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# Particulate matter exposure in roadwork companies: A mental models study on work safety

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ABSTRACT

Particulate matter (PM) exposure, amongst others caused by emissions and industrial processes, is an important source of respiratory and cardiovascular diseases. There are situations in which blue-collar workers in roadwork companies are at risk. This study investigated perceptions of risk and mitigation of employees in roadwork (construction and maintenance) companies concerning PM, as well as their views on methods to empower safety behavior, by means of a mental models approach. We held semi-structured interviews with twenty-two employees (three safety specialists, seven site managers and twelve blue-collar workers) in three different roadwork companies. We found that most workers are aware of the existence of PM and reduction methods, but that their knowledge about PM itself appears to be fragmented and incomplete. Moreover, road workers do not protect themselves consistently against PM. To improve safety instructions, we recommend focusing on health effects, reduction methods and the rationale behind them, and keeping workers' mental models into account. We also recommend a healthy dialogue about work-related risk within the company hierarchy, to alleviate both information-related and motivation-related safety issues.

## 1. Introduction

Particulate matter, or PM, is an important health risk in modern society (WHO, 2013), as well as an environmental risk (Roels et al., 2014). It originates from a number of sources, such as vehicle emissions, machinery and industrial processes, but also natural sources (Anderson et al., 2012). PM exposure through air is associated with various diseases, mainly respiratory and cardiovascular diseases (Anderson et al., 2012; Hänninen and Knol, 2011), due to people breathing in the particles. These health effects lead to a reduction in life expectancy; annual premature death estimates due to PM exposure are 800,000 worldwide (Anderson et al., 2012), and 12,000 in the Netherlands alone (Health Council of the Netherlands, 2018). This study focuses on PM in the workplace, and investigates to what extent blue-collar workers are empowered to protect themselves against PM.

The two main characteristics of PM that contribute to health effects are particle size and chemical composition. When it comes to particle size, the fraction of PM with a particle size of 2.5 μm or less ($PM_{2.5}$) is likely to have most detrimental health effects, including lung cancer, bronchitis and cardiopulmonary disease (Hänninen and Knol, 2011). The $PM_{2.5}$ fraction permeates more deeply into your lungs than the $PM_{10}$ fraction (Hänninen and Knol, 2011; Strak, 2012) while having higher levels of inflammatory response compared to the $PM_{0.1}$ fraction (Strak, 2012). When it comes to chemical composition, various adverse health effects are caused by substances such as black carbon (Janssen et al., 2011), silicon (Van Deurssen, 2015), metals and various organic compounds (Strak, 2012).

Research indicates that blue-collar workers in construction companies (Van Deurssen, 2015) and highway maintenance companies (Meier, Cascio, Danuser and Riediker, 2013) have a high PM exposure risk. Especially usage of equipment such as mowing machines or chain saws causes PM exposure (Meier et al., 2013). There are indications that it increases workers' risk of cardiovascular disease; therefore, earlier research recommends taking actions to reduce PM exposure in highway maintenance companies (Meier et al., 2014). In this study, we broaden our focus to roadwork companies in general instead of only highway maintenance companies, because the aforementioned causes of PM exposure are also relevant for road construction companies (Sobus et al., 2009), or companies that maintain other roads than highways.

European and national laws require rules and regulations towards

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exposure risks, and companies should take precautions whenever exposure limits are exceeded. Exposure limits for the course and fine PM fractions ($PM_{10}$ and $PM_{2.5}$) have not been determined for the workplace, but there are exposure limits for specific substances. For example, the quartz exposure limit in occupational settings is 75 $\mu g/m^3$ (Van Deurssen, 2015), and these exposure limits are regularly exceeded.[1] According to Uchiyama (2013), the most important precautions against dust inhalation, other than avoiding certain locations altogether, include using respirators and sprinkling water.

In the occupational hygiene strategy for the Dutch situation, additional precautions regarding PM are mentioned, specifically regarding diesel emission (Heederik et al., 2009). These include using other types of fuel, alternative work schedules, filtering systems and ventilation. The occupational hygiene strategy is based on a four-level hierarchy of types of precautions. If possible, companies should focus on taking away the source of exposure, before choosing collective measures, such as filtering systems, or individual measures, such as alternative work schedules. Protective equipment, such as respirators, should be used if none of the other options is sufficient.

Awareness about possible risks and precautions is essential for health protection, since accurate perceptions of risk lead to safe risk behavior (Milne et al., 2000). In some cases, simply giving the appropriate information about PM exposure, health risks and mitigation options to workers is used as a means of risk communication. This has been effective to a certain extent in workplace situations involving other exposure risks, including welding fumes (Cezar-Vaz et al., 2015) and ionizing radiation (Sheyn et al., 2008). Influencing risk perceptions by means of instruction might especially be useful with mostly imperceptible exposure risks such as PM, since these types of risks could be relatively overlooked due to their imperceptibility, and workplace prevention has traditionally focused more on observable direct physical risks (Arezes and Miguel, 2008).

Fischhoff et al. (2011) state that ideally, risk communication takes workers' mental models into account. Mental models were originally defined as *'"small-scale models" of reality that [the mind] uses to anticipate events, to reason, and to underlie explanation'* (Craik, 1943). According to Craik (1943), having such a model is essential in choosing safe alternatives in emergencies, which underlines its importance in risk communication. In a more recent publication, Jones et al. (2011) define mental models as *"personal, internal representations of external reality that people use to interact with the world around them"*. Here, they focus on the contrast between the internal idea and the external reality, which may be a key factor to focus on in risk communication. Ideally, this would lead not just to an increase in safety knowledge, but also in safety motivation, which is also strongly related to safety performance (Christian et al., 2009).

The mental models approach in risk communication and perception studies seeks to construct the mental models of scientific experts and non-experts with respect to a specific risk, contrasting these two with each other (Morgan et al., 2002). Non-experts have some intuitive idea about certain risks, which can be mapped in a systematic way (Breakwell, 2001). The differences between the mental models can then be used to identify specific information needs: gaps in knowledge relevant for decisions, misconceptions, questions and concerns, different use of terminology and typical non-expert beliefs (Slovic and Weber, 2002). Breakwell (2001) states that basic information about risk properties, effects and control measures is always necessary, and that new information should match the level of understanding of the target group. In group settings such as workplaces, this target group tends to have a shared mental model, which helps facilitate the task performance in companies (Lim and Klein, 2006). The shared mental model of a certain risk can be influenced by means of risk communication.

[1] The 2017 amendment to the EU directive 2004/37/EC, concerning carcinogens and mutagens at work, states a slightly adjusted limit of 100 $\mu g/m^3$.

Although the concept of safety culture is rather ill-defined (Nielsen, 2014), safety culture is important nonetheless. Having a culture in which it is considered normal to discuss improvement of safety measures has a positive effect on work safety (Hambach et al., 2011; Petts et al., 2002; Toppazzini and Wiener, 2017). Nielsen (2014) argues that a change in culture, specifically towards higher levels of safety behavior and commitment, can be equated with a change in basic assumptions. In our situation, the mental models approach can identify which basic assumptions, both about PM itself and about work safety in general, need to be addressed in order to improve work safety related to PM.

It should be noted that designing a system of risk communication is not always the only, or even the best, solution when it comes to inducing work safety behavior (Fischhoff et al., 2011; Mankin, 2009; Smith and Ragan, 2005). Before focusing on risk communication, companies should design the workplace in such a way that working safely becomes the automatic thing to do (Evans and Stanovich, 2013; Mols, Haslam et al., 2015). Another method is to force workers to work safely by coercive means (Hasle et al., 2014), but this might lead to defiance (Sunstein, 2016) and loss of safety culture (Lipscomb et al., 2013). Safety climate, which is subtly different from safety culture but sometimes used interchangeably with it (Nielsen, 2014), is more related to safety participation than to safety compliance (Christian et al., 2009) – that is, a company with a healthy safety climate leads its employees to actually feel involved with the safety procedures, not just comply with its rules.

In this study, we use a mental models approach to investigate to what extent workers are empowered to work safely in occupational circumstances involving PM exposure risk. Based on scientific knowledge about PM, mentioned earlier in this article, we construct a scientific mental model that encompasses the properties, causes, health effects, control measures, and education about PM. We then contrast this mental model with the employee mental model

The two main research questions in this paper are as follows: 'How do roadwork companies and their employees perceive PM exposure risk and mitigation', and 'How are employees in roadwork companies empowered to work safely?' We discuss how companies could empower their employees to work safely, resulting in specific ideas for a risk communication solution.

## 2. Method

This study aims to use a mental models approach to investigate PM risk perception and empowerment to work safely. The scientific mental model is based on insights from literature, as discussed in the introduction section. The content has also been cross-checked with an expert on the subject, in order to help prevent inaccuracies. To build the employee mental model, we held semi-structured interviews with various employees of roadwork companies. We chose semi-structured interviews because they aim for a general systematic order while still allowing deviations from the script (McIntosh and Morse, 2015), and because they emphasize the intended meaning of the questions over the phrasing (Denzin, 1989). This setup matches up well with the mental models approach, as this approach also aims to investigate the thought processes of certain groups of people (Morgan et al., 2002). The employees in these companies can be further divided into work safety specialists, site managers, and blue-collar workers.

### 2.1. Sampling

We contacted seven companies in the Netherlands that are involved with roadwork, and three of those companies participated in this study; the other four chose not to participate due to time constraints. The three companies each selected one work safety specialist, two or three site managers and four blue-collar workers to interview; the total number of interviews added up to 22. We did not get any further details on the selection procedure of participants within the companies. All

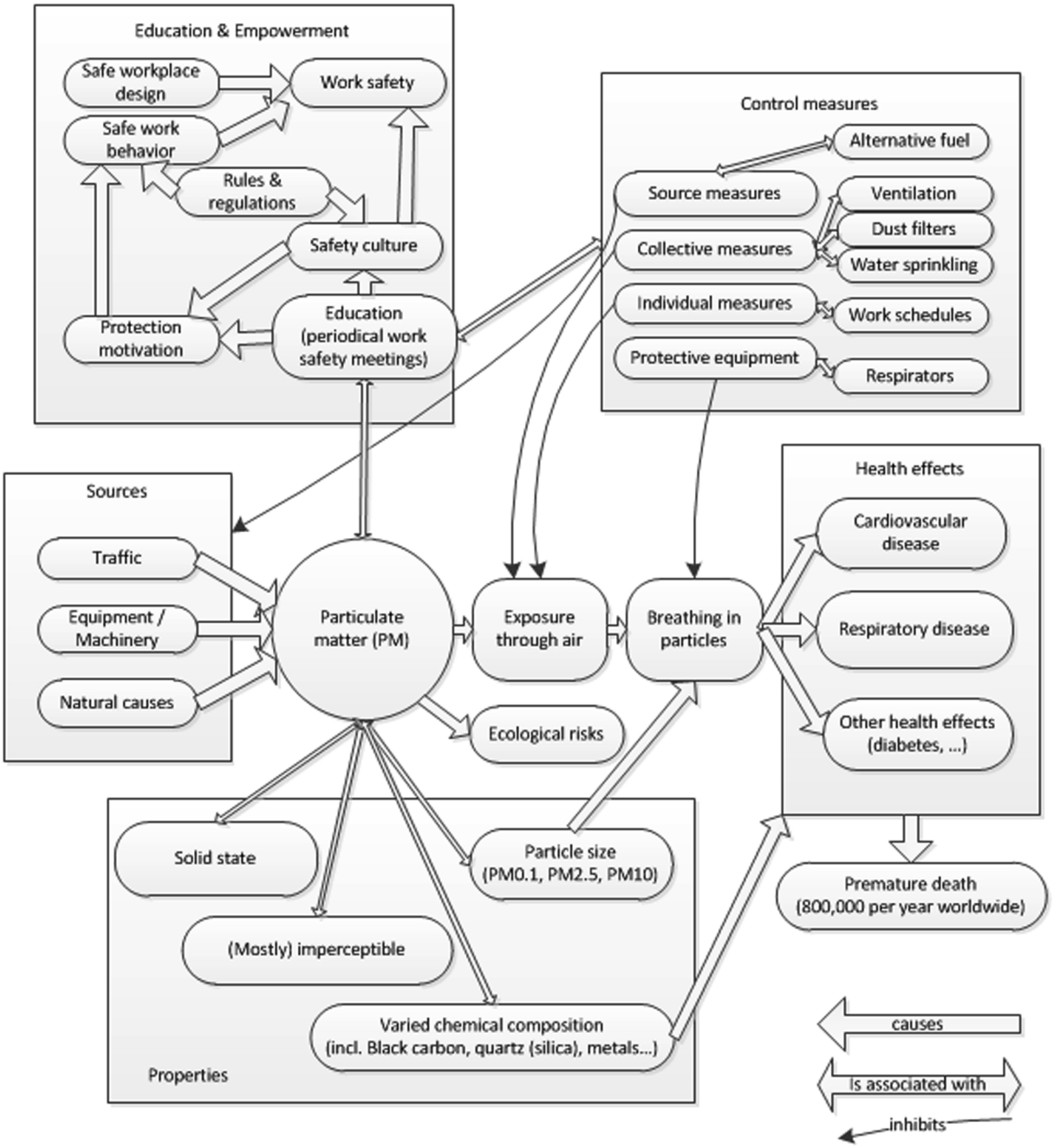


**Fig. 1.** Scientific mental model of PM.

participants were men, which was unintentional, but a logical consequence of the predominantly male demographic of the roadwork branch. Their ages varied between 23 and 59 years old.

The three companies are all involved with roadwork, but the specific primary processes for each company are slightly different. Company A is mainly involved with highway maintenance, including road reparations, but also activities such as lawn mowing and cleaning. Company B is more involved with road construction, both inside and outside of urban areas, but also with ground preparations involving electricity and sewerage. Company C focuses on both road construction and maintenance.

### 2.2. Data collection

We interviewed all participants face to face and one on one, with the exception of one interview where one manager wished to join the interview with another manager near the end. The first author performed all the interviews over the course of four months, during the spring and summer of 2017. They were held in various locations, but always related to the companies themselves, ranging from offices to work shacks. Before the interviews, we asked them whether they had any objections to recording. We also informed all participants of their guaranteed anonymity, and we guaranteed that anything within the limits of the law would remain between the researchers and the participant. No participants had any objections to these terms.

The interviews started by asking participants to give a description of their job, in order to set the stage of the conversation. Subsequently, participants were asked which risks they encounter within their work, to see whether they consider PM one of the primary risks. If they did not include PM at this point, they were asked about it directly, by using

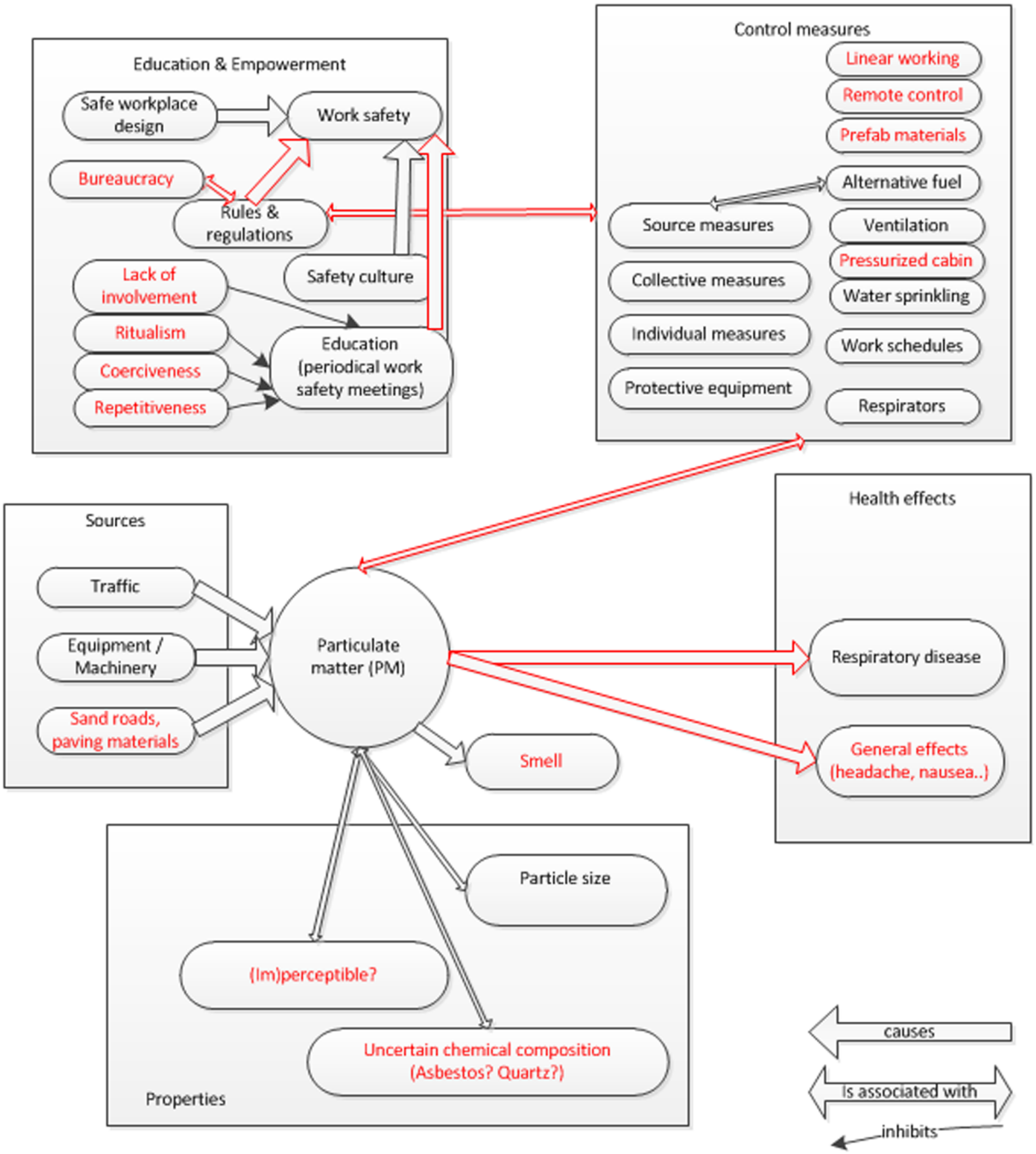


**Fig. 2.** Employee mental model of PM.

questions such as *'what do you know about PM?'*. The participants were also asked about their knowledge and beliefs about PM exposure, health effects and mitigation, and about rules and regulations regarding safety behavior present within the company. In the second half of the interview, the focus was on information and instruction practices in the company and on contextual influences on work safety behavior. Participants were also asked about PM information needs for blue-collar workers. The interviews were all concluded by asking participants whether there were other noteworthy things to mention.

### 2.3. Data analysis

All 22 interviews were transcribed verbatim. We then performed a qualitative analysis using Atlas.TI version 7 (Muhr et al., 2016), a program that helps structure the coding process. In the coding process, keywords are systematically linked to certain fragments of text, in order to identify themes that were present in various interviews. The first author first identified and coded the relevant text fragments of the first two interviews through open coding; that is, keywords were added without following a predetermined schedule for coding. To a certain extent, these codes were in line with the questions we asked during the interviews, but we did not have a predetermined schedule, in order to remain open to unexpected findings.

After the coding of the first two interviews, the first and third authors deliberated the codes and potential overarching themes and discussed how to refine and continue the coding process. These steps were repeated several times. In this iterative process, returning to the earlier transcripts to ensure that all codes were applied consistently across

transcripts, the codes and themes evolved and became more refined, resulting in 143 codes. Using the evolved coding scheme both authors coded the final three interviews (allowing for additional newly defined codes) and compared the coding. In this last step, a few more codes were added, but no profoundly new themes or subthemes were identified, implying that the data were close to reaching saturation. Although we found some differences between coders in code name usage and quote length, both researchers identified the same themes and subthemes within these interviews. After discussing the differences and revising the coding scheme accordingly, we concurred that there were no essential discrepancies between coders.

## 3. Results

As mentioned, the scientific mental model of risk was based on insights from literature. This mental model can be found in Fig. 1, and it provides a schematic overview of expert knowledge on this subject. In order to increase the legibility, some of the nuances provided in the introduction section were left out; for example, the scientific mental model mentions the distinction between particle sizes, but it does not specify that $PM_{2.5}$ is considered the most important fraction when it comes to health risk. The scientific mental model focuses on several aspects of the risk that were identified during the data analysis of this study. These aspects include: definitions of PM, causes, effects, precautions, and empowerment (including education).

The scientific mental model (Fig. 1) shows in the 'Properties' section that PM is (mostly) solid matter suspended in air (Strak, 2012), consisting of small, usually imperceptible particles often divided into size fractions such as $PM_{0.1}$, $PM_{2.5}$ and $PM_{10}$ (Hänninen and Knol, 2011), varied in chemical composition (Janssen et al., 2011, Van Deurssen, 2015). Its sources include, among others, traffic, machinery, and natural causes (Anderson et al., 2012), as shown in the 'Sources' section. The center of the model shows that PM causes ecological problems (Roels et al., 2014), and health effects in humans due to exposure through air via breathing (Strak, 2012). These effects, shown in the 'Health effects' section, include cardiovascular, respiratory and other diseases, resulting in around 800,000 annual premature deaths worldwide (Anderson et al., 2012). There is an occupational hygiene strategy involving a four-level prevention model (Heederik et al., 2009), which is shown in the 'Control measures' section, recommending various measures including alternative fuel, ventilation, dust filters, water sprinkling, alternative work schedules, and respirators (Heederik et al., 2009; Uchiyama, 2013). Various factors involving workplace education on PM were included in the 'Education and Empowerment' section of the model, including effects of protection motivation (Rogers, 1983), rules' effect on culture (Hasle et al., 2014), culture's effect on work safety (Lipscomb et al., 2013), safe work behavior and safety by design (Evans and Stanovich, 2013; Mols et al., 2015).

A schematic overview of employees' perceptions of PM risk, as well as risk information needs, can be found in the employee mental model (Fig. 2). The same five aspects of the risk were used, and both of the mental models were designed to be able to overlap each other to investigate the differences between them. The differences between the scientific and employee mental models are shown in red in the employee mental model. As seen in Fig. 2, the scientific mental model is more detailed and less conflicted in the effects and properties sections, but the employee mental model is more detailed in the control measures section. The scientific mental model also showcases more consistency between the sections. A more detailed description of the results from the interviews, including quotes, can be found from chapter 3.1 onward.

In the analyses of the interviews five main themes were identified: perceptions of work-related risk (PM and otherwise), risk information needs, company policy towards PM, instruction methods, and contextual influences. The results will be described within the first four main themes, with the contextual influences mentioned wherever applicable. They will also be stratified, wherever possible and necessary, among the three groups of participants: work safety specialists, site managers, and blue-collar workers.

### 3.1. Perceptions of work-related risks

When asked about the risks that are involved with their work, the three work safety specialists unanimously agreed that traffic is the most important risk, and they all mentioned it as the first risk in the interview. Almost all other participants – workers and managers – agreed, and one participant (a worker) illustrated this with the following quote:

> *The further I'm away from the highway, the safer I feel.* (worker 1)

The participants then mentioned other direct physical (short-term) risks, including machinery, heavy lifting, fatigue, tripping, falling, and so on.

When asked about the long-term exposure risks, there was less unanimity. One of the work safety specialists mentioned noise as the first exposure risk that came to mind, one of them mentioned UV radiation, and the third (who is working for the company involved with ground preparations) mentioned soil pollution first. The other participants, workers and managers, also gave a wide range of answers; some of them mentioned PM as the first risk.

#### 3.1.1. Particulate matter: sources, composition and effects

All participants except for one worker had at least heard of PM before the interview. When it came to the sources of PM, in Company A exhaust gases were most frequently mentioned, whereas company B and C focused more on dirt roads, sawing and material dust. Participants in all employee groups – specialists, managers and workers – gave similar answers.

All workers and managers struggled to give an exact definition or many properties of PM, but two out of three work safety specialists assessed that particle size is what defines PM. Site managers and blue-collar workers did not mention anything about particle size, but they expressed ideas on the composition of PM, particularly by referring to quartz and asbestos:

> *Well, I did not really dive into this, but there is some kind of quartz involved, I think.* (manager 5)
> *It is possible that there are asbestos particles, and all sorts of junk, of course.* (worker 10)

Conversely, not everyone agreed with the notion of quartz or asbestos being involved with PM:

> *Yes, that is how I view particulate matter, because quartz is not particulate matter to me. Quartz is visible.* (specialist 1)
> *See, if I am not mistaken, it [PM] is all clean material. Yes, there is particulate matter, but asbestos and fibers? If I am not mistaken, there is no such thing inside of it.* (worker 12)

The quote by the specialist above also implies that he considered PM to be invisible. However, a small number of workers thought that only visible matter qualifies as PM, as illustrated by the following quotes. The second one of these workers is fairly young and unexperienced, while the first one has about forty years of experience:

> *If you see it, then it is defined as PM. But there is also a lot of invisible dust that we cannot see. Diesel soot particles cannot be seen.* (worker 8)
> *Well, it can be easily seen in the tunnels. There is some sort of fog.* (worker 1)

One of the site managers pointed out that PM is present whenever visible dust is present, implying (but not specifying) that PM and visible dust are different things, but are always present at the same time:

> *As soon as you see smoke, there is PM present.* (manager 3)

When it came to health effects of PM, only one participant, a site

manager, mentioned the possibility of cardiovascular diseases. However, most participants agreed that PM is unhealthy, specifically for the lungs. The phrase 'black lung' (also called miner's lung or pneumoconiosis, a lung disease caused by inhalation of particles) was mentioned several times as a potential health effect, and lung cancer was also seen as a possibility by some. Other participants mentioned different, more direct effects, attributing headaches and nausea to PM. For some, the presence of a nasty smell was an indication of the unhealthiness of PM. Some participants, on the other hand, did not see PM as an important source of risk at all, mainly because they give priority to other types of risks.

Considering precautions against PM, the majority of employees are aware of the two most important precautions: moistening materials and using respirators. A few other precautions were mentioned once or twice, including alternative fuel sources, working night shifts, working in pressurized cabins, using prefabricated materials to avoid unnecessary sawing, and using a remote control to avoid high-exposure areas. A more detailed overview of the company policies on these precautions can be found in the next section.

### 3.2. Risk information needs

The most frequently mentioned information needs by work safety specialists and site managers are health effects and preventive measures. This is illustrated by the following quote:

> *What I find important is that they know that it is bad for them, that you will not notice the effects immediately, but only in the long term. I say to them: "It is like a retirement plan; that is also not something you are aware of at the age of twenty-five, but it becomes interesting at fifty-five." […]So that they recognize the risk, that they understand that they might notice the effects later in life. And how do you protect yourself against it? How do you implement it? Because the work has to be done either way.* (specialist 2)

The chemical and physical characteristics were deemed not that important by blue-collar workers. It should be noted that two of the site managers were interested in getting more information about PM for themselves, even the 'less important' physical and chemical characteristics, although they recognize that it would be unfit for the blue-collar workers:

> *I would find it [physical/chemical characteristics] rather interesting, but those guys outside, well, they probably would not.* (manager 4)

One work safety specialist made the point that workers should not only know what they should do, but also why they have to do it:

> *Actually, if you ask someone "You are wearing a helmet, why are you wearing a helmet?", and he answers, "Because I have to", then that is not the right answer. For what you actually want to hear from him is: "Well, I am walking in an environment where the risk exists that someone falls down, or that I bump my head, and that is why I am wearing a helmet." And then he understands why he does it.* (specialist 3)

The blue-collar workers had somewhat differing opinions on what they would like to know. As well as the people higher in the hierarchy, they tend to consider health effects and reduction methods most important. Some of the younger, more inexperienced workers are particularly vocal about this, as illustrated by this quote:

> *I find it important to know what the dangers are. […] A man who is in this business for thirty years, but still dies because of the slow killer. And your lungs are pulled closer together and you die, so to say.* (worker 5)

A few workers were interested in finding out more details about PM than just basic information, for example concerning dosimetry:

> *Or maybe they could send someone with some kind of measuring equipment for a week.* (worker 1)
>
> *See, that might be a good idea. To see how much you take in, and whether or not it is really damaging. So they could inform us in a way such as: "You are subjected to dust for a certain percentage, and that could probably not hurt you", or…* (worker 11)

A small number of workers – older workers with a lot of work experience – had little interest in information about PM at all, as illustrated by this quote:

> *There are few things [regarding PM] of which I say 'boy, I would like to know that'.* (worker 10)

Even more than specific information about PM or other risks, workers feel the need to be taken seriously, because they are in charge of the primary process. Workers sometimes perceive a lack of understanding and involvement of people higher in the hierarchy of the company, which in turn might make them question their superior's authority. This is illustrated by the following quote:

> *If anyone is worried about safety, it is the people outside. But the people on the inside do not get that. They really think, "oh, we need to spell it out for them, because they do not understand a thing." They are thinking every day that we are on some kind of suicide mission, but we are not. We care the most about safety out of everyone, more than the one walking outside, the safety coordinator. He is not concerned half as much about safety as we are.* (worker 11)

### 3.3. Company policy towards PM

The companies involved in this study did not seem to have a specific policy towards PM when it came to allowed PM concentrations, but they are strict about certain reduction methods. Since material sawing is an important source of PM exposure, workers are required to moisten these materials beforehand, which the majority of participants considered important. Furthermore, at least two of the companies imposed sanctions to those who forego moistening the materials, with one company using a warning system in which getting too many warnings might get an employee fired, and one company using financial sanctions.

In situations where moistening materials is required due to high PM exposure, workers are also prompted to wear respirators, although this is not considered mandatory. The majority of the participants who mentioned respirators had negative opinions on it, describing them as obstructive and unnecessarily alarming to other people. Some examples of these sentiments include:

> *Well, not necessarily, but sometimes some things need to be communicated. For example, if a dangerous situation arises or we need to warn someone, or we need to talk to someone. And then, well, you have that thing [a respirator] in front of your mouth, so…* (worker 1)
>
> *If we, for example, have to clear out trees in an urban neighborhood, and we are going to walk with these things [respirators], people might think: 'What is going on here?', you know, 'Is this dangerous?'.* (manager 1)

Of course, company policy can be broader than simply defining rules for workers to follow. One of the specialists made the important point that designing a safe workplace is actually more important than complying with all of the rules:

> *We do not want to bring people into temptation, so we want to design it optimally, so that they do not need to make any choices on the building location about safety, because the choices are already completed in the initial planning phase.* (specialist 3)

One worker added that they cannot always follow every rule, because it would lead to an immense loss in productivity. This is illustrated with the following quote:

> *I think […] everything is being done here to keep it all as safe and healthy as possible. I think so. But as I am saying, some things are just not*

*doable. […] Well, then you cannot do anything anymore. Then you will just sit there with your arms crossed. […] I do not believe that you can eliminate everything for one hundred percent, all the risks.* (worker 12)

There are situations in which a safety regulation can get in the way of people performing their job. An example given by one participant involves the sand roads; they might cause a large amount of dust in the summer, but there are no water trucks in sight. To comply with PM limits, one might have to stop working in such a situation.

### 3.4. Instruction methods

All three companies utilize mandatory periodical work safety meetings in which they share risk information with employees, and they all do it in roughly the same way. The site managers send a letter to the workers in advance, clarifying the contents of the upcoming meeting. Then the workers get the required information from the managers on paper and read it. Sometimes the managers explain some more details if needed, and sometimes the workers get the opportunity to ask questions. Finally, the managers sign the papers for the workers, to prove that they attended.

The majority of specialists and managers deemed the principle of keeping every employee up to date about work safety issues important. There are many possible hazards that could be the focus of such a meeting. However, the specific approach was also criticized. The main problem, mentioned by about half of the participants in all hierarchical layers of the companies, appears to be that the work safety meetings are performed more as a ritual than as an actual method of instruction. This is illustrated by the following quotes:

*In the meeting itself it has occurred that we are shoved a piece of paper under our nose. "Just sign this and… […] and get out of here."* (worker 1)

*I am moderately satisfied in the sense that… […] Every month again you have to remind managers of the fact that… "You have not done it [the meeting] yet – go and do it." And I do feel that a number of the site managers are taking it very seriously. […] But there are also some colleagues that are doing it simply because they have to. And, yes, for them the signature is the most important thing, so they can show me that they did it.* (specialist 1)

One of the site managers highlighted another problem. He tried to explain that workers are expected to know everything they ever learned, and that they will be punished unfairly if it turns out that they made a mistake:

*But then you will see, the application of it is more in the sense of a criminal record, and in the end there is some employee who was supposed to know something because it was shared with him in a roundabout way a year ago. Or that he had heard something nine years ago in his VCA [safety checklist for contractors], and now he will get a large fine and a sanction instead of compassion and tolerance from a governmental institution. […] Even though in the end it is human work, and wherever humans work, mistakes are made.* (manager 2)

Work safety meetings about PM specifically appear to be rare. In one of the companies, there appears not to have been any instruction about PM at all in the last years; the employees did not specify any further how they got information on PM. The other two companies have had a meeting about PM at least once, but they have no institutionalized educational materials regarding PM.

Most risk information is shared with employees in the work safety meetings, but there are other informal and formal methods of discussing and sharing work safety issues, the most notable of which is the instruction booklet. New employees in all three companies got an instruction booklet about quality, safety and environment-related subjects. They contained at least some reference to situations involving PM exposure and reduction, but none of them specifically mentioned the phrase 'particulate matter'.

## 4. Discussion

The aim of this study was to investigate how employees in roadwork companies perceive particulate matter (PM) exposure risk and mitigation, and how they are empowered to work safely. We found that participants tend to know about the most important safety procedures related to preventing PM exposure. However, workers are often unaware why these safety procedures are so important, and they tend to have fragmented or incomplete knowledge about other aspects of PM, such as the health effects of exposure. The incompleteness of employee mental models of PM can be problematic, as the urgency of using certain mitigation methods might not be felt as much if there is insufficient clarity about the scope of the problem. The three companies we visited all held mandatory periodical work safety meetings, which appear to be the main framework in which risk information is given. However, these meetings tend to suffer from being more of a ritual than an actual means of risk communication.

### 4.1. Scientific and employee mental models of PM

A similarity between the expert and employee mental models is the knowledge and beliefs about mitigation methods, as well as most sources of PM. The vast majority of employees in roadwork companies, even blue-collar workers, appear to be aware of the most important safety procedures against PM, sprinkling water and respirators (Uchiyama, 2013). Employees sometimes even mention some of the less common mitigation methods, including using newer equipment, asphalting sand roads, working linearly and working night shifts (Heederik et al., 2009). Furthermore, some of them mention mitigation methods that could prove useful, but are nowhere to be found in literature – the idea to use remote controlled systems to stay out of environments with high PM exposure comes to mind. These procedures are in line with the idea from one of the specialists that it would be best to design a safe workplace in advance, so that workers do not have the opportunity to work unsafely (Evans and Stanovich, 2013; Mols et al., 2015). However, in the case of PM, these procedures do not sufficiently decrease PM exposure from the workplace (Heederik et al., 2009), indicating a further need for exposure reduction from the workers themselves, for example by means of respirators.

Although workers know about mitigation methods, they do not always know why they perform these procedures, even though both the participants and the risk communication literature (Hambach et al., 2011; Petts et al., 2002) say they should. This might be an indication that workers perform safety procedures only because they feel coerced, which is a symptom of an unhealthy safety culture (Lipscomb et al., 2013). Nevertheless, it should be noted that few workers complain about their companies' safety culture.

An important difference between the scientific and employee mental models of PM can be found in knowledge and beliefs about health effects. The findings indicate that employees of roadwork companies have little knowledge about the health effects of exposure to PM, beyond the fact that PM is bad for your lungs. While this is certainly true (Anderson et al., 2012; Hänninen and Knol, 2011), the evidence for cardiovascular diseases because of PM exposure in roadwork companies is stronger (Meier et al., 2014), and employees tend to be unaware of those cardiovascular diseases. Furthermore, the way in which roadwork employees speak about health effects – often claiming that PM is bad for you without giving many more details – indicates that their ideas may be based more on hunches than on facts, and that they need more detailed information about long-term effects of PM exposure. Another thing that leads to confusion is the invisibility of PM; some workers are under the misconception that PM is in fact visible, which might lead to workers not protecting themselves in situations where they should, because they are not seeing any PM.

The most important aspects of PM for workers to know, according to the participants in this study, would be health effects and reduction methods. Dosimetry and physical or chemical characteristics of PM were mentioned, but considered less important. Although literature does not give details on which aspects to focus on when it comes to PM risk communication, research does suggest that blue-collar workers value practical and direct instructions over more theoretical and thorough explanations (Niewöhner et al., 2004; Petts et al., 2002). It should be noted, however, that employee mental models of PM characteristics tend to be lacking and in conflict with each other, for example concerning the visibility of PM and the presence or absence of quartz and asbestos. The mental models approach recommends focusing on subjects such as these in risk communication, so that misconceptions are alleviated and omissions are filled (Morgan et al., 2002).

### 4.2. Empowerment to work safely

The mandatory periodical work safety meetings remain the most salient source of risk information throughout the roadwork branch. Research supports periodical repetition of the most important risk information (Hasle et al., 2014), as well as periodical meetings about health and safety (Nielsen, 2014), and therefore the idea of these meetings is well supported. Currently, many instructions are read out aloud or even just given on paper, and the meetings simply require a signature to complete them. For these meetings to fulfill their aim, they should be taken more seriously, both at the top and at the bottom of the company hierarchy. If the system sheds this problem, it could provide a framework for development of better risk communication, provided companies consider workers' mental models as well as their individual needs.

Even though the meetings themselves are mandatory, there is ample freedom when it comes to their form. Petts et al. (2002) describe a wide variety of instruction methods, including *"notices, posters, in-house bulletins, information sheets, circulars, safety committee minutes, incident and near-miss reports, meetings and team briefings"* (p. 3). Literature recommends using a two-way system of sending and receiving (Visschers et al., 2011). This is in line with findings from this study, suggesting that communication within the hierarchy can be improved.

Some frictions were found in the roadwork branch when it comes to authority, which was also found in earlier research (Lipscomb et al., 2013; Sunstein, 2016). Besides their more advanced technical knowledge about risk, safety specialists should also value the pragmatic insights from blue-collar workers (Slovic and Weber, 2002). Communication within the hierarchy could easily take place in work safety meetings, as referred to by several participants in this study; this could help with the need for employees to be heard (Hambach et al., 2011). By using the work safety meetings as platforms for discussing possible improvements in the work safety area, while also allowing more input from the workers themselves, these meetings could shed the problem of being too ritualistic, and they could provide a way for employees in all layers of the company to share their ideas on PM mitigation. This idea of getting employees more involved in the safety process is associated with a positive safety culture (Christian et al., 2009).

### 4.3. Strengths and limitations

This study provides insight into perceptions of PM risk and mitigation, as well as promising leads for development of better risk communication in roadwork companies regarding PM, but there are also some limitations. We focused on the situation in the Netherlands, but this does not consider different approaches in surrounding countries. Furthermore, additional risk communication systems beyond the periodical meetings, such as incidental participation evenings or instruction booklets, might not be getting enough attention. Finally, since this qualitative study only focused on a limited number of participants, the findings cannot be generalized to the entire roadwork branch. It is also possible that there was some selection bias involved, since we did not get any details from companies how employees were recruited for this study. Nevertheless, this study can be used as a starting point for further research into risk communication regarding PM, and it will help to improve its status in roadwork companies.

### 4.4. Conclusions & recommendations

Our findings suggest that blue-collar workers in roadwork companies tend to have sufficient knowledge about protective measures against PM, but they do not always know why and when they should use them. Their knowledge and beliefs about the properties (i.e. the composition and perceptibility) and health effects of PM are incomplete, which may contribute to a lack of risk awareness. Other than discrepancies in the mental models of PM, we also found various factors that are perceived to be detrimental to the effectiveness of periodical work safety meetings, of which ritualism seems to be the most salient.

We recommend a further development of work safety meetings regarding PM to empower workers, provided they are performed as an actual method of risk communication and not just as a ritual. The mental models approach in this article provides a good starting point for investigating the most necessary bits of information. For example, the invisibility of PM and the visibility of 'normal' dust that is present at the same time have proven to lead to confusion, so this subject should certainly be included. Beyond that, a focus on health effects and reduction methods, with the rationale behind them, seems plausible; participants in all layers of the hierarchy agree that these subjects are important. Including the characteristics and possible sources of PM can make workers more aware of risk situations and help to decide when to use which reduction methods.

Blue-collar workers need information on these subjects, but mostly they need a dialogue on various mitigation methods, in which all layers of the hierarchy can be involved. This should lead to an improvement not just in workers' safety knowledge, but also their safety motivation. As it turned out, various types of employees mentioned mitigation methods not even mentioned in literature, sometimes very creative and potentially useful in practice. For this reason, and in order to help with workers' need to feel heard, an improved system of interactive work safety meetings could help improve safety culture and empower blue-collar workers in work environments with PM exposure risk.

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## Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssci.2019.06.043.

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