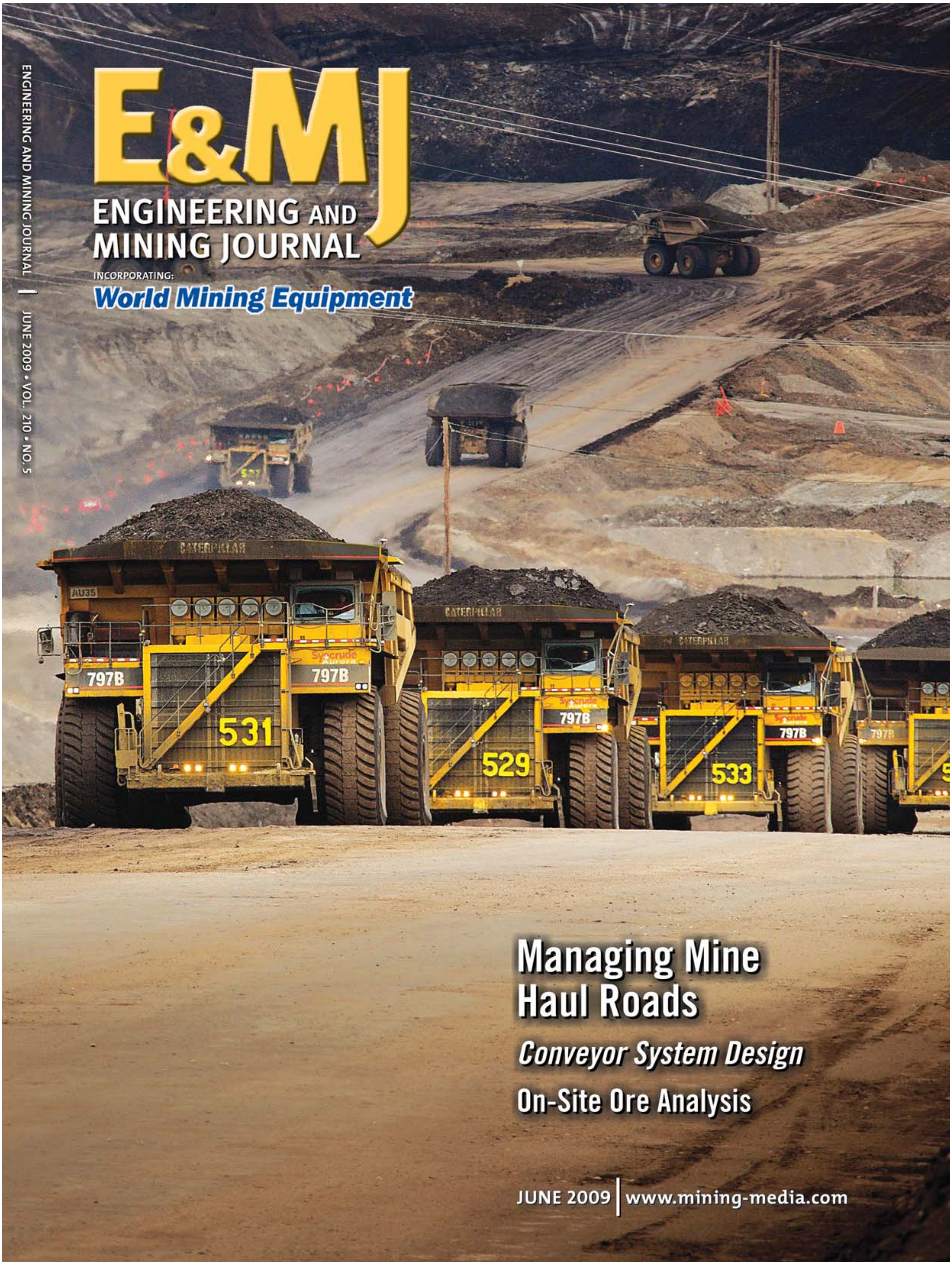

ENGINEERING AND MINING JOURNAL | JUNE 2009 • VOL. 210 • NO. 5

E&MJ
ENGINEERING AND MINING JOURNAL

INCORPORATING:
World Mining Equipment

Managing Mine Haul Roads

Conveyor System Design

On-Site Ore Analysis

JUNE 2009 | www.mining-media.com

Haul Road Design Considerations

Recognizing, managing and eliminating safety critical defects on mine haul roads

By Dr. Roger Thompson

The design and management of mine roads has developed over the past decade, both in response to the requirements of mine operators for more safe and efficient haulage systems, and the truck manufacturers' requirements for a more predictable and controlled operating environment. These developments have been paralleled by the need to minimize haulage hazards, from both a health and safety perspective. Generally, both objectives have been achieved, but with some specific areas of design and operation still presenting on-going potential health and safety hazards.

This article summarizes more than a decade of mine road accident data to illustrate a strong correlation between well designed and managed roads and reduced health and safety hazards. However, some hazards and incidents on mine roads are more common than others—what does this tell us about design, and more critically, management of a haul road network, to reduce these specific "safety-critical" incidents?

About half of the accidents on mine roads arise from design deficiencies centered on functional factors of dustiness, poor visibility, skid resistance and large stones in or on the road. Inappropriate junction layout, the absence or inadequacy of safety berms and lack of a road shoulder area were most frequently cited as factors in sub-standard geometric design. The balance of the accidents were attributable to non-standard acts including human interactive errors.

It is these human factor interactive effects that are the most difficult to eliminate in road design. They encompass the geometric, structural, functional and maintenance design components, and to prevent an accident or reduce the severity of its consequences, a road should be more accommodating to human error. In this way a haul road can be designed to compensate for human error; the more that is known about human error, the better the road can be designed to accommodate those actions or non-standard practices.

The article also summarizes design guidelines for these safety-critical issues. Implementation of the approach is seen as a basis for reducing the potential of an under-designed mine road to lead to health and safety defects and secondly as a means of giving haul road safety issues greater prominence in the minds of the road-user, operator, mine planner and designer alike.

Considerations for an Uncertain Economy

In uncertain economic climates, investment and operating decisions come under scrutiny. In the long run, this scrutiny returns improved efficiencies and leaner, healthier operations. The focus of this evolving evaluation process should and will certainly fall on haulage operations—simply by virtue of their contribution to overall cost of operations—often in excess of 50% of total costs for deep open-pit mines. While the end result—improved efficiency and reduced cost per ton hauled—is not in itself problematic, it is the route, or process followed to achieve these savings that needs to be carefully managed. Understanding how a road is designed, and, critically, the interplay between a good design and safe, cost efficient haulage are the key factors in eliminating safety critical defects.

Design and construction costs for the majority of haul roads represent only a small proportion of the mine's total operating and maintenance costs over its operating life. While it is possible to construct a mine haul road that requires no maintenance over its service life, this would be prohibitively expensive. On the other hand, a cheaply-built haul road would be expensive to operate, in terms of truck operating and road maintenance costs. In both cases however, there is no guarantee that an accident could be avoided—although it is clear that a well designed road would have a more predictable and controlled response to a potential failure.

Where no formal haul road design is used (i.e., an empirical approach based

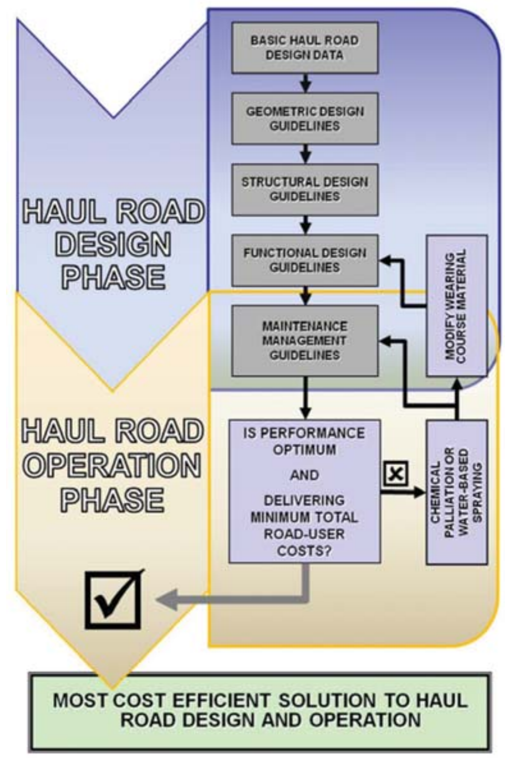

Figure 1: Typical haul road design terminology.

on local experience)—safe, economically optimal roads eventually result—but the learning curve is often steep and slow. This approach does not lend itself to an understanding of the road design process and more importantly, if haul road safety is sub-standard, does not easily allow the underlying cause of the unsafe condition or the role of road design in contributing to an accident (as a root-cause or associated factor) to be identified.

The haul road design forms a principal component of a transport operation on both surface and underground mines. Most mine operators will agree that a strong relationship exists between well constructed and maintained roads, and safe, efficient mining operations. Large modern surface mining operations generally incorporate high standards of road design work into the overall mine plan. The result is usually a well constructed roadway that is safe to operate and easy to maintain. This situation can be quite different for smaller surface or underground mining operations where either only a few vehicles are used in the transport of material or traffic volumes are comparatively low. Larger operations usually exhibit stronger and more well-defined management philosophy in which special localized consideration is often given to haul road construction and maintenance, whereas smaller operations, by virtue of their size, generally operate without such extensive management.

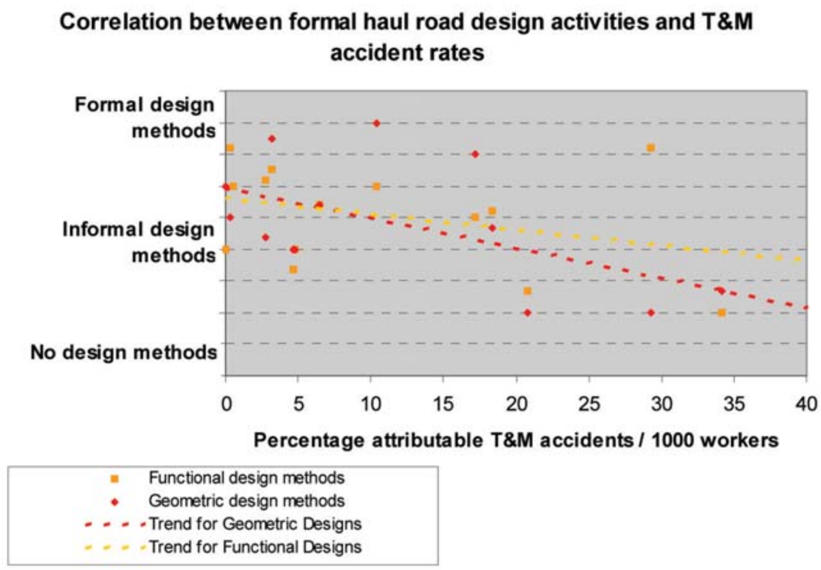

Figure 3: Relationship between how well the road is designed and the attributable accident rates.

Haul Road Design

Designing a safe and efficient haul road can only be achieved through an integrated design approach. If one design component is deficient, the other components will not work to their maximum potential and road performance and safety are often compromised. This will most often be seen as inherently unsafe, maintenance intensive and commonly, high rolling resistance roads. This combination of circumstances translates into hazardous, high-operating cost, low-productivity haul roads. A target for improvement certainly—but on what basis should an intervention be planned?

The cure is not necessarily just more frequent maintenance; faster cycle times, better driving habits, etc. No amount of maintenance will fix a poorly-designed road. A drive to reduce cycle times may compromise safety while driver training depends to a great extent on how well the driver 'reads' and anticipates road conditions.

Each component of the road infrastructure must be correctly addressed at the design stage. Figure 1 illustrates the integrated design approach. The various issues that must be addressed in a haul road design are:

The geometric design is commonly the starting point for any haul road design and refers to the layout and alignment of the road, in both the horizontal (curve radius) and vertical (incline, decline, ramp gradients, cross-fall, super-elevation) plane, stopping distances, sight distances, junction layout, berm walls, provision of shoulders and road width variation, within the limits imposed by the mining method. The ultimate aim is to produce an optimally efficient and safe geometric design and considerable data already exists pertaining good engineering practice in geometric design, suffice to say that an optimally safe and efficient design can only be achieved when sound geometric design principles are applied in conjunction with the optimal structural, functional and maintenance designs.

The structural design which will provide haul road strength to carry the imposed loads over the design life of the road without the need for excessive maintenance, caused by deformation of one or more layers in the road—most often soft or wet insitu materials below the road surface.

The functional design, centered on the selection of wearing course (or surfacing) materials where the most suitable choice, application and maintenance strategy is required which minimizes rolling resistance and the formation of defects in the road surface.

The maintenance design which identifies the optimal frequency of maintenance (routine grading) for each section of haul road in a network; thus maintenance can be planned, scheduled and prioritized for

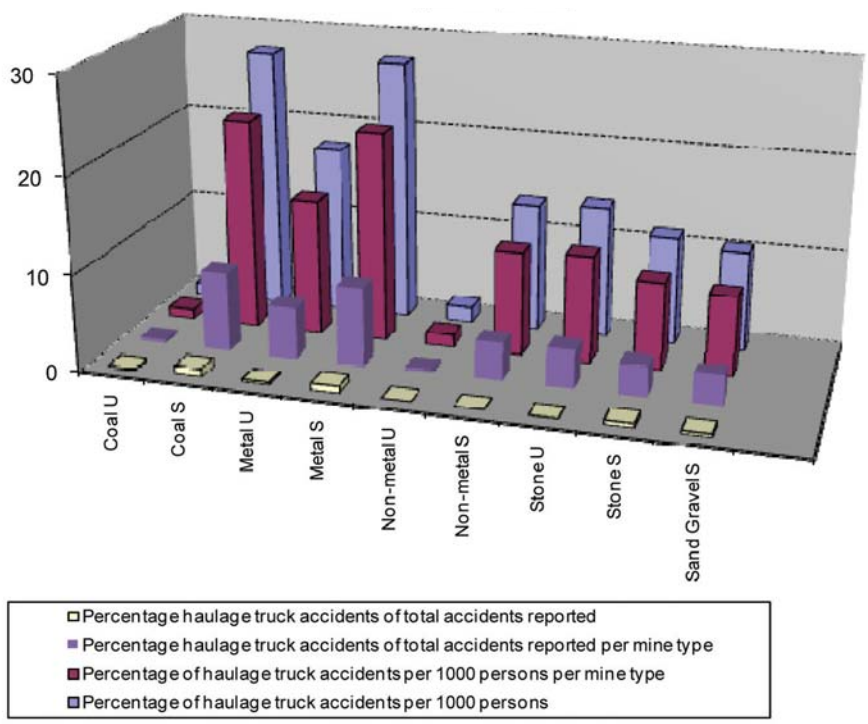

Figure 2: Powered haulage (truck haulage) accident/injury rates. (MSHA 2008 preliminary extrapolated data)

ACCIDENT AGENCY							
Sub-standard acts			Sub-standard conditions				
			Road design factor				
Human error	Non-standard practice	Other	Structural	Functional	Geometric	Maintenance	Other

Table 1: Classification system adopted to determine attributable accident causes.

optimal road performance and minimum total (vehicle operating and road maintenance) costs across the network. This is especially important where road maintenance assets are scarce and need to be used to best effect.

Safety Critical Defects in Mine Road Design

The U.S. Mine Safety and Health Administration (MSHA) database was used to make a preliminary assessment of truck-related accident rates in U.S. mining. Data has been extracted (and extrapolated where necessary) to analyze Powered Haulage – Haulage Truck class of accidents (See Figure 2). Accidents referred to here are based on all injury types reported (Fatal, Non-Fatal Day Lost and No Day Lost types).

Although the incident rates are low on an industry-wide basis, when accidents are attributed to mine type, only underground coal and non-metal mining attribute less than 4% of accidents attributed to truck haulage, a reflection more of the mining-method and equipment as opposed to any particular truck-haulage related safety strategy. When the incident rate per 1,000 employees is considered, surface coal and metal mining predominate, reflecting to an extent the highly mechanized nature of transport on these mines—but also the greater contribution of truck haulage accidents to (overall lower) mine-type accident rates.

While the data presented above puts the paper into context, without referring to each incident report to examine the details of the accident, it is difficult to determine how the role of road design impacts on safety.

A more detailed study was conducted in South Africa, encompassing truck accident reports from 1996, where it was found that in the majority of accident reports analyzed, scant attention or recognition was given to basic road design components, even where the deficient condition which led directly to the accident was clearly stated. The type of design activity related to attributable accident rate (accidents that involved vehicles on mine haul- or road-ways) is shown in Figure 3. It is seen that the more "formal" a design activity is, the less it is the attributable accident rate.

The attributable accident records were further analyzed to determine the sub-standard act or condition which either led to, or was implicated in each attributable accident. The criteria used in the assessment where the agency involved is initially identified (either sub-standard acts or conditions) is shown in Table 1. Once the agency is alerted, the specific action or condition implicated is identified. Table 2 summarizes the principal deficient road design factors thus determined, while Figure 4 presents the various percentages of agency factors implicated in these attributable accidents.

Of the total transport accidents analyzed and categorized, about 50% could be directly attributed to road design and operation. Of these, 60% were related to non-standard acts including human error. Of the 40% associated with sub-standard road design factors, geometric and functional components predominate as the agencies implicated, with maintenance and structural design exhibiting very little influence. From an analysis of the principal sub-standard surface mine road design factors which were most frequently encountered in the accident reports, the primary areas of concern were the functional factors of dustiness, poor visibility, skid resistance (wet or dry conditions) and large stones in or on the road. In the case of geometric design it was seen that inappropriate junction layout, the absence or under-design of safety berms and lack of a road shoulder area (road width) were most frequently cited as factors in sub-standard geometric design.

Solutions to mine haul road safety problems are physical in nature since they relate to the road design components of geometry and function mostly. However, this work has shown that human factors (including nonstandard practices), vehicle (mechanical) factors and other deficiencies in road design are all implicated in attributable accidents.

While improved mine haul road design activities may well reduce design-related accidents, it would appear that little recognition is given to the human factors which are a significant contributor to haulage accidents. The human factor is the most problematic to address in

Functional Design	Geometric Design
Dustiness Wearing course material selection inappropriate. Visibility compromised locally.	*Junction layout* Poor junction layout or incorrect or inappropriate signage. Poor visibility of or from junction. Vehicle turning collisions.
Poor visibility Excessive dustiness generated from vehicle wind shear or due to windy conditions, especially at night.	*Safety berms* No safety berms where road runs on an embankment (fill area) or berms too small. Vehicles which lost control on these sections ran off the road.
Skid resistance Wet wearing course material, either after rain or watering to allay dust. In several instances, dry skid resistance also problematic.	*Road shoulders/width* Collisions with vehicles (breakdown, etc.) parked on roadside, no shoulder or road too narrow. Poor demarcation of parked equipment. Collisions due to vehicle to vehicle interaction on narrow roads.
Large stones/road defects LDV's or smaller utility vehicles running over large stones protruding from the wearing course. Spillage from trucks is also a common causative factor. Defect in road caused loss of vehicle control.	*Run-aways- brakes* Accidents due to brake failures whilst hauling laden down-grade or vehicle run-aways down-grade. Excessive local gradients (>10%) combined with poor/slippery road conditions.

Table 2: Summary of principal deficient surface mine road design factors.

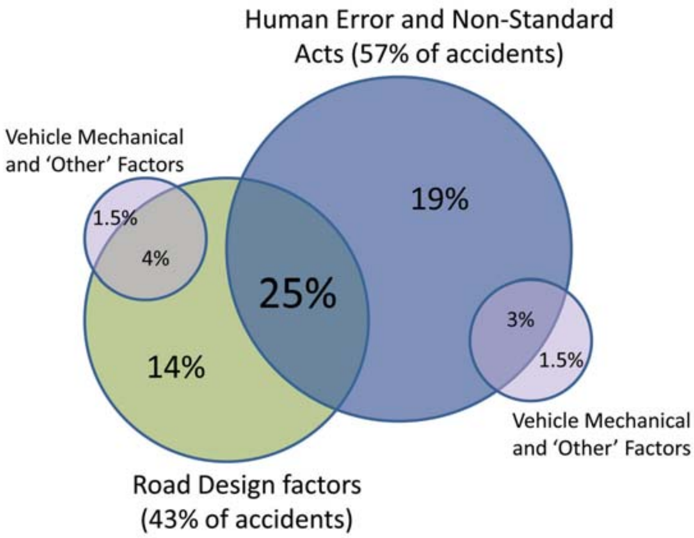

Figure 4: Factors interactions contributing to truck haulage accidents.

a road design. It is often easier break the link between the interactive effects which may lead to accidents than trying to predict and reduce human error.

These human factor interactive effects include the structural, functional, maintenance and geometric design components and from Figure 4 it is seen that 25% of the accidents in which human error was implicated were also associated with deficiencies in road design. To prevent an accident or reduce the severity of its consequences, a road should be more accommodating to human error. In this way a haul road can be designed to compensate for human error; the more that is known about human error, the better the road can be designed to accommodate those actions or non-standard practices. Since the interaction of the road and road-user extends to more than just the four design categories previously described, a more comprehensive review of a road design is required, in which many of the other causative factors are assessed as part of a broader approach to audit and mine standards' development.

Mine Haul Road Safety Audit System

In the analysis of truck haulage accidents and in particular those attributable to road design factors it was found that although only a small percentage of such accidents are directly attributable to poor design standards, there was a general lack of recognition of the role of the various design factors in safe transportation operations. A haul road safety audit is essentially a formal examination of an existing or proposed haul road which interacts with the roadusers, in which road or project accident potential and safety performance is analyzed. The benefits of a haul road safety audit are primarily:

- To provide an appraisal of potential safety problems for road-users and road operators alike;
- To ensure that suitable measures for hazard elimination are fully evaluated and applied;
- To promote haul road safety in the minds of road-user, operators and designers; and
- To eliminate the need for costly remedial work (if the audit is implemented at the design stage).

A mine haul road safety audit can be conducted on any existing haul road, or on any proposal which is likely to alter the interactions between different road-users (i.e., haul trucks, service vehicles, maintenance equipment and the road), or between road-users and their physical environment. The approach to haul road safety auditing is based on the application of the technique at the earliest possible stage of the project, thereby ensuring early elimination of any potential safety problems. The technique should also be applicable to existing roads to enable operators to identify potential safety problems and take appropriate steps to rectify them. Five stages involved are: the feasibility stage, the draft design stage, the detailed design stage, the pre-opening stage and the audit of existing haul roads.

For each stage the components of geometric, structural, functional and maintenance design are assessed according to a number of design factor issues for each component. The scope of the design factor issues increases as the design process becomes finalized, the most comprehensive list of issues being associated with the audit of existing haul roads. The breakdown of audit stages and design components is shown in Table 3.

The first four checklists are most usefully applied consecutively during a road design project. The checklist compiled for existing roads may be used as a guide to the efficacy of an established design and as an aid in recognizing specific transportation and haul road hazards. This should ideally be carried out when some modification to the haul road network, traffic volumes or vehicle types are made. Full audit checklists can be found on the Mine

AUDIT STAGE	FEASIBILITY	DRAFT DESIGN	DETAILED DESIGN	PRE-OPENING	EXISTING
Design components	General Topics General Design Issues Alignment Junctions Environmental Road Users	General Topics General Design Issues Alignment Junctions Environmental Road Users Signs and lighting	General Topics General Design Issues Alignment and cross section Junctions Environmental Road Users Signs and lighting Physical Objects Construction	General Topics General Design Issues Alignment and cross section Junctions Road Users Signs and lighting Physical Objects Maintenance Finishing Training road-users	General Topics General Design Issues Alignment and cross section Junctions Road Users Signs and lighting Physical Objects Maintenance Training road-users Road-user feedback

Table 3: Mine haul road design safety audit components.

Health and Safety Council (South Africa) Web site.

Changes in the economic climate are the drivers for a re-evaluation of investment and operations. As the focus falls on haulage operations, opportunities for cost savings on road design and construction may become apparent. It is the route, or process followed to achieve savings in transport operations that needs to be carefully managed. Engineers can be guided on this journey by the understanding of how a road is designed, and, critically, the interplay between a good design and safe, cost efficient haulage.

There is clear evidence to suggest that where there is no formal recognition of road design requirements, safety is compromised and remediation hampered by a lack of understanding of what is safety critical, why the condition exists and how to fix it. A formal checklist of road design components would enable mine operators to focus on the particular design deficiency identified in the accident and improve or modify that design component accordingly. It was also argued that of those accidents in which human error or non-standard practices were implicated, some of these types of accidents could be avoided by providing greater accommodation of error, or reducing the inherent error potential and hazards associated with transportation operations.

The mine haul road safety audit system was developed to improve awareness of the role of good design in reducing transportation accidents. The safety audit approach was based on the recognition and systematic auditing of a number of key design components and issues. The benefits of the approach, in the light of the findings relating to the role of road design in truck haulage accidents are seen as a potential reduction in the number and severity of accidents, haul road safety being given greater prominence in the minds of the roaduser, operator and designer alike and finally, as a basis for evaluating the impact on safety and performance of any changes to the haulage system as a whole.

Dr. Roger Thompson is a professor of mining engineering at the Western Australian School of Mines, Curtin University of Technology, in Kalgoorlie. This article was based on research work (in conjunction with Proffs Visser, Fourie and Smith) and adapted from a presentation he made at Haulage & Loading 2009, held during May, in Phoenix, Arizona. The full report along with his presentation will be available at www.mining-media.com. E-mail: r.thompson@curtin.edu.au.