005;36:213-22.

Bellamy LJ, Damen, M. Risico horoscoop, Voorspelling aantallen ongevallen voor sectoren en beroepen, Report for SZW, 2008.

Brouwer DH, Huijbers RF, Lurvink MWM. Stofreductie door vernevelingstechnieken tijdens sloop- en grondverdichtingswerkzaamheden. TNO rapport. 2001; V2892.

Burdorf A, Swuste P. The effect of seat suspension on exposure to whole-body vibration of professional drivers. Ann Occup Hyg 1993; 37: 45-55.

Burdorf A, Beek A van der Beek. Exposure assessment strategies for work-related risk factors for musculoskeletal disorders. Scand J Work Environ Health 1999; 25 (suppl4): 25-30.

Burdorf A, Windhorst J, Van der Beek A, Van der Molen H, Swuste P. The effects of ergonomic interventions on physical load among road workers and floor layers in the construction industry. Int J Ind Ergon 2007; 37: 133-43.

Chen W, Zhuang Z, Attfield MD, Chen BT, Gao P, Harrison JC, Fu C, Chen JQ, Wallace WE. Exposure to silica and silicosis among tin miners in China: exposure-response analyses and risk assessment. Occup Environ Med. 2001; 58: 31-37.

Chen W, Hnizdo E, Chen JQ, Attfield MD, Gao P, Hearl F, Lu J, Wallace WE. Risk of silicosis in cohorts of Chinese tin and tungsten miners, and pottery workers (I): an epidemiological study. Am J Ind Med. 2005; 48: 1-9.

Chrisholm J. Respirable dust and respirable silica concentrations from construction activities. Indoor Built Environ. 1999; 8:94-106.

Dawson M, Klep P, Beek A van der, Burdorf A, Elders L. Belastende taken, activiteiten en werkhoudingen in de steigerbouw: een werkplekonderzoek. T Ergonom 1999; 24: 134-9.

Dekkers S, Preller EA, Baars AJ, Marquart J, Raaij MTM van. Identification of important occupations and chemicals in the development of diseases and the burden of diseases due to exposure at the workplace RIVM report 320506002; TNO report V7148, 2006 (in Dutch).

Elders LAM, Burdorf A. Prevalence, incidence, and recurrence of low back pain in scaffolders during a 3-year follow-up study. Spine 2004; 29: e101-6.

Eysink PED, Blatter BM, Gool CH van, Gommer AM, Bossche SNJ van den, Hoeymans N, 2007. Occupational burden of disease in the Netherlands. RIVM report 270012001 (in Dutch).

Eysink PED, Hamberg-van Reenen HH, van Gool CH, Hoeymans N, Burdorf A, 2010. Meten van verloren arbeidsjaren door ziekte: Disease-Adjusted Working Years (DAWY). Verkenning van een nieuwe maat. RIVM report 270244001, 2010 (in Dutch).

Fransman W, Schinkel J, Meijster T, VAN HJ, Tielemans E, Goede H. Development and evaluation of an exposure control efficacy library (ECEL). Ann Occup Hyg. 2008; 52 (7): 567-575.

Gommer AM, Poos MJJC, Hoeymans N. Verloren levensjaren, ziekte en ziektelast voor 56 geselecteerde aandoeningen In: Volksgezondheid Toekomst Verkenning, Nationaal Kompas Volksgezondheid. Bilthoven: RIVM, <http://www.nationaalkompas.nl> Nationaal Kompas Volksgezondheid\ Ziekte, kwaliteit van leven en sterfte\ Sterfte, levensverwachting en DALY's\ Ziektelast in DALY's, 22 maart 2010.

Hartmann B, Fleischer AG. Physical load exposure at construction sites. Scand J Work Environ Health 2005; 31(suppl 2): 88-95.

Hnizdo E, Sluis-Cremer GK. Risk of silicosis in a cohort of white South African gold miners. Am J Ind Med. 1993; 24: 447-57.

Hoogendoorn WE, Bongers PM, Vet HC de, Twisk JW, Mechelen W van, Bouter LM. Comparison of two different approaches for the analysis of data from a prospective cohort study: an application to work related risk factors for low back pain. Occup Environ Med 2002; 59: 459-65.

Hsiao H, Stanevich RL. Biomechanical evaluation of scaffolding tasks. Int J Ind Ergonom 1996; 18: 407-15.

Kreiss K, Zhen B. Risk of silicosis in a Colorado mining community. Am J Ind Med 1996; 30: 529-39.

Lacasse Y, Martin S, Gagne D, Lakhal L. Dose-response meta-analysis of silica and lung cancer. Cancer Causes Control. 2009;20(6):925-933.

Lakhal L, Lacasse Y. Reply to: Dr. Peter Morfeld's Letter to the Editor (Manuscript Number: CACO2009): 'Comment on Lacasse Y, Martin S, Gagne D, Lakhal L (2009). Dose-response meta-analysis of silica and lung cancer. Cancer Causes and Control; [e-pub ahead of print] doi: 10.1007/s10552-009-9296-0'. Cancer Causes Control. 2009.

Lötters F, Burdorf A, Kuiper J, Miedema H. A model for the work-relatedness of low back pain. Scand J Work Environ Health 2003; 29: 431-40.

't Mannetje A, Steenland K, Attfield M, Boffetta P, Checkoway H, DeKlerk N, Koskela RS. Exposure-response analysis and risk assessment for silica and silicosis mortality in a pooled analysis of six cohorts. Occup Environ Med. 2002; 59: 723-728.

Miller, BG, Hurley, JF. Comparing estimated risks for air pollution with risks for other health effects, Institute of Occupational Medicine Research Report TM/06/01, Edinburgh, 2006

Mets O, Rooyackers J, de Jong PA, Mali WPThM, Amelsvoort - van de Vorst S van, Prokop M. Increased numbers of micronodules are more common in occupational silica-dust exposed heavy smokers than in control heavy smokers. Submitted, 2010.

Meijer E, Tjoe Nij E, Kraus T, Zee JS van der, van Delden O, Leeuwen M van, Lammers J-W, Heederik D. Pneumoconiosis and emphysema in construction workers: results of hrct and lung function findings. Submitted, 2010.

NCVB (Nederlands Centrum voor Beroepsziekten). Registratierichtlijn aspecifieke lage rugklachten D004. Amsterdam, accessed 2010.

Onos, T, Spee, T. Samenvattend rapport stofbelasting in de afbouwsector. 2004. ARBOUW.

Paquet V, Punnett L, Buchholz B. An evaluation of manual materials handling in highway construction work. Int J Ind Ergonom 1999; 24: 431-44.

Paquet V, Punnett L, Woskie S, Buchholz B. Reliable exposure assessment strategies for physical ergonomics stressors in construction and other non-routinized work. Ergonom 2005; 48: 1200-19.

Picavet HS, Schouten JS. Musculoskeletal pain in the Netherlands: prevalences, consequences and risk groups, the DMC(3)-study. Pain 2003; 102: 167-78.

Rijswijk CM van. Het arbeidsbestand in de bouw in 2006. Economisch Instituut voor de Bouwnijverheid, 2008.

Saurin TA, Macedo Guimaraes LB de. Ergonomic assessment of suspended scaffolds. Int J Ind Ergonom 2008; 38: 238-46.

Sonnenberg FA, Beck R. Markov models in medical decision making: a practical guide. Medical Decision Making 1993; 13: 322-38.

Spee, T, West, J, Zanen, N van. Validatie stoffenmanager bouwnijverheid. 2010. ARBOUW.

Spielholz P, Wiker SF, Silverstein B. An ergonomic characterization of work in concrete form construction. Am Ind Hyg Assoc J 1998; 59: 629-35.

Steenland K, Brown D. Silicosis among gold miners: exposure-response analyses and risk assessment. Am J Public Health 1995; 85: 1372-7.

Thorpe A, Ritchie AS, Gibson MJ, Brown RC. Measurements of the effectiveness of dust control on cut-off saws used in the construction industry. Ann Occup Hyg. 1999; 43(7): 443-456.

Tjoe NE, Burdorf A, Parker J, Attfield M, van DC, Heederik D. Radiographic abnormalities among construction workers exposed to quartz containing dust. Occup Environ Med. 2003a; 60(6): 410-417.

Tjoe Nij E, Burdorf A, Parker J, Heederik D. Radiographic abnormalities among construction workers exposed to quartz containing dust. Occup Environ Med. 2003; 60: 410–417.

Tjoe Nij E, Hilhorst S, Spee T et al. Dust control measures in the construction industry. Ann Occup Hyg. 2003b; 47(3): 211-218.

Tjoe NE, Hohr D, Borm P et al. Variability in quartz exposure in the construction industry: implications for assessing exposure-response relations. *J Occup Environ Hyg.* 2004; 1(3): 191-198.

Vink P, Urlings IJM, Molen HF van der. A participatory ergonomics approach to redesign work of scaffolders. Safety Science 1997; 26: 75-85.

Appendix A – Selection of agents for pilot study

The selection of agents and diseases for the pilot study is based on their relative importance for the occupational burden of disease and the availability of data and models.

The Centre for Substances and Integrated Risk Assessment (SIR) of RIVM carried out a survey to determine the most important combinations of harmful substances, diseases and sectors for the occupational burden of disease (Baars et al., 2005, Dekkers et al., 2006). The Centre for Public Health Forecasting (VTV) of RIVM carried out a broader survey into the occupational burden of unfavourable working conditions in the Netherlands (Eysink et al., 2007). This survey also included e.g. workload and physical stress.

A workshop was held on 2 March 2009 to determine the availability of models and data and to prioritize the agents, diseases and sectors for inclusion in the OHIA model. Participants in the workshop were B.J. Baars (RIVM, SIR), H. Baksteen (Rondas), L. Bellamy (White Queen), A. Burdorf (Erasmus MC), R. Houba (NKAL), H. Kromhout (Universiteit Utrecht, IRAS), M. Ruijten (Crisistox), E. Tielemans (TNO, Kwaliteit van leven) and P. Uijt de Haag (RIVM, CEV). Prior to the workshop, an overview of data and models was made.

Based on the surveys into the occupational burden of disease and the discussions at the workshop, an overview of work-related diseases, agents, relevant sectors, relative importance and the availability of data and models was compiled. The results are shown in Table 25. For the pilot study, one sector was selected, namely the construction sector, with different agent-disease combinations.

Table 25 Number of employees per job in the construction industry and correction factor cohort**.**

Disease	**Agents**	**Sectors**	**Importance**[1]	**Availability data, models**	**Pilot**	**Motivation**
Burnout			++++	–	No	Difficult to diagnose, data and models hardly available.
CANS			+++	–	No	Difficult to diagnose, data and models hardly available.
Accidents			++	++	Yes	Accidents are included in the ORCA model and relevant for the integrated OHIA model.
Lung cancer and mesothelioma	Passive smoking, welding fumes, PAHs, Asbestos, Silica,	Construction work, manufacturers, railways, hotel- and catering industry,	+++	+	Yes	Data and models are available for various sectors/agents. As example, lung cancer related to silica exposure is selected

[1] The relative importance is defined as the average of the occupational burden of the total work force and the active work force, classified as ++++ (15-20%), +++ (10-15%), ++ (5-10%) or + (1-5%).

Disease	Agents	Sectors	Import-ance[1]	Availability data, models	Pilot	Motivation
	Diesel, Bitumen, Rubber, Chrome/Nickel	Metal industry				
Lower back pain	Lifting	Health care, construction, garbage collectors	++	+	Yes	Data and models are available for various sectors/agents.
PTSS			++	–	No	Data and models hardly available.
Contact dermatitis	Wet work, Grease removers, Soaps and detergents	Cleaners, hairdressers, health care, laboratory workers, food production many large occupational groups	++	±	No	Availability of data and models is limited.
COPD and silicosis and asthma	Asbest, Silica, Diesel, Bitumen, Rubber, Passive smoking, Chrome/ Nickel, Corrosive substances, Silica, allergenes	construction industry, chicken and pig farms, grain and cotton production, bakers and other workers in the food production; welding fumes and grain, flour and wood dust occur in many large occupational groups	+++	+	Yes	Data and models are available for various sectors/agents. As example, silicosis related to silica exposure is selected.
Knee and hip artrose			++	–	No	Data and models hardly available.
Hearing impairment	Noise		+	+?	No	Less relevant for an OHIA model since measures are straightforward.

Disease	Agents	Sectors	Import-ance[1]	Availability data, models	Pilot	Motivation
Cardiovascular disorders due to substances			++	?	No	Availability data and models unclear.
Rhinitis and sinu-sitis due to substances	Irritating substances, allergenes		+	?	No	Availability data and models unclear.
Skin cancer (excluding UV radiation outside work)	UV, oil- and coalproducts, arsene		–	?	No	Importance low.
Toxic inhalation injury	Metal vapour, organic dust, PTFE		–	?	No	Availability data and models unclear, importance low.
Chronic toxic Encephalopathy	Solvents, pesticides, heavy metals		–	?	No	Availability data and models unclear, importance low.
Reproductive disorders	Pesticides Solvents Cytostatica Physical stress (working at night)		?	+	No	Data are available for some sectors. Importance not known. Interesting research subject, but not for the feasibility study.

Appendix B – Background mortality rates

The mortality rates used in this project for the calculation of survival probability and life expectancy is given in Table B1. Calculation of survival probabilities is explained in (Miller, 2006).

Age [year]	All cause mortality [-]	Survival prob. [-]	Cum surv. prob. [-]	Life Expect. [year]	Age [year]	All cause mortality [-]	Survival prob. [-]	Cum surv. prob. [-]	Life Expect. [year]
20	0.00069	0.99931	0.98931	74.19	60	0.01626	0.98387	0.86747	75.79
21	0.00069	0.99931	0.98863	74.20	61	0.01626	0.98387	0.85348	75.92
22	0.00069	0.99931	0.98794	74.21	62	0.01626	0.98387	0.83971	76.07
23	0.00069	0.99931	0.98726	74.22	63	0.01626	0.98387	0.82616	76.23
24	0.00069	0.99931	0.98658	74.23	64	0.01626	0.98387	0.81283	76.40
25	0.00075	0.99925	0.98584	74.25	65	0.02742	0.97296	0.79085	76.59
26	0.00075	0.99925	0.98511	74.26	66	0.02742	0.97296	0.76946	76.80
27	0.00075	0.99925	0.98437	74.28	67	0.02742	0.97296	0.74865	77.03
28	0.00075	0.99925	0.98364	74.29	68	0.02742	0.97296	0.72841	77.28
29	0.00075	0.99925	0.98290	74.31	69	0.02742	0.97296	0.70871	77.55
30	0.00093	0.99907	0.98199	74.33	70	0.04558	0.95544	0.67713	77.84
31	0.00093	0.99907	0.98108	74.34	71	0.04558	0.95544	0.64695	78.17
32	0.00093	0.99907	0.98017	74.36	72	0.04558	0.95544	0.61812	78.52
33	0.00093	0.99907	0.97926	74.38	73	0.04558	0.95544	0.59058	78.90
34	0.00093	0.99907	0.97835	74.40	74	0.04558	0.95544	0.56426	79.31
35	0.00125	0.99876	0.97713	74.43	75	0.07482	0.92788	0.52357	79.75
36	0.00125	0.99876	0.97592	74.45	76	0.07482	0.92788	0.48581	80.22
37	0.00125	0.99876	0.97470	74.47	77	0.07482	0.92788	0.45077	80.74
38	0.00125	0.99876	0.97349	74.50	78	0.07482	0.92788	0.41826	81.29
39	0.00125	0.99876	0.97228	74.52	79	0.07482	0.92788	0.38809	81.87
40	0.00191	0.99809	0.97042	74.55	80	0.15409	0.85693	0.33257	82.48
41	0.00191	0.99809	0.96857	74.58	81	0.15409	0.85693	0.28499	83.15
42	0.00191	0.99809	0.96672	74.61	82	0.15409	0.85693	0.24422	83.86
43	0.00191	0.99809	0.96487	74.65	83	0.15409	0.85693	0.20928	84.62
44	0.00191	0.99809	0.96303	74.68	84	0.15409	0.85693	0.17933	85.41
45	0.00311	0.99690	0.96004	74.72	85	0.18596	0.82986	0.14882	86.23
46	0.00311	0.99690	0.95707	74.76	86	0.18596	0.82986	0.12350	87.08
47	0.00311	0.99690	0.95410	74.80	87	0.18596	0.82986	0.10249	87.96
48	0.00311	0.99690	0.95114	74.85	88	0.18596	0.82986	0.08505	88.85
49	0.00311	0.99690	0.94819	74.90	89	0.18596	0.82986	0.07058	89.77
50	0.00522	0.99480	0.94325	74.95	90	0.27870	0.75539	0.05332	90.70
51	0.00522	0.99480	0.93834	75.00	91	0.27870	0.75539	0.04027	91.65
52	0.00522	0.99480	0.93346	75.07	92	0.27870	0.75539	0.03042	92.60
53	0.00522	0.99480	0.92860	75.13	93	0.27870	0.75539	0.02298	93.57
54	0.00522	0.99480	0.92377	75.20	94	0.27870	0.75539	0.01736	94.55
55	0.00932	0.99072	0.91520	75.28	95	0.40538	0.66294	0.01151	95.53
56	0.00932	0.99072	0.90670	75.37	96	0.40538	0.66294	0.00763	96.52
57	0.00932	0.99072	0.89829	75.46	97	0.40538	0.66294	0.00506	97.52
58	0.00932	0.99072	0.88996	75.56	98	0.40538	0.66294	0.00335	98.51
59	0.00932	0.99072	0.88170	75.67	99	0.40538	0.66294	0.00222	99.51

Appendix C – Calculation of DALY for occupational injuries

To calculate the number of DALY lost due to injuries from occupational accidents, we need to multiply the following two parameters:
a) The period a worker suffers from the injury.
b) The weighing factor of the injury.

a) The period a worker suffers from the injury
The period a worker suffers from the injury is derived differently for permanent and recoverable injuries. For permanent injuries it is assumed that the injury will last the rest of the workers life (the remaining life expectancy). For the recoverable injury it is assumed that the time of absence from work is needed for the recovery. The time of absence from work is known for the accidents with carpenters, road pavers, tilers and concrete drillers. (Where this parameter is unknown it is assumed to be one year for calculation purposes.)

b) The weighing factor of the injury
To derive a weighing factor the following procedure was used:
– Petra Eysinck sent a sheet with weighing factors for different injuries for First Aid Treatment (Spoedeisende Eerste hulp, SEH) and Hospitalisation (Ziekenhuisopname), see Table C1. Only the columns for hospitalization were used as the occupational accidents are reports for hospitalization within 24 hours. The columns for temporary and permanent disability were used for recoverable and permanent injuries. In the column for permanent disabilities the values that were blank were filled in with the value for recoverable disabilities.
– The weighing factors given by Petra Eysinck mostly are for a combination of the place of injury (INJP parameter of the accident analyses) and the type of injury (INJT parameter). An example is: ‘Fractuur aangezicht’ (= Broken bones in the facial area) with a weighing factor of 0.072. Thus a combination of ‘INJP|12 Facial area’ and ‘INJT|020 Bone fractures’ would have to lead to a weighing factor of 0.072.
– Some injury types, such as ‘INJT|1st degree burns’ are not mentioned in the sheet of Petra Eysinck. For this a list with the ‘severity’ of injury types was made, see Table C2. This last assumption is needed to be able to calculate the weighing factors and is an assumption that needs validation for a follow up project.
– An example of the calculation of a weighing factor for a recoverable injury: the place of injury is ‘Torso and organs, not further specified’ this would lead to a weighing factor of 0.103 (Table C1). The injury type is ‘INJT|020 Bone fractures’, which would lead to a ‘Severity factor’ of 1 (Table C2). In total this leads to a weighing factor of 0.103 × 1 = 0.103.

Table C1 Weighing factors for injuries after first aid treatment and hospitalisation with comparison to codes used in accident analysis.

		First Aid Treatment		Hospitalisation	
Injury group	**Accidents code (Injury place)**	**Temp. disability**	**Perm. disability**	**Temp. disability**	**Perm. disability**
Commotio cerebri		0.015	0.151	0.1	0.151
Ander schedel-hersenletsel	INJP|19 Head, other parts not mentioned above	0.09	0.323	0.241	0.323
Open wond hoofd	INJP|10 Head, not further specified INJP|11Head (Caput), brain and cranial nerves and vessels	0.013		0.209	
Oogletsel	INJP|13 Eyes	0		0.256	
Fractuur aangezicht	INJP|12 Facial area	0.018		0.072	
Open wond aangezicht	INJP|12 Facial area	0.013		0.21	
Fractuur/ luxaties/distorsies wervelkolom	INJP|30 Back, including spine and vertebra in the back	0.133		0.258	
Whiplash					
Ruggenmergletsel	INJP|31 Back, including spine and vertebra in the back INJP|39 Back, other parts not mentioned above			0.676	0.676
Letsel inwendige organen	INJP|40 Torso and organs, not further specified	0.103		0.103	
Fractuur ribben/borstbeen	INJP|41 Rib cage, ribs including joints and shoulder blades INJP|42 Chest area, including organs	0.075		0.225	
Fractuur clavicula/ scapula	INJP|51 Shoulder and shoulder joints	0.066		0.222	0.121
Fractuur bovenarm	INJP|52 Arm, including elbow	0.115		0.23	0.147
Fractuur elleboog/onderarm		0.031	0.074	0.145	0.074
Fractuur pols	INJP|55 Wrist	0.069	0.215	0.143	0.215
Fractuur hand/vingers	INJP|53 Hand INJP|54 Fingers	0.016		0.067	
Luxatie/distorsie schouder/elleboog		0.084		0.169	
Luxatie/distorsie pols/hand/vingers		0.027		0.029	
Perifeer zenuwletsel arm/hand					
Complex weke delen letsel arm/hand		0.081		0.19	

Injury group	Accidents code (Injury place)	First Aid Treatment		Hospitalisation	
		Temp. disability	Perm. disability	Temp. disability	Perm. disability
Fractuur bekken		0.168		0.247	0.182
Fractuur heup	INJP|61 Hip and hip joint	0.136		0.423	0.172
Fractuur bovenbeen	INJP|62 Leg, including knee	0.129		0.28	0.169
Fractuur knie/onderbeen		0.049	0.275	0.289	0.275
Fractuur enkel	INJP|63 Ankle	0.096	0.248	0.203	0.248
Fractuur voet/tenen	INJP|64 Foot INJP|65 Toe(s)	0.014		0.174	
Luxatie/distorsie knie		0.109	0.103	0.159	
Luxatie/distorsie enkel/voet		0.026		0.151	
Luxatie/distorsie heup		0.072		0.309	
Perifeer zenuwletsel been/voet					
Complex weke delen letsel been/voet		0.093		0.15	
Oppervlakkig letsel		0		0.15	
Open wond		0.013		0.093	
Brandwonden		0.055		0.191	
Intoxicatie		0.041		0.041	0.322
Vreemd lichaam		0.044		0.06	
Na onderzoek geen letsel		0		0	
Overig letsel	INJP|00 Part of body injured, not specified INJP|14 Ears INJP|15 Teeth INJP|20 neck INJP|43 Pelvic and abdominal area including organs INJP|50 Upper Extremities, not further specified INJP|60 Lower Extremities, not further specified INJP|70 Multiple sites	0.111		0.212	

Table C2 Severity of injury types for calculation of weighing factors.

Injury type	Severity
INJT|000 Type of injury unknown or unspecified	1
INJT|010 Wounds and superficial injuries	0.1
INJT|011 Superficial injuries	0.1
INJT|020 Bone fractures	1
INJT|022 Open fractures	1
INJT|030 Dislocations, sprains and strains	0.5
INJT|032 Sprains and over-stretching	0.5
INJT|040 Traumatic amputations (Loss of body parts)	1
INJT|050 Concussion and internal injuries	0.5
INJT|051 Concussions and intracranial	0.5
INJT|052 Internal injuries and bruises	0.5
INJT|059 Other types of concussion and internal injuries	0.5
INJT|060 Burns, scalds and frostbites	1
INJT|061 Burns and scalds (thermal)	1
INJT|120 Multiple injuries	1
INJT|1st degree burns	0.1
INJT|2nd degree burns	0.5
INJT|3rd degree burns	1
INJT|999 Loss of sight	1
INJT|999 Other specified injuries	1
INJT|Concussion	0.5
INJT|Loss of function	1
INJT|Object(s) entering body NOT via natural opening	1

The average weighing factors for recoverable and permanent injury can now be calculated per job:

– For the recoverable injuries the above weighing factors were multiplied with the time of absence. Thus if a worker with a weighing factor of 0.103 is away from work for 1 year, 0.103 DALY will have been lost, whereas if the worker was away from work for 1 week it would be $0.103 \times 1/52 = 2.0 \times 10^{-3}$ DALY. When summing these factors and averaging over the number of accidents an average value per job has been calculated. The results are shown in Table C3.

– For the permanent injuries the weighing factors were not multiplied with the time of absence as it is assumed that the worker will have a decreased quality of life during the remaining life expectancy. These results are also shown in Table C3.

Table C3 Average weighing factors for recoverable injuries including absence time and permanent injuries excluding absence time per job type.

Job	Average weighing factor recoverable injury with time (weight × severity × absence time)	Average weighing factor permanent injury (weight × severity)
Carpenter	0.10	0.16
Concrete driller	0.10	0.20
Road paver	0.06	0.13
Tile setter	0.15	-
Average	0.10	0.15

Calculation of DALY

– To simplify the calculations the average weighing factors from Table C3 are used for the DALY calculations for all jobs.

– For DALY due to permanent injuries the number of calculated permanent injuries is multiplied by 0.15 (average weighing factor for permanent injury from Table C3) and the remaining life expectancy. Example for the group of carpenters with the normal distribution of age: there are 9.61701 carpenters of age 20 in the starting year 2011. The calculated number of permanent injuries in this group after one year = $9.61701 \times 3.6 \times 10^{-4} = 3.5 \times 10^{-3}$. The calculated number of DALY = $3.5\times10^{-3} \times 0.15 \times (74.2 - 21) = 2.8\times10^{-2}$ DALY.

– For DALY due to recoverable injuries the number of calculated recoverable injuries is multiplied by 0.1 (average weighing factor for recoverable injury with time from Table C3). Example for the group of carpenters with the normal distribution of age: there are 9.61701 carpenters of age 20 in the starting year 2011. The calculated number of recoverable injuries in this group after one year = $9.61701 \times 8.4\times10^{-4} = 8.1\times10^{-3}$. The calculated number of DALY = $8.4 \times 10^{-3} \times 0.1 = 8.4 \times 10^{-4}$ DALY.

RIVM

National Institute
for Public Health
and the Environment

P.O. Box 1
3720 BA Bilthoven
The Netherlands
www.rivm.nl