

MINE HAUL ROAD DESIGN AND MANAGEMENT BEST PRACTICES FOR SAFE AND COST-EFFICIENT TRUCK HAULAGE

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Abstract

Well designed and maintained haul roads are the key to minimizing truck haulage on-road hazards and costs, as well as increasing productivity. However, practically designing and managing a haul road for optimal performance is often difficult to achieve. Poorly designed and built roads exhibit high rolling resistance - a 1% increase in road rolling resistance can typically reduce speed on ramp by as much as 10% - and on the flat by up to 26%. In the current economic climate, 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. Whilst 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. We can be guided on this journey by our understanding of how a road design is developed, and, critically, the interplay between a good design and safe, cost efficient haulage.

This paper briefly summarizes the evolution of mine haul road design, from the seminal USBM work of Kaufman and Ault in 1977, through to current geometric, structural, functional and maintenance management design components. These augmented design and management guidelines have been 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, both from a health and safety perspective.

Whilst improved mine haul road design does indeed reduce haulage accidents, recognition also needs to be given to human factors which are a significant contributor to haulage accidents. The human factor is the most

problematic to address in 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 geometric, structural and functional design components and to prevent an accident or reduce the severity of its consequences, a road should be more accommodating to human error. The more that is known about human error, the better a road can be designed to accommodate those actions or non-standard practices that would, on a poorly designed road, invariably escalate an error into an accident.

Introduction

The haul road design and subsequent road management and maintenance forms a principal component of a transport operation in surface 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 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 and stronger and more well-defined management philosophy in which special localized consideration is often given to haul road design, management and maintenance, whereas smaller operations, by virtue of their size, generally operate without such extensive design and management input (MHSC⁽¹⁾, Randolph and Bolt⁽²⁾).

Where design and management input is lacking (i.e. using an empirical approach based on local experience) - safe, economically optimal roads eventually result - but the learning curve is steep & 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, it 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.

One of the first, and arguably most important initiatives to formalize the approach to design and management of mine haul roads was the USBM⁽³⁾ Information Circular 8758 - Design of Surface Mine Haulage Roads - A Manual, by Walter Kaufman and James Ault. The aim of this publication was to provide a complete manual of recommended practices that promote safer, more efficient haulage. The authors recognized that the development of surface mine haulage equipment had outstripped available (mine) road design technology, resulting in numerous accidents caused by road conditions that were beyond the vehicle's and driver's ability to negotiate safely.

The content of the USBM design guidelines was developed primarily in response to haulage accidents, but also included current practice information from mining companies and equipment manufacturers. Content covered such aspects as road alignment (both vertical and horizontal), road cross-section, construction materials, surfacing materials, road width, cross-slope and berm design, together with traffic control and drainage provisions, as was suggested criteria for road and vehicle maintenance and for runaway vehicle safety provisions.

A more rigorous approach categorizes the various issues that must be addressed in a haul road design (following Thompson and Visser⁽⁴⁾);

- The geometric design - commonly the starting point for any haul road design and refers to the layout and alignment of the road, in both the horizontal and vertical 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, 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 provides 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, weak or wet in-situ materials below the road surface.
- The functional design, centered on the selection of wearing course (or surfacing) materials where the most suitable choice and application is required which minimizes the rate of defect formation in the road surface, which would otherwise compromise road safety and performance.
- 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 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.

Comparing the content of the USBM work to the more recent 'integrated mine road design' methodology of Thompson and Visser⁽⁴⁾, it is evident that the USBM work addressed each of the design components, although not specifically relating each design guideline to its associated design component. Designing a safe and efficient haul road is best 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 is 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.

The cure, however, is not necessarily just 'more frequent maintenance'; 'faster cycle times', 'better driving habits', etc. No amount of maintenance will fix a poorly-designed road. Each component of the road infrastructure must be correctly addressed at the design stage. Figure 1 illustrates the integrated design approach.

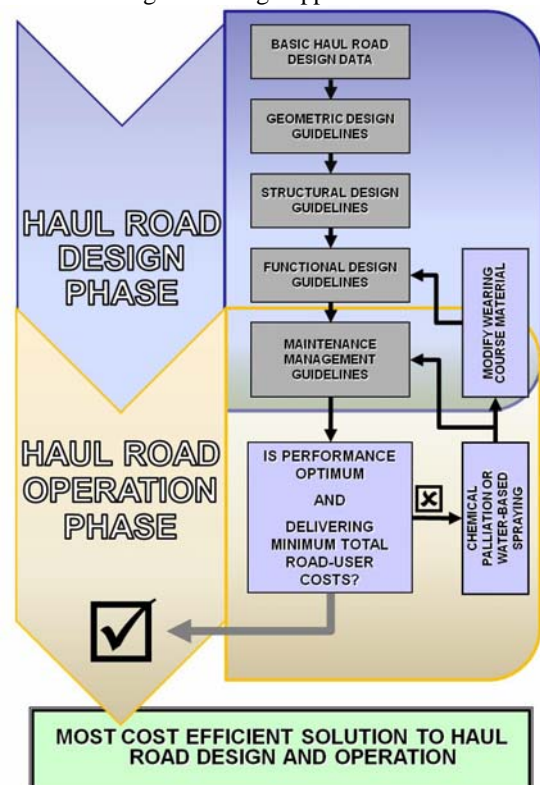


Figure 1. Typical integrated approach to road design.

Safety Critical Defects In Mine Road Design

Just as when developing the original USBM guidelines in 1977, amending existing or developing new mine road design methodologies requires reference to current surface (powered) haulage accident and incident records to identify the major contributory factors that led to these accidents. Several studies have been undertaken, both in the United States (Randolph and Boldt⁽²⁾, USBM⁽⁵⁾, Aldinger et al⁽⁶⁾), and South Africa (MHSC⁽¹⁾). From an analysis of the principal sub-standard surface mine road design factors which were most frequently encountered in the accident reports, these studies lead to the identification of several key problem areas which should guide development of appropriate design recommendations.

Using the MSHA data-base to make a preliminary assessment of truck-related accident rates in US mining for the period January – December 2008, although the incident rates are low on an industry-wide basis (about 1% of all accidents), when the ‘Powered Haulage – Haulage Trucks’ class of accidents are analyzed per mine type, for surface coal and metal mines approximately 8% of accidents are attributable. When the incident rate per 1000 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 contribution of truck haulage accidents to overall accident rates.

Whilst this data 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 textual analysis was reported by Randolph and Boldt⁽²⁾, based on the

analysis of Aldinger et al⁽⁶⁾, using accident reports over the period 1989-1991, which is shown in Figure 2.

In their study of surface coal mining, equipment operation was the most common category of accident for haulage trucks (46%). Within the equipment operation accidents, the most common types were jarring (38%) and loss of control (27%). The main jarring categories were rough ground (44%), loading (33%), and dumping (16%). Loss of control categories included too close to edge (36%) and runaway (28%). Whilst there is no specific reference to the design component that was implicated in these accidents, it has been shown that haul road structural design defects contribute significantly to jarring-rough ground incidents (Miller et al⁽⁷⁾), whilst functional and geometric design were likely contributory factors in the loss of control accidents.

The MSHA safety bulletin (Fesak, Breland and Spadaro⁽⁸⁾) reported the results of 4397 accidents from 1990-1996 from which some 1300 lost time accidents associated with water trucks, front end-loaders, tractor/scrapers, ore carrier/large trucks, ore haulage trucks, or other utility trucks were isolated and evaluated. They reported that 39% of the lost-time accidents were associated with roads and (traffic) control issues. However, the specific road or (traffic) control design component that was deficient or implicated in the accident was not recognized.

Internationally, a study conducted in South Africa by Thompson et al⁽⁹⁾ 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.

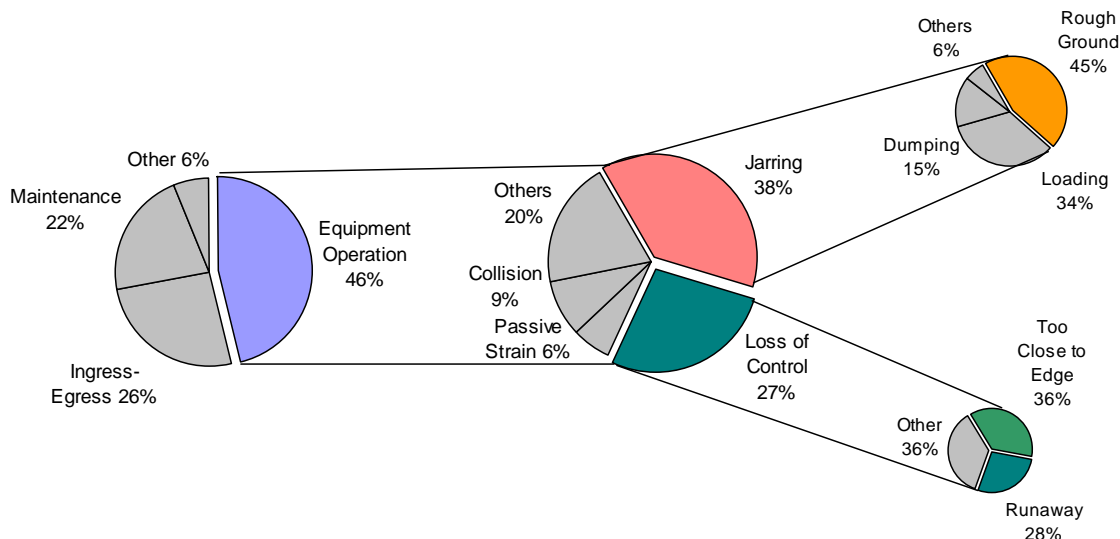


Figure 2. Surface coal haulage truck accident categories (after Aldinger et al⁽⁶⁾).

Figure 3 shows how the type of design activity relates to attributable accident rate (accidents that involved vehicles on mine haul- or road-ways). It is seen that the more 'formal' a design activity is, the less is the attributable accident rate.

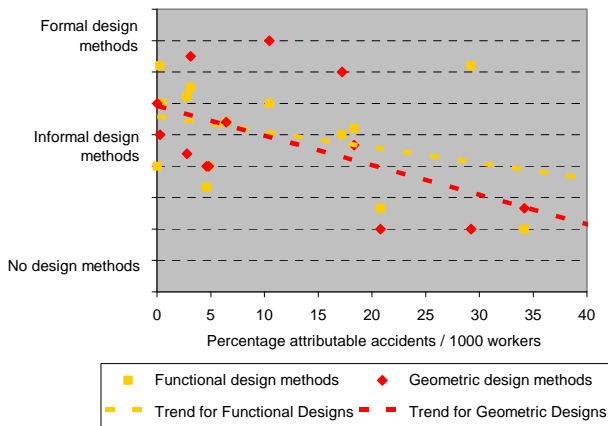


Figure 3. Relationship between road design and attributable accident rates.

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. Once the agency is identified, the specific action or condition implicated is identified. The principal deficient road design factors thus determined were;

- Geometric Design
 - Junction layout: Poor junction layout or incorrect or inappropriate signage. Poor visibility of or from junction. Uniformity of traffic controls.
 - Safety berms: No safety berms where road runs on an embankment (fill area) or berms too small. No berm maintenance. Vehicles which lost control on these sections ran off the road.
 - Road shoulders: Collisions with vehicles (breakdown, etc.) parked on roadside, no shoulder or road too narrow. Poor demarcation of parked equipment. Poor or temporarily obstructed sight lines.
 - Run-aways- brakes: Accidents due to brake failures whilst hauling laden down-grade or vehicle run-aways down-grade. Excessive gradients (>10%).
- Structural Design
 - Jarring: Poor ride quality due to permanent deformation in base or in-situ materials and reflected damage in surfacing (wearing course).

- Directional stability: Large areas of potholing and slip cracks. Evasive action of vehicle in leaving demarcated lane.
- Functional Design
 - Dustiness: Wearing course material selection inappropriate.
 - Poor visibility: Excessive dustiness generated from vehicle wind shear or due to windy conditions, especially at night.
 - Skid resistance: Wet wearing course material, either after rain or watering to allay dust. In several instances, dry skid resistance also problematic. Inappropriate material for geographic location of road.
 - Large stones: LDV's or smaller utility vehicles running over large stones protruding from the wearing course. Spillage from trucks is also a common causative factor. Evasive action of vehicle in leaving demarcated lane.

Figure 4 presents the various percentages of agency factors implicated in these attributable accidents. Of the total transport accidents analyzed and categorized, 47% could be directly attributed to road design and operation. 60% of these 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 less influence.

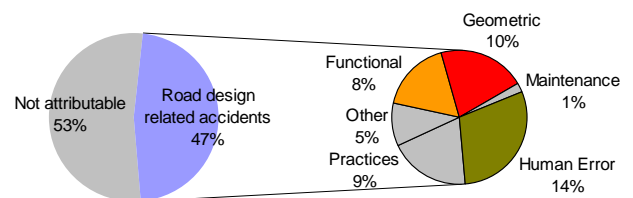


Figure 4 Role of road design in attributable accidents.

Solutions to mine haul road safety problems are physical in nature since they predominantly relate to the road design components of geometry, structure and function. However, this work has shown that human factors (including non-standard practices), vehicle (mechanical) factors and other deficiencies in road design are all implicated in attributable accidents. Figure 5 illustrates the relative percentage contributions of each of these factors to attributable accidents.

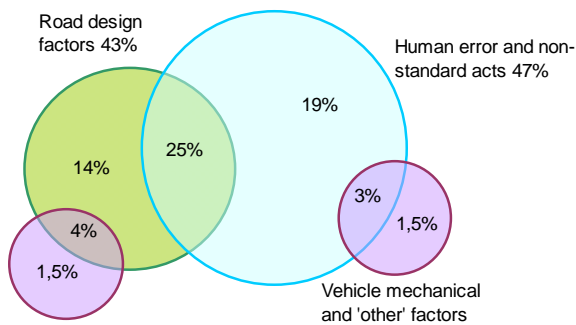


Figure 5 Factor interactions contributing to truck haulage accidents.

Whilst 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 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 5 it is seen that 25 percent 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.

Mine Road Design Guideline Development

Just as the authors of the original USBM guidelines recognized that the development of surface mine haulage equipment had outstripped mine road design technology, the continuing increase in truck size to-date, together with more recent powered haulage accident and incident analyses, has warranted further development of mine road design guidelines. Using the USBM⁽³⁾ manual as a starting point, these key developments are summarized below, as applied to the geometric, structural and functional design components defined earlier.

Geometric Design

The geometric layout of a mine haul road is dictated to a great extent by the mining method used and the geometry of both the mining area and the orebody. Mine planning software enables various haul road geometric options to be considered and the optimal layout selected,

both from a road design and economic (lowest cost of provision) perspective. Whilst these techniques often have default design values embedded in the software, it is nevertheless necessary to review the basic concepts of geometric design if any modifications are to be considered in the design of mine roads, either on the basis of economics or, more critically, from a safety perspective.

The road layout – or alignment, both horizontally and vertically is generally the starting point of the geometric design. Practically, it is often necessary to compromise between an ideal layout and what mining geometry and economics will allow. Any departure from the ideal specifications will result in reductions of both road and transport equipment performance.

The USBM data of Kaufman and Ault still forms a sound basis for this design component – albeit with updates to truck types and dimensions. Broadly speaking, safety and good engineering practice require haul road alignment to be designed to suit all vehicle types using the road, operating within the safe performance envelope of the vehicle, or, where this is not possible, at the speed limit applied. Ideally, geometric layout should allow the vehicles to operate at their maximum safe speed, but since the same road is used for laden and unladen haulage, there is often the need to minimize laden travel times, through appropriate geometric alignment, whilst accepting compromise (generally in the form of speed limits) on the unladen return haul. Some of the more common geometric design problems are listed below;

- Avoid sharp horizontal curves at or near the top of a grade section of road. If a horizontal curve is necessary, start it well in advance of the vertical curve.
- Avoid switchbacks where possible - but if mine plan dictates their use, make radius as large as possible and avoid placing on grade.
- Avoid sharp horizontal curves requiring a (further) speed reduction following a long sustained downgrade where haul trucks are normally at their highest speed.
- Avoid short tangents and varying grades, especially on multi-lane roads. Grades should be smooth and of consistent grade percentages.
- Avoid intersections near the crest of vertical curves or sharp horizontal curves. Intersections should be as flat as possible with sight distances being considered in all four quadrants. Where an intersection lies at the top of a ramp, consider 100-200m of level road before the intersection and avoid stopping and starting a laden haul truck on grade.
- Avoid intersections with poor drainage. Drainage design at intersections should stop any ponding of water against intersection super-elevated curves.

- Avoid sections of road with no camber or cross-fall. Often encountered at curve super-elevation run-in or -out, these flat sections should preferably be at a 1-2% vertical grade to assist drainage.
- Avoid staggered cross roads or other multiple road junctions. Re-align roads to provide for conventional cross road layouts and at any junction, always provide splitter or median islands to prevent vehicles cutting corners through a junction.
- Avoid signage, vegetation, roadside furnishings or excessively high splitter islands that would otherwise eventually limit sight distances in any of the four quadrants required.
- Avoid having the inside (and lower) side of a super-elevated bench-to-ramp access road at a steeper gradient than the ramp road itself, by reducing the center-line grade of the curve. The inside grade of the curve should not exceed that of the ramp road. Using a transition spiral, and where pit room permits, set the inside gradient of the curve flatter than the ramp grade by 2-3% to compensate for increased curve rolling resistance.

With regard to safety berms, crest (outslope) or road-edge (windrow) berms will not reliably stop trucks (especially high speed laden or unladen trucks) from leaving the road. At best, they will provide limited deflection and warning to the driver that the truck path needs correcting. For large haul trucks, the berm height should be at least 66% of the truck wheel diameter. The slope of the sides of the safety berm should be preferably 3H:1V to ensure stability and maintenance of height.

Truck GVW has a significant deformation effect on the berm, which is typically constructed from unconsolidated material and as the truck climbs the berm, the high centre of gravity in combination with a narrow width of the wheel track make trucks susceptible to overturn. Furthermore, large tire sizes and non-centering steering mechanisms reduce the tendency of the truck to redirect itself when encountering a berm. With 4x6 and 6x6 wheel drive articulated dump trucks, berm dimensions in excess of 66% wheel diameter are recommended, due to the trucks ability to climb smaller berms. Other factors such as inertial characteristics, sprung mass ratio and suspension characteristics indicate significantly different response patterns for haul vehicles when encountering berms.

Structural Design Guidelines

The CBR cover-curve design method (USBM⁽³⁾) has been widely applied to the design of mine haul roads in which untreated materials are used. Although it has generally been superseded by the mechanistic approach described later, there are some design cases where it

would still be appropriate. In Figure 6, an updated version of the USBM CBR design charts are presented, appropriate for the wheel loads of ultra-class trucks, together with the approximate bearing capacities of various soils types defined by the Unified Soil Classification and American Association of State Highway Transportation Officials' systems.

The following formula can also be used to estimate the thickness of cover (Z_{CBR} (m)) required above a material of California Bearing Ratio (CBR %);

$$Z_{CBR} = \frac{9.81t_w}{P} \left[0.104 + 0.331e^{(-0.0287t_w)} \left[2 \times 10^{-5} \left(\frac{CBR}{P} \right) \right] \left[\left(\frac{CBR}{P} \right)^{-(0.415 + P \times 10^{-4})} \right] \right]$$

Where t_w is the truck wheel load (metric tons), P is tire pressure (kPa). When the ESWL is used to estimate wheel load (to replicate the increased induced stresses deeper in a road layer), the cover Z_{ESWL} (m) required is given by;

$$Z_{ESWL} = Z_{CBR} + \left[0.184 + \left(0.086CBR + \frac{17.76CBR}{t_w} \right) \right]^{-1}$$

However, when multi-layered roads are considered in conjunction with a base layer of selected blasted waste rock, a mechanistic approach is more appropriate. When a selected waste rock layer is located under the wearing course, road performance is significantly improved, primarily due to the load carrying capacity of the waste rock layer which reduces the susceptibility of the soft sub-grade and in-situ to the effects of high axle loads. It also has the added advantage of reduced construction costs (by virtue of reduced volumetric and compaction requirements), compared with the CBR cover-curve design approach.

A mechanistic design is based on a theoretical linear-elastic multi-layer system model of road layers. A limiting design criteria of vertical compressive strains in the sub-grade or in-situ is then used to assess the haul road under the specific loading conditions, thereby determining the adequacy of the structural design.

More details are presented by Thompson and Visser⁽¹⁰⁾, but in general terms, applied load, sub-grade strength and the pavement structural thickness and layer strength factors predominantly control the structural performance of a haul road. An upper limit of 2000 microstrain is generally placed on layer strain values. Strain values exceeding 2500 microstrains are associated with unacceptable structural performance in all but the most lightly traffic and short-term roads. Data from Figure 7 can be used to assist in selecting a limiting strain value, according to the category of road to be built, its operating life and traffic volumes. In addition, to prevent excessive damage to the wearing course, deformation at the top of this layer must be limited to no more than 3mm.

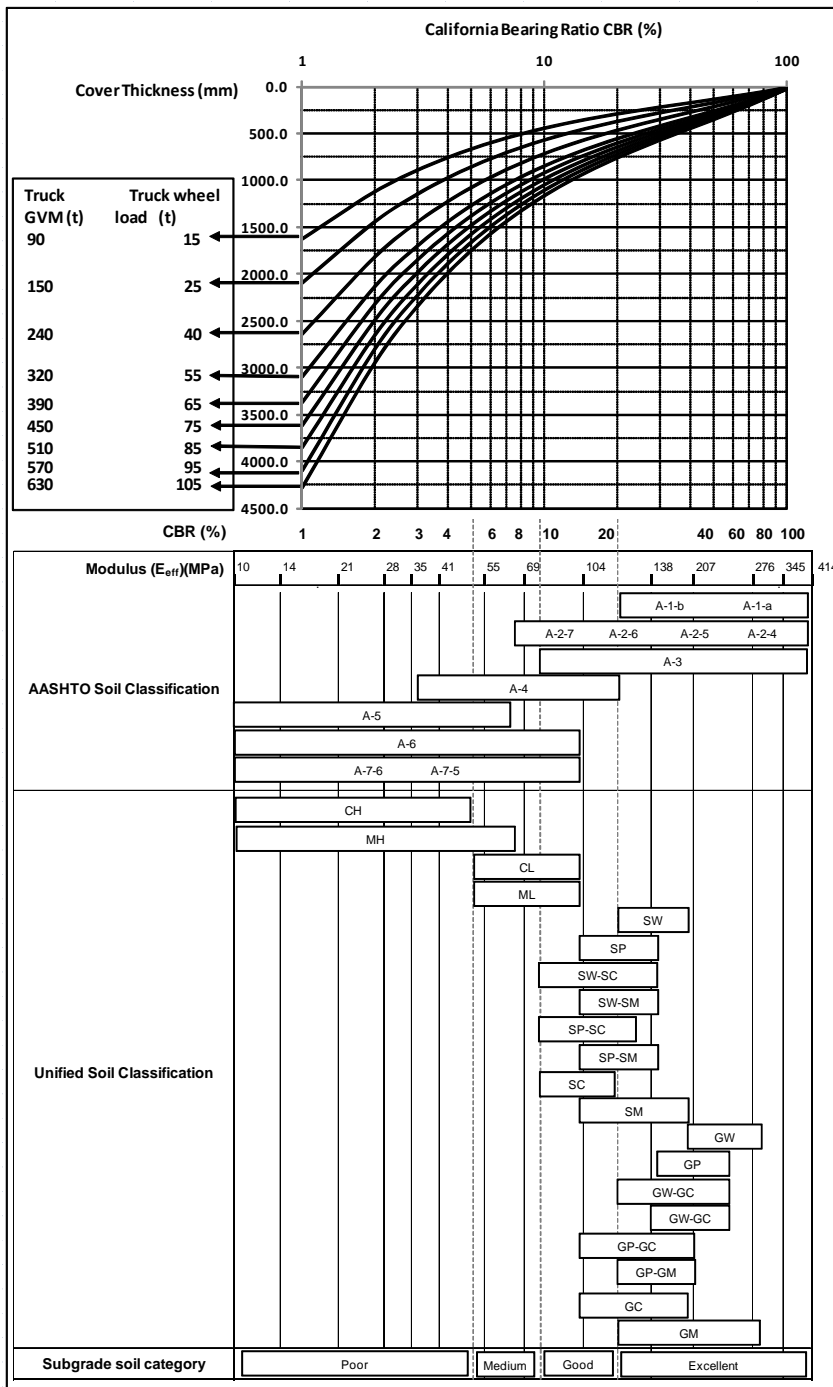


Figure 6 CBR cover curves for 90-630 metric ton GVM haul trucks and approximate bearing capacities of various soils types defined by the Unified Soil Classification and American Association of State Highway Transportation Officials (AASHTO) systems.

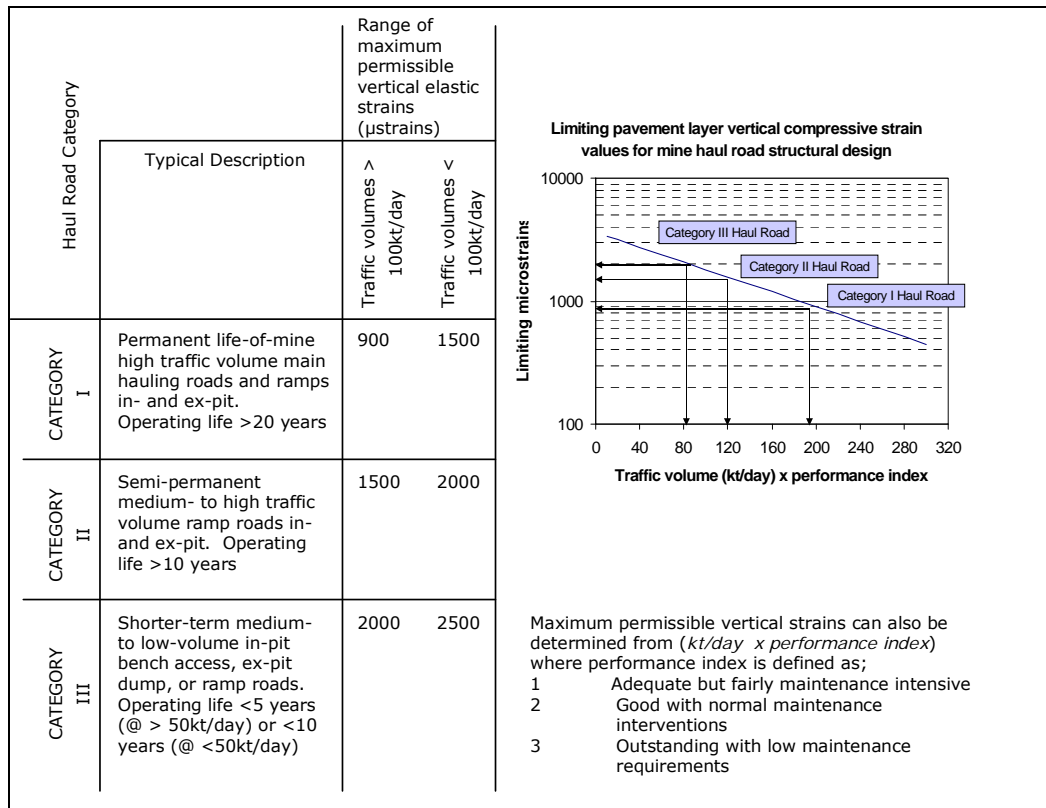


Figure 7 Haul road classification and associated mechanistic structural design limiting strain criteria.

Functional Design Guidelines

The USBM guidelines provided the first insight into haul road functionality through consideration of general road performance. The primary characteristics considered were road adhesion and rolling resistance and the most practical construction materials recognized were asphaltic concrete, crushed stone or gravel and stabilized earth. The concept of functionality was not specifically introduced but rather alluded to in terms of some of the defects reported with these various construction materials. In conclusion, they recommended crushed stone or good quality natural gravel as wearing course materials, together with specifications for gradation and Atterberg limits.

The most common wearing course material for haul roads remains compacted gravel or gravel and crushed stone mixtures. In addition to a low rolling resistance and high coefficient of adhesion, their greatest advantage over other wearing course materials is that roadway surfaces can be constructed rapidly and at relatively low cost. As with structural designs, if local mine material can be used for construction, the costs are all the more favorable. This cost advantage is, however, not apparent in the long term

if the characteristics of the wearing course material result in an inherently unsafe and maintenance intensive road.

By relating wearing course performance in terms of safety-critical defects (derived from an analysis of those road design factors implicated in haulage accidents, following Thompson and Visser⁽¹¹⁾), the defects most commonly associated with mine haul roads, in order of decreasing impact on haulage safety and operational performance are typically;

- Skid resistance - wet, Skid resistance - dry, Dustiness, Loose material, Corrugations, Stoniness - loose, Potholes, Rutting, Stoniness - fixed, Cracks - (slip, longitudinal and crocodile).

By examining which wearing course material property parameters lead to these defects, a specification was developed for wearing course materials selection. The specifications are based on an assessment of wearing course material shrinkage product (Sp) and grading coefficient (Gc), defined as;

$$Sp = LS \times P425$$

$$Gc = \frac{(P265 - P2) \times P475}{100}$$

where;

- LS = Bar linear shrinkage
- P425 = Percent wearing course sample passing 0.425mm sieve
- P265 = Percent wearing course sample passing 26.5mm sieve
- P2 = Percent wearing course sample passing 2mm sieve
- P475 = Percent wearing course sample passing 4.75mm sieve

A suitable wearing course material can be determined from the selection chart in Figure 8, in terms of two parameters that describe the material; the grading coefficient (Gc) and shrinkage product (Sp). If the three most critical haul road defects are considered, it appears that mine road-user preference is for much reduced wet skid resistance, dust and dry skid resistance defects. This defines the focus point of the specifications to an area bounded by a grading coefficient of 25-32 and a shrinkage product of 95-130 in which the overall and individual defects are minimized (Area 1). Extending this region to encompass poorer (but nevertheless operable) performance enables an additional area (Area 2) to be defined.

The specifications should also be evaluated in the light of other material property limits identified as important in functional performance but not directly assessed in Figure 8. Table 1 presents a summary of these property limits.

Table 1. Additional wearing course material selection parameters.

Material Parameter	Range	
	Min	Max
Shrinkage Product	85	200
Grading Coefficient	20	35
Dust Ratio	0,4	0,6
Liquid Limit (%)	17	24
Plastic Limit (%)	12	17
Plasticity Index	4	8
4-day soaked CBR at 98% Mod AASHTO	80	
Maximum Particle Size (mm)		40

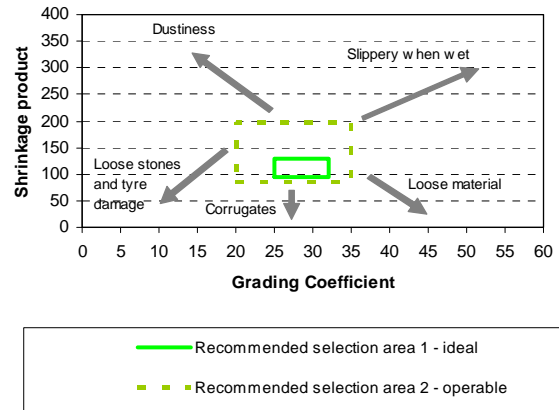


Figure 8 Haul road wearing course material selection.

Maintenance Design

The maintenance aspect of haul road design cannot be considered separate from the geometric, structural and functional design aspects since they are mutually inclusive. Design and construction costs for the majority of haul roads represent only a small proportion of the total operating and maintenance costs. Whilst it is possible to construct a mine haul road that requires no maintenance over its service life, this would be prohibitively expensive, as would the converse but rather in terms of operating and maintenance costs. An optimally safe and efficient road design will include a certain amount and frequency of maintenance (watering, grading etc.) and thus maintenance can be planned, scheduled and optimized within the limits of required road performance and minimum vehicle operating and road maintenance costs.

Road maintenance itself is rarely implicated as a contributory factor in mine road accidents. This is because maintenance is seen as a reactionary measure, a maintenance activity, (blading, grading, watering, etc.) being initiated when road performance becomes unsatisfactory. However, if the geometric, structural or functional design components are incorrectly addressed at the design stage, a road will invariably become maintenance intensive as a result and frequent maintenance interventions will be required. Maintenance per se will not correct the underlying road design deficiency, only temporarily reduce its impact on safety and operational efficiency. Hence in this discussion, maintenance management system design (Thompson and Visser^(4,12)) should not be considered as a universal remedy for poor road design in the first instance and the root-cause of road under-performance should be sought in the geometric, structural or functional design components.

Conclusions

Well designed and maintained haul roads are the key to minimizing truck haulage on-road hazards and costs, as well as increasing productivity. However, practically designing and managing a haul road for optimal performance is often difficult to achieve. We can be guided on this endeavor by our understanding of how a road design is developed, and, critically, the interplay between a good design and safe, cost efficient haulage.

The seminal USBM work of Kaufman and Ault in 1977 was the starting point of a formalized approach to mine road design. Just as the authors of the original USBM guidelines recognized that the development of surface mine haulage equipment had outstripped mine road design technology, the continuing increase in truck size to-date, together with more recent powered haulage accident and incident analyses, has warranted further development of mine road design guidelines.

Augmented design and management guidelines have been 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. Amending existing or developing new mine road design methodologies requires an analysis of surface (powered) haulage accident and incident records to identify the major contributory factors that led to these accidents. Several studies are summarized from which it was seen that the principal sub-standard surface mine road design factors were geometric and functional design issues, with a lesser, but still significant contribution from inadequate structural design.

Whilst improved mine haul road design does indeed reduce haulage accidents, recognition also needs to be given to human factors which are a significant contributor to haulage accidents. The human factor interactive effects include the geometric, structural and functional design components and to prevent an accident or reduce the severity of its consequences, a road should be more accommodating to human error. The more that is known about human error in the context of mine haulage, the better a road can be designed to accommodate those actions or non-standard practices that would, on a poorly designed road, invariably escalate an error into an accident.

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