International Journal of Occupational Safety and Ergonomics (*JOSE*) 2012, Vol. 18, No. 3, 363–373

Hazard Awareness of Construction Site Dumper Drivers

Jonathan Bohm

Health and Safety Executive, UK

Don Harris

HFI Solutions, UK

In UK's construction industry, site dumpers cause more serious accidents than in any other type of construction plant. Previous research has indicated that driver behaviour plays a pivotal role in the vast majority of these accidents. Using a mental models-based approach, 20 dumper drivers were interviewed with regard to the process by which several typical types of accident occurred. It was found that drivers were generally well-informed about the hazards of driving dumpers on a construction site. However, the findings also exposed some critical knowledge gaps, which could increase a driver's chances of an accident. Educational material relating to these knowledge deficiencies could easily be prepared and incorporated into revised construction information leaflets or driver training courses.

mental models   hazard awareness   risk perception   construction site dumper accidents

1. INTRODUCTION

Construction site dumpers are among the most common pieces of plant to be found on construction sites; they also have one of the poorest accident records, accounting for approximately one third of construction transport accidents in the UK [1]. Furthermore, they cause more fatal, major and lost-time accidents than any other type of construction plant [2]. On U.S. construction sites, half of all truck-related deaths involve a dumper truck [3]. While dumper design has evolved considerably, the basic principle has remained the same. All have a skip positioned forward of the driver (front-tipping, side-tipping, swivel or high-lift). The driver is seated in the open. Dumpers can be articulated or rigid-framed; have two- or four-wheel drive and have a manual, automatic or semi-automatic transmission. They can range in size from those with a payload of under one to over 10 tonnes.

Driver behaviour is implicated in the vast majority of dumper accidents [4]. Bohm and Harris described a series of fatal accidents [5]. For example, one driver was killed when he was thrown from his dumper after it hit a shallow trench, another was killed when a dumper overturned on a slope after reversing and still another was killed when his dumper overturned in a ditch after it had run off the road. Rundmo suggested that the "misjudgement of risk may cause inappropriate decisions, as well as unsafe behaviour and human error" (p. 393) [6]. However, such unsafe behaviours may either be predicated upon an ignorance or misunderstanding of the risks or a willingness to drive unsafely despite knowledge and understanding of the risks involved. Bohm and Harris found that driver risk perception significantly differed from measures of "objective risk" derived from accident data, and from experts' perception of risk [5]. Driver risk perception is more influenced by the "perceived dread" of an

Correspondence and requests for offprints should be sent to Don Harris, HFI Solutions Ltd., Bradgate Road, Bedford MK40 3DE, United Kingdom. E-mail: don.harris@hfisolutions.co.uk.

accident (its consequences) rather than its likelihood of occurrence.

There is a clear distinction between hazard and risk. A hazard can be defined as something with the potential to cause harm. Risk is "founded upon some notion of mathematical probability (likelihood of occurrence), frequently combined with [aspirations towards] some objective measure of severity" (p. 1) [7]. Hazard awareness simply involves having a knowledge or understanding of hazards involved in the operation of dumpers on a construction site.

There have been relatively few studies of either hazard awareness or risk perception in the workplace. With respect to hazard awareness, studies have tended to concentrate on health hazards rather than safety hazards. Studies of risk perception have encompassed a wide range of industries, including nuclear [8]; offshore oil production [6, 9, 10]; farming [11, 12]; construction [13]; fishing [14, 15]; forestry [16] and mining [17].

If unsafe driver behaviour is a result of ignorance or misunderstanding of the hazards, it can be suggested that the drivers have an inappropriate mental model. Usually the mental models approach is subsumed under theories of risk perception; however, having drawn a distinction between risk perception and hazard awareness, it is suggested that this approach can equally be used for addressing problems of hazard awareness.

Cox, Niewöhner, Pidgeon, et al. described the development of a mental models approach for the study of hazard and risk knowledge [18]. The approach comprises four main steps: development of a mental model to capture and represent the expert understanding and knowledge of a particular hazard domain; mapping of nonexpert knowledge and understanding of the same domain; identification of nonexpert knowledge gaps and misunderstandings and, finally, development of risk communication materials which precisely target these knowledge gaps.

The mental models developed with this approach are usually represented in influence diagrams, defined by Atman, Bostrom, Fischhoff, et al. as a "directed network that represents the dependencies and events in a process" (p. 780) [19]. This approach has been variously applied to the study of societal and environmental risks like radon [19], wildland fires [20] and global climate change [21]. In the workplace, the mental models approach has been used to explore workers' knowledge of the health hazards related to electroplating [22], perchloroethylene (the chemical used for dry cleaning) and solder flux [18]. These studies revealed significant gaps between expert and nonexpert (or workers') understanding of the hazards involved when handling these chemicals. The mental models approach offers several benefits to the study of workers' knowledge of hazards in the workplace. These include the accurate pinpointing of knowledge gaps and misunderstandings, and then representing them in a simple, readily comprehensible manner in influence diagrams.

There can be significant variance between experts' knowledge. Petts, McAlpine, Homan, et al. suggested that the "single expert model does not exist" (p. 5) and it is more appropriate to talk in terms of multiple expertise [22]. They also suggested that there was an artificial dichotomy between the expert and the nonexpert, with a tendency to undervalue the latter's knowledge [22]. These issues can be resolved with simple practical measures, including ensuring that the experts enlisted encompass a broad range of knowledge for a given hazard domain and by updating the final composite mental models produced with components elicited from the workers (nonexperts) which serve to identify gaps in the experts' knowledge.

The objective of this study was to identify drivers' knowledge gaps of the hazards associated with operating dumpers, by comparing driver mental models and those of subject matter experts (SMEs).

2. METHOD

2.1. Sample

Twenty male dumper truck drivers took part; mean age was 37.9 years (*SD* 10.5, range: 17–55). The mean number of years of experience of driving dumpers was 15 (range: 2 months to 30 years). All were formally certificated or in the process of being formally certificated as competent to operate a dumper.

A SME group comprised a Health and Safety Executive (HSE) specialist inspector and expert on earth-moving plants, the managing director and the head of engineering from a small dumper manufacturer, the head of engineering and senior design engineer from UK's largest manufacturer of dumpers, a senior instructor for construction skills from the National Construction Industry Training Board, the managing director of a regional company providing plant training and an expert witness on dumper accidents. These SMEs were selected as they could offer differing perspectives on the hazards, operation and risks associated with using dumper trucks.

2.2. Deriving the Baseline, Expert Mental Models

In keeping with previous research that used mental models (e.g., Zaksek and Arvai [20]), first a comprehensive expert model of the hazards and risks associated with driving dumpers was produced based on

- an extensive literature review;
- relevant HSE advice sheets (e.g., HSE [1]), publications (e.g., HSE [23]) and studies of accidents involving dumpers (e.g., Male and Corbridge [2] and Moutrie [24]);
- manufacturers' handbooks for dumper operators;
- in depth, open-ended interviews with the SMEs aimed at exhaustively identifying the hazards and risks associated with dumper use.

The information from these sources was collated into a comprehensive taxonomy of hazards and risks relating to three key risk areas of dumper operation (accounting collectively for over half the accidents involving serious injury or death) based on Moutrie's analysis of accidents [24]. These were

- dumper overturns;
- accidental engagement of controls;
- loss of control of the dumper.

Mental models were produced for each category; they were further refined in a series of interviews with the SMEs with a similar methodology as that for the drivers (see section 2.3). Consistent with previous research [18, 20], the mental models were presented in the form of "influence diagrams" [19]. These diagrams depict the accident category and the interrelationships between all the identified factors which the accident outcome could depend on.

After the expert mental models, the interview protocol for dumper drivers was developed.

2.3. Interview Protocol for Dumper Drivers

A 48-item interview schedule, consistent with Cox et al.'s methodology [18], was developed based directly on the content of the three expert mental models. The interviews were semi-structured to permit elaboration on the stimulus topics, discussion and digression. They aimed to elicit the driver's knowledge on the hazards and risk factors.

The interview had three sections, each concentrating on a different topic of dumper risk. Each section commenced with a general question on the potential hazards. Interviewees were asked to generate as many answers as they could. More specific questions followed. For example, under the category of dumper overturns, interviewees answered the general question "What are all the different situations you can think of in which it might be possible to overturn a dumper?".

Once the driver had finished giving his initial answer, he answered further prompting questions under headings such as travelling across site, load factors, ground conditions, tipping, maintenance factors and gradients, etc. For example, "What circumstances can you imagine where it would be possible to overturn a dumper while travelling across a site?".

Some of the further prompting questions under these headings were quite specific and were designed to tap any misconceptions or misunderstandings. An example of such a question was "When coming down a gradient fully laden is it better to drive down or reverse down or does it not matter?".

There was an implicit methodological risk in occasionally asking direct and detailed questions, in that they could potentially sensitize some. However, given that some participants were not particularly articulate nor had well-developed metacognitive skills, this was judged to be an acceptable compromise in contrast to failing to elicit a driver's tacit knowledge. This pragmatic position is consistent with that taken in previous mental models research [20].

This general approach was repeated for all three accident scenarios. The same interviewer conducted all interviews, which took between 20 min and one hour to complete. Interviews were recorded and transcribed for later coding and analysis.

2.4 Treatment of Data and Construction of Mental Models

Using the expert mental models as templates, drivers' responses were coded based on an analysis of the hazards for which they had either

- full knowledge and understanding;
- no knowledge;
- an incorrect understanding; or
- knowledge which had not previously been identified in the expert model.

This allowed the construction of individual mental models for each driver for each key area, resulting in 60 individual mental models in total.

The results from the interviews of dumper drivers were combined with the original expert mental models to create three composite mental models for overturns, accidental engagement of controls and loss of control. These showed not just gaps in dumper drivers' knowledge (expressed as proportions of the overall sample size) but also highlighted the enhancements they provided to the original expert mental models. Figures 1–3 present these mental models in the form of influence diagrams. The directional arrows show the factors each negative outcome potentially depends on. Main factors are indicated with larger font sizes and thicker arrows. The baseline expert mental models are denoted with boxes with solid lines. Where appropriate, within these items in the composite mental models, the percentage of dumper drivers with either no knowledge of the hazards or an incorrect understanding of these hazards are included. Additional factors from interviews with dumper drivers are added to the SMEs' baseline model in the form of further items denoted with boxes with dotted lines.

3. RESULTS

3.1. Overturns Model

As the influence diagram in Figure 1 clearly shows, drivers had reasonably good knowledge of the hazards compared to the datum model derived from the SMEs. For example, most drivers were aware of the dangers related to tipping near excavations and could cite at least one precaution, some including factors the SMEs had not mentioned. Similarly, they evidenced a good understanding of the way load factors, or poorly inflated tyres, might affect stability.

However, in other respects they showed a significant lack of understanding of the hazards. The three most important knowledge gaps identified for dumper overturns related to keeping the weight uphill, turning or tipping on a gradient, and the safety function of the seatbelt and roll-bar (roll over protection system, ROPS).

A sizeable majority of the respondents (80%) did not fully understand the principle of keeping the greater weight of the dumper uphill. This is good practice and is taught to all trainee dumper drivers. When laden, the greater weight is at the front, in the skip; when unladen, it is at the back. It thus follows that when ascending a gradient laden, best practice is to drive up; when unladen, best practice is to reverse. Similarly, if descending laden, the machine is most stable reversing and if unladen, the driver should drive down. Four fifths of the sample failed to give correct responses in all four of these scenarios. Drivers typically responded "always reverse down, always drive up" (irrespective of whether laden or not). It was also apparent that some drivers considered other factors in addition to dumper stability, such as visibility or spillage of

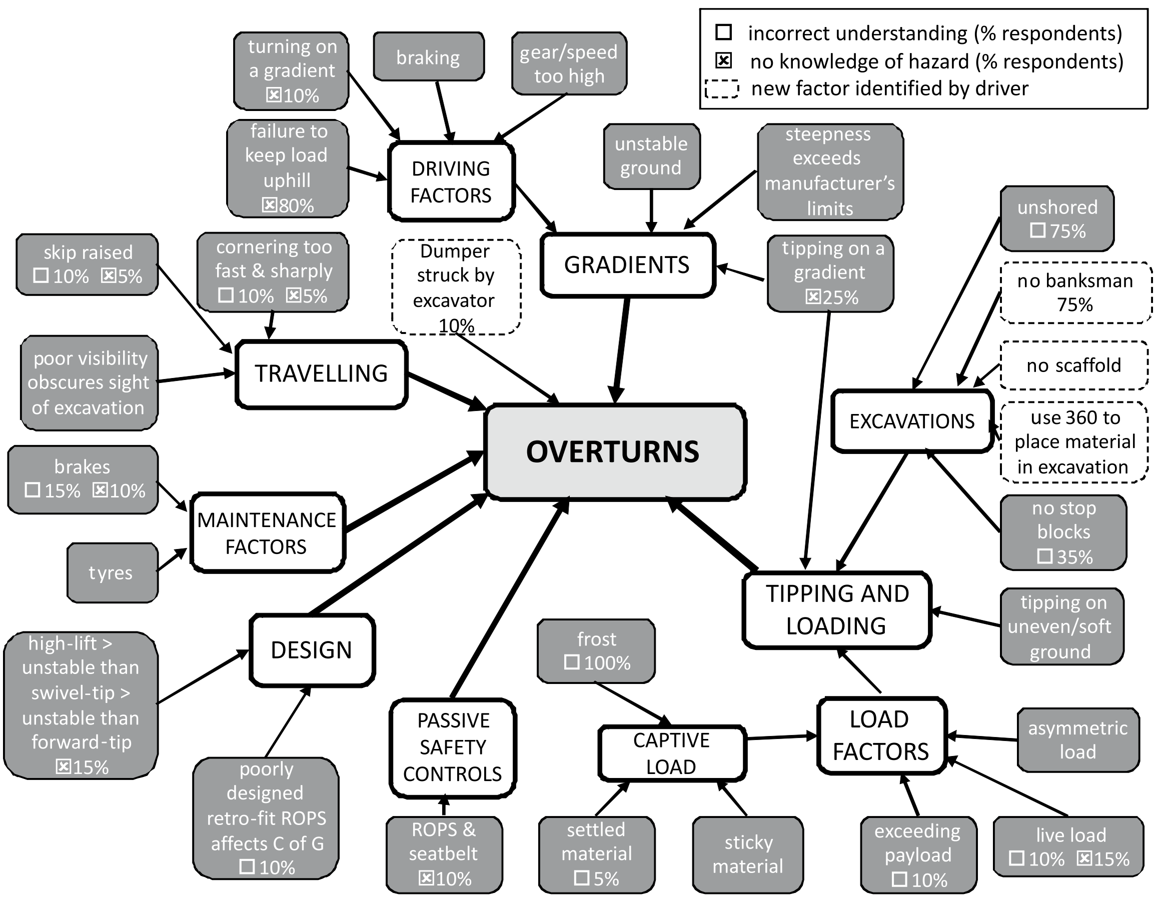

Figure 1. Composite SME (baseline) and driver mental model in the form of an influence diagram to describe the factors underlying dumper overturns. *Notes*. SME—subject matter expert, ROPS—roll over protection system, C of G—centre of gravity, 360—a term often used on a building site in the UK for a mechanical excavator; dark grey—factors SMEs identified, white—higher-level composite factors, light grey—central construct.

material. For example, one driver with 29 years' experience responded correctly that he would drive up a gradient when laden but also stated that if the slope was too steep, "the muck [in the skip] could come back at you" and in this case he would reverse. It is within the design parameters of all dumpers to go up and down gradients the "wrong" way (i.e., with the greater weight downhill) but this depends on steepness. Operator's manuals usually show the maximum gradient that can be attempted in both directions.

Furthermore, 25% thought that it was safe to tip on a gradient and 10% thought it was safe to turn on a gradient. Tipping on a slope is dangerous and is usually proscribed in operator's handbooks. Most drivers (75%) were aware of the risks. A typical comment was "It's not good practice anyway—apart from throwing the weight at the front, you'd lift your ar*e end up and come out anyway". However, a significant minority thought it was safe to tip uphill on a slope, and there were even some who thought it was safe to tip downhill, which is even more dangerous. In a similar vein, turning on a gradient is also a highly dangerous practice, explicitly banned in operator's manuals. The vast majority of the drivers were well aware of this hazard. Nevertheless, two drivers still thought it was safe to turn on a gradient.

One quarter of the sample stated it was safer not to wear a seatbelt. All drivers were able to cite the reasons why they should wear a seatbelt; however, it became apparent on further questioning that at least 25% of the drivers genuinely believed it was less safe to be wearing a seatbelt if the dumper overturned. Drivers suggested that the ROPS did not provide enough protection. In the event of an overturn, if they were held in the seat, there was the possibility of their head or body striking the "cut" of an excavation or materials left around the site. Other reasons included the possibility of tipping into water or a bog and drowning, getting trapped upside down with people unable to effect a rescue or even the ROPS collapsing.

3.2. Accidental Operation of Controls Model

Practically all drivers knew about the accidental operation of controls. Nevertheless, two knowledge gaps were still identified. The first was associated with driving older, manual geared dumpers; the second concerned accidentally pulling on the steering wheel. However, the most striking feature of the mental model in Figure 2 is the extent to which driver knowledge significantly enhanced the original expert model. Drivers identified many more hazards than the SMEs.

There were many knowledge gaps evident in both the SMEs' and driver mental models associated with the older dumpers with a manual gearbox. These machines can be started while in gear and lurch forward, running over anyone nearby. If left in gear with the ignition turned off, they can also be bump-started just by being knocked by another machine. The most common incident was the gearstick being knocked into gear either accidentally by the driver (or their

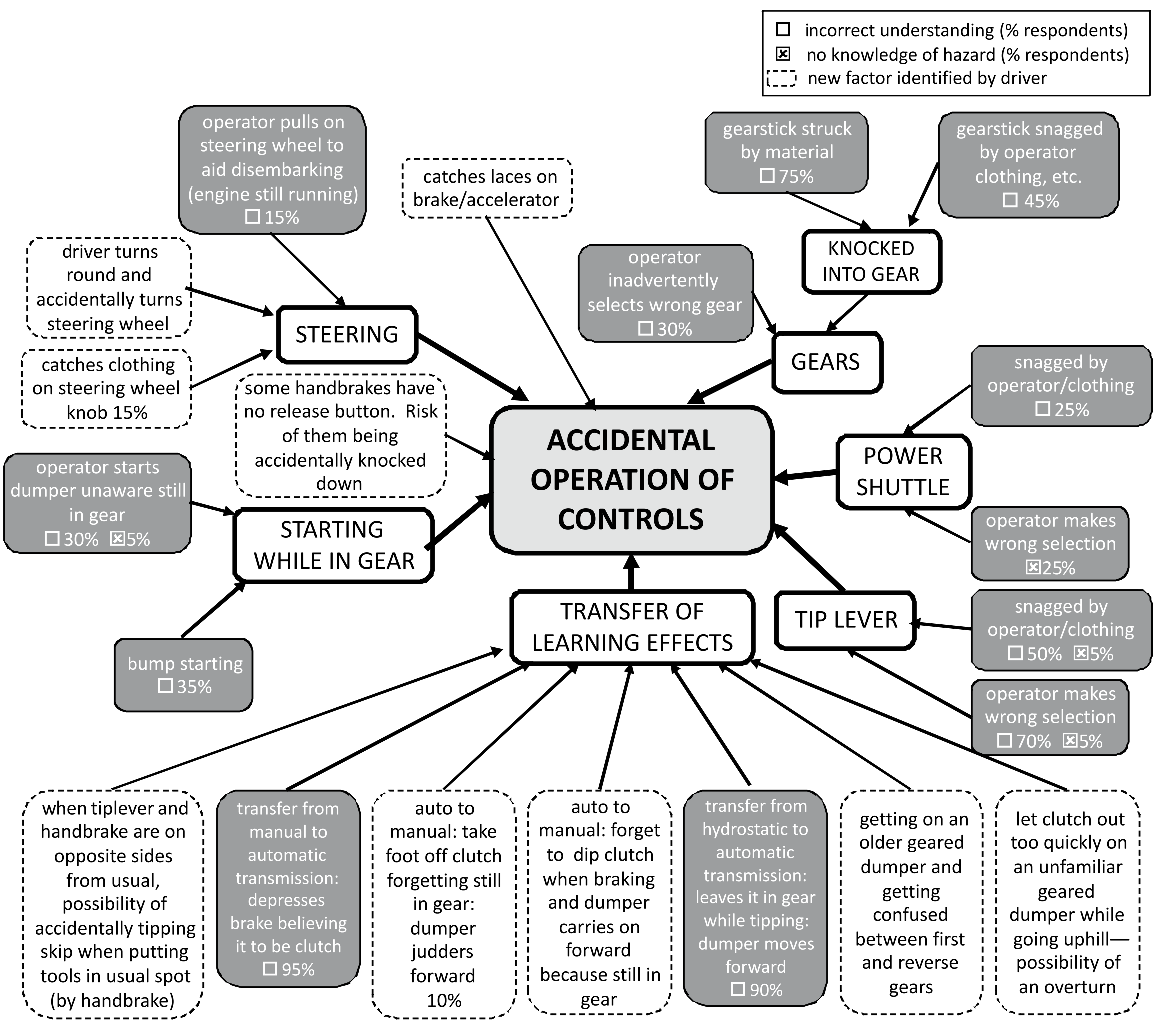

Figure 2. Composite SME (baseline) and driver mental model in the form of an influence diagram to describe the factors underlying the accidental operation of dumper controls. *Notes*. SME—subject matter expert, dark grey—factors SMEs identified, white—higher-level composite factors, light grey—central construct.

clothing) or by spoil falling off the back of the skip. However, 75% of drivers were unaware that loose material could potentially knock the gearstick into gear; 30% were unaware of the hazards associated with starting a dumper in gear and 35% did not know dumpers could be bump-started. Furthermore, significant numbers of drivers did not believe it was actually possible to move accidentally a control or make a wrong selection.

With regard to inadvertently pulling on the steering wheel, it needs to be understood that most dumpers are "frame steer" machines. This means that to steer the dumper, the driver will turn the steering wheel which will cause the skip to articulate around a central pivot point. This creates "crush zones" in the area between the front and rear sections of the dumper. The danger results from leaving the engine running and then climbing on or off the dumper while grabbing hold of the steering wheel, as illustrated by a driver's comments:

> If you're climbing up the dumper while it's running and pull on the steering it will come in. If it's slightly turned already, you've reduced that area, that little bit of leeway you've got has reduced, so it could come in on you. Oh they'll come in, right in, some of them. They'll still squash you between the skip and the steps or between the skip and the mudguard. Obviously if you are a bit fat like me you have a bigger body area to get squished, obviously a skinnier person might just get away with it.

This hazard is common to all frame steer machines, including new ones; however, 15% of the sample were still unaware of the potential for crushing.

3.3. Loss of Control Model

Figure 3 shows that drivers demonstrated generally high levels of knowledge of the main factors involved in losing control of the dumper. They also made several insightful contributions in addition to the baseline expert model. Almost

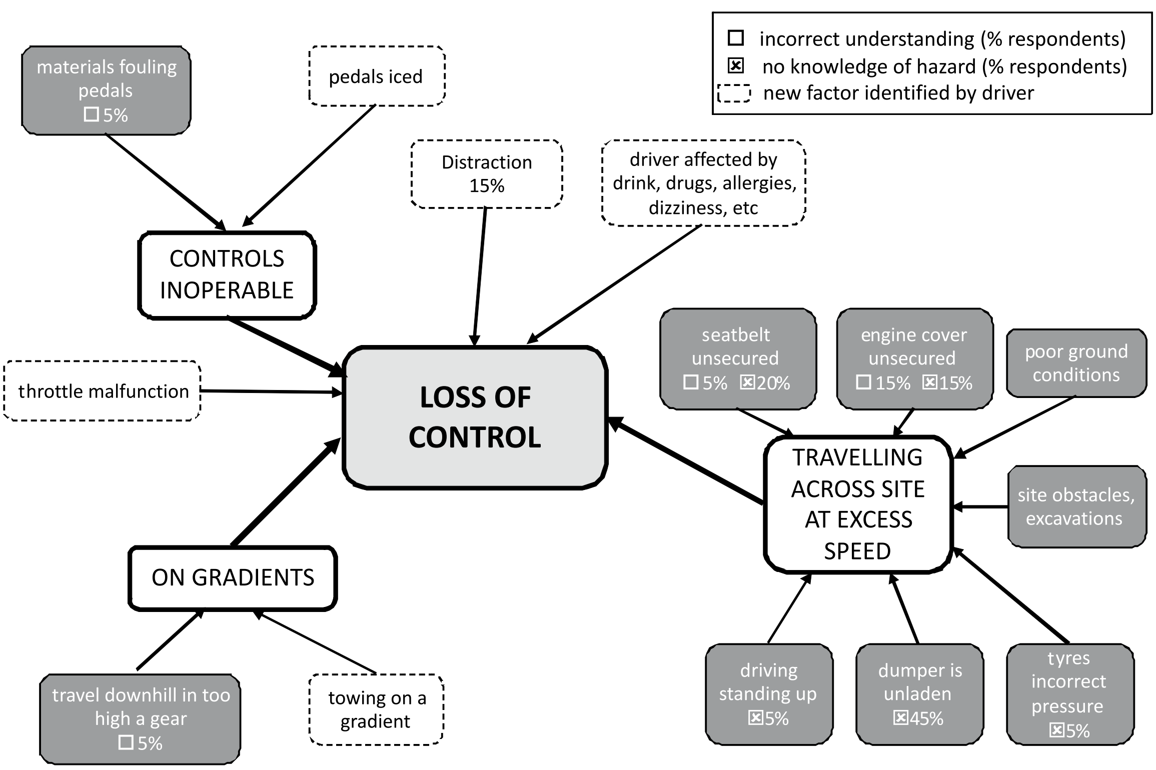

Figure 3. Composite SME (baseline) and driver mental model in the form of an influence diagram to describe the factors underlying the loss of control of a dumper. *Notes.* SME—subject matter expert, dark grey—factors SMEs identified, white—higher-level composite factors, light grey—central construct.

all drivers had experienced losing of control as a result of material fouling the pedals, and either the accelerator sticking or the driver being unable to depress the brake. The vast majority also appreciated the potential for being thrown off the dumper if going too fast across rough ground when not wearing a seatbelt.

However, there were two key knowledge gaps. The first related to how the weight of the machine might affect control if travelling at speed; the second was concerned with how a loose engine cover might affect control.

There was a high level of confusion (45% of interviewees) whether being unladen would exacerbate or ameliorate the risks if travelling at excess speed. One driver's comments highlighted this confusion:

> I would have thought having a load would be better—I suppose it depends on what you mean. Presumably it would be more stable and more centered [with a load] but once having lost control I would imagine the loss of control would be greater because of the load.

The expert mental model contended that a driver would have more control over a dumper travelling at speed if it was laden. However, some drivers suggested that with a load, the dumpers were much harder both to stop and steer.

Over a quarter of the drivers either failed to appreciate or were ignorant of the hazard of being ejected from the dumper if travelling at excess speed without a seatbelt on or with a loose engine cover. With some makes and models of dumper, the driver's seat is mounted on top of the engine cover, which is hinged at the back and has a clasp mechanism at the front. If this clasp is broken or not properly secured, there is a danger of the engine cover, seat and driver being bounced into the air. Several drivers were aware that in a worst-case scenario, the engine cover could go all the way back to 90° with the driver getting fired "straight out of the back of the dumper". A common misconception was that the driver's weight would keep the cover down even if the clasp was broken or not properly secured.

4. DISCUSSION

The results demonstrate that drivers were generally knowledgeable about the hazards and risks associated with driving dumpers. However, consistent with previous mental models research [18, 20], a number of knowledge gaps were also identified. Some were unexpected and are potentially of profound practical significance.

It is of concern if there is widespread misunderstanding about the most appropriate way to tackle gradients. A sizable proportion of drivers also felt that it was safe to tip or turn on a slope. These gaps in knowledge become more critical when it is considered that most dumper accidents have happened "on relatively modest slopes" within the limits specified by manufacturers [24]. The implications of these knowledge gaps are obvious. Any driver who does not fully appreciate or understand these hazards is vastly increasing their chances of having an overturning accident.

Wearing a seatbelt was a highly contentious issue where dumper drivers were concerned. The official HSE guidance on this matter states

> The correct use of the seat restraint [or seatbelt] is an essential part of the ROPS protection system and is designed to hold the driver in position when the vehicle tips over. A ROPS bar on its own will not adequately protect the driver in the event of a roll-over. Drivers will instinctively try to jump clear of the vehicle as it tips, but often this is only partially successful and they suffer serious injuries from being trapped by the vehicle as it comes to rest. It is safer to be held by the seat restraint within the area protected by the ROPS (p. 2) [1].

McCann also identified the failure to ensure that there was adequate ROPS for dumper trucks and to enforce seatbelt wearing as a key factor in the large number of dumper truck driver deaths [3].

While all drivers were aware of the reasons for seatbelt use, many genuinely believed that it was safer not to wear one. The reasons proffered were essentially a balance of risk arguments, rather than a deficiency in knowledge per se.

These drivers had considered the hazards associated with both wearing and not wearing a seatbelt and had concluded (in contrast to HSE) that the balance of risk favours not wearing one. In the event of an overturn, they would rather take their chances and jump.

There was a high level of ignorance regarding the hazards associated with manual, geared dumpers. In a study of dumper accidents occurring between 1986 and 1996, over half could be attributed to just two main causes: being knocked into gear when stationary (40%) and started when in gear (17%) [2]. However, in a later study spanning 2000–2005, accidental operation of controls accounted for just 17% of accidents [24]. This decline is largely attributable to a number of design changes, including safety features, which mean that new dumpers cannot be started in gear. As manual, geared dumpers are becoming rare on UK' building sites, this may explain why there were knowledge gaps relating to them, but was still slightly surprising, particularly given the age profile of the sample. Although manual geared dumpers are becoming less common, there is still a high possibility that a driver might have to operate one and this could clearly be highly dangerous if they were unaware of the hazards.

A surprising aspect of the mental model relating to the accidental operation of controls is the extent to which drivers' knowledge significantly enhanced the SMEs' model. The influence diagram in Figure 2 shows drivers were aware of hazards and risks of which the SMEs were unaware. Most of these related to the transfer of learning effects concerned with operating different types of dumper. This highlights the benefits of using a collaborative approach to the process of building influence diagrams, which recognizes that no single party has a monopoly on knowledge.

The final mental model elicited concerned losing control of dumpers (Figure 3). In general, drivers had a good knowledge of the hazards in this area. However, there was a significant issue identified in the effect of the weight of the dumper on controllability. The expert mental model contended that a driver would have more control over a dumper travelling at speed if it was laden. However, some drivers suggested that with a load, dumpers were much harder to stop and steer. In a sense, both views could be deemed correct; both circumstances have negative implications for maintaining control. As a result, it is difficult to conclude definitively that there is a gap in dumper drivers' knowledge without further exploration of this issue.

5. CONCLUSIONS

Dumper drivers were generally knowledgeable about the hazards associated with their work; however, there were certain critical knowledge gaps, such as failing to understand the principle of keeping the weight of the dumper uphill or to appreciate some hazards associated with driving the older type of manually geared dumper. Such knowledge gaps are of profound practical significance as they have the potential to increase the likelihood of a serious accident. These findings challenge the presumption that unsafe driver behaviour originates from a violation of rules [4] and supports the notion that some aspects of poor driving are predicated upon ignorance or misunderstanding of the hazards involved. This is in line with other studies which have used the mental models approach [18, 22]. This study also extends the approach used in previous studies to supplement the baseline mental model elicited from the SMEs with additional hazardous factors from the interviews with workers, completing a more comprehensive picture. This vindicates Petts et al.'s approach; they characterized operators as "experiential experts" [22] (see also Zaksek and Arvai [20]).

The implications for the construction industry of the results are quite straightforward. Educational and instructional materials can easily be developed to address the knowledge gaps identified. These can be promulgated via revised information leaflets to dumper operators [1] or incorporated into industry training courses and training standards. These would also benefit from the additional observations made by dumper truck drivers, which exposed gaps in the operational knowledge of the SMEs.

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