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IMPROVED VISIBILITY SYSTEMS FOR LARGE HAULAGE VEHICLES

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16. Abstract (Limit: 200 words)
An improved visibility system was developed for use on the large (100 ton+) haulage trucks typically operated in open pit and surface mines. The improved visibility system provides the truck driver with a means of viewing hazardous situations that occur in the extensive blind areas adjacent to his truck. The cost effective, reliable, visibility system consists of a closed-circuit television, three unique fresnel viewers, and two improved mirrors. This report describes the visibility problems of large trucks in the surface mining environment, shows the performance of existing mirrors, substantiates concept selection, and describes the prototype improved visibility system.

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Open pit	Fresnel lens
Surface mining	CCTV

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- FOREWORD -

This report was prepared by MBAssociates, San Ramon, California under USBM Contract HO262022. The contract was initiated under the Federal Coal Mines Health & Safety Program. It was administered under the technical direction of Twin Cities Mining Research Center with Mr. Guy A. Johnson acting as Technical Project Officer. Mr. R. J. Simonich was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period June, 1976 to December, 1977. This report was submitted by the authors on April 30, 1978.

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EXECUTIVE SUMMARY

Large Rear Dump Haulage trucks in use in surface mining operations have a severe problem with restricted driver visibility. The driver cannot directly see large areas adjacent to his haulage truck. These blind areas can conceal large utility vehicles, pick-up trucks, cars, personnel, structures and road hazards from the driver, resulting in very hazardous situations. Analysis of blind areas, haulage truck operation, usage, traffic situations, accident history and environmental factors reveals that present visibility aids (mirrors) are inadequate and that the visibility problem is greatest in the right front and rear areas around the typical haulage truck. The problem becomes acute in shovel, dump, and utility areas in the typical surface mine. The benefit of improved visibility is a reduction in the accident potential in many situations which will result in fewer fatalities and loss time injuries, and substantially less property damage.

Based on visibility needs, design concepts, and cost effectiveness, an improved visibility system was developed. This system was demonstrated in mock-up and on an actual production haulage truck to evaluate the effectiveness, prove the design concepts and investigate design and production specifications.

The improved visibility system consists of a larger left view mirror assembly, a very effective rectangular convex right mirror, a unique blind area viewer and an improved CCTV system. The blind area viewer is a first application of a unique fresnel lens concept to the problem of large haulage truck blind areas.

The improved left mirror is a nine-inch wide by twenty-seven-inch high mirror, with a small convex mirror attached. It is designed for quick maintenance and provides an optimum view of the left rear area including orientation features such as the rear tire and the top edge of the load bed simultaneously.

The right mirror assembly is a rugged 12 by 16-inch rectangular convex (spherical) mirror with a 20-inch radius. The rectangular shape gives the optimum view configuration with a compact shape for mirror protection. The blind area viewer is used to view the blind areas forward and to the right of the driver. Three units are used for coverage. They are mounted on the engine head and on the right deck. Each blind area viewer increases the driver's two to ten degrees downward angle of view by 70 degrees. This gives the driver a view of objects within five feet of his truck as opposed to the driver's usual 60 feet to 70 feet wide blind area. The blind area viewer consists of a three-element fresnel lens which give an oriented 85 degrees vertical and 60 degrees horizontal wide angle view with the 20 degrees to 50 degrees downward angle emphasized.

The CCTV system is designed to give the driver a view to the rear similar to a automotive rear view mirror. It consists of a ruggedized camera enclosure with a semiautomatic lens window cleaning system. The CCTV camera is a tubeless CCD charge coupled type which uses only five watts of power at 12 volts. It has a wide angle auto iris lens for extended light range and blooming is eliminated by the CCD device. The monitor is a standard CCTV type with the picture reversed right to left for rear view orientation.

The visibility system as developed eliminated 85 percent of the forward and right blind area and 95 percent of the rear blind areas. This is near total coverage of the areas with an identifiable history of accidents. The visibility system is cost effective for trucks of 85 tons or larger with the exception of the CCTV system which can be cost effective for trusks larger than 170 tons.

The system has been shown to be effective in a short term demonstration on a 150-ton production haulage truck. It is recommended that the effectiveness be proven and documented by a long term testing program of actual use. This would qualify the benefit effectiveness, maintenance requirements and costs of a system. Exposure in the mining industry would also expedite the application of these safety concepts.

1.0 INTRODUCTION

1.1 STATEMENT OF THE REQUIREMENT. Haulage trucks with rated capacities of 100 tons or more are being utilized in many surface mining operations at the present time. Trucks in this class which are designed to maneuver on narrow benches of surface mines are common in base metal and iron mining operations which excavate more than 80,000 tons per day. At such large operations the interface between trucks, people, and equipment is a considerable problem. The restricted visibility of haulage truck operators creates a serious threat to personnel and equipment as well as problems with the efficient positioning of haulage trucks while loading and dumping.

With increased size, the area and volume of blind zones adjacent to a haulage truck becomes greater. Visibility aids for haulage truck operators are required to provide increased safety of personnel, euqipment, and truck tires, as well as provide better visual reference for maneuvering.

1.2 OBJECTIVE. The overall objective is to develop a reasonably priced, reliable improved visibility system for large haulage trucks in surface mines. The system must overcome severe environmental problems, and be acceptable to the truck and mine operators. The system must improve safety in haulage truck maneuvering areas and benefit productivity.

1.3 SCOPE. This study is focused on rear dump haulage trucks of 100 tons or over rated capacity in use in Copper, Iron, and Coal surface mines. However, in conducting the mine survey work, valuable information was obtained regarding articulated tractor trailer trucks of 100 tons or larger size in surface coal mining use. Fifteen (15) mining divisions involving a total of nineteen (19) individual mines were visited. Most of these were visited on two shifts (day and night). All manufacturers of large haulage trucks were contacted and detailed information obtained regarding both existing and future designs.

First hand knowledge of the driver's task was obtained by MBA researchers when they rode with 92 drivers (sometimes two or three on each shift) at the 19 mines that were visited. On six occasions the researchers were allowed to actually drive the trucks and maneuver them in backing and sharp turn situations.

1.4 TECHNICAL DISCUSSION OF APPROACHES

1.4.1 Background. It seems axiomatic that the operator of a moving vehicle should be able to see where he is going. Yet since the advent of the modern transportation era, the visibility needs of vehicle operators have often been subordinated to other considerations having nothing to do with safety or efficiency.

Significant visibility advances, such as the one-piece windshield, narrow windshield pillars, convex mirrors, anti-glare mirrors, and the like, have had to compete with vehicle designs permitting glare on the windshield from dashboard components, enlarged rear-quarter panels and correspondingly reduced rearward visibility fields, large rearview mirrors affixed to the windshield providing a large blind spot, and so on.

From the standpoint of rearward visibility, the U. S. Department of Transportation has been attempting to ease the problem by proposing standards to require passenger vehicles to have an uninterrupted 90-degree field-of-view to the rear. For special purpose vehicles, such as the large haulage trucks that were studied under contract, however, there have been no similar standards as yet proposed with regard to operator visibility.

These trucks encounter a particular set of visibility problems as a consequence of their unusual design and size. In order for the operator to "see" reasonably well in a forest of other king size vehicles, the cab height provides him with eye levels ranging from 13 to 18 feet. However, the requirement to protect the cab from load spills has caused it to be positioned under a protective overhang of the bed, which in turn places constraints on the driver's visibility. As the size of these trucks has increased, so has the width. The largest haul truck currently in existence, the 350-ton Terex Titan is 28 feet wide, which places the operator some 24 feet away from the right side of the vehicle. This means that he will be at least 25 feet away from a right side mirror, a distance which greatly reduces its effectiveness due to the small visual angle it subtends at the eye of the operator and consequent difficulty in locating (fixating) it rapidly, as is required when the driver is backing and has to alternate his attention between his two side mirrors. In addition, since the right side mirror is usually convex, it creates images that are reduced in size (compared with a flat mirror), making judgments of spatial relations all the more difficult.

Apart from the problem of seeing to the right side of his vehicle, the large haulage truck drive has essentially no vision behind the truck and, unfortunately a large blind area in front of the truck due to components (such as the radiator) that project forward of the cab and block the driver's view of the ground in front of his vehicle for distances of 35 feet or more. The configuration of the blind areas in front, to the right and to the rear of the truck varies widely with the make and model of the vehicle. For example, Figure 1.4-1 shows a large haulage truck plus a composite photograph showing the driver's view from behind the wheel. Figures 1.4-2 through 1.4-4 are similar photographs for four other large haulage vehicles. The marked differences in driver visibility are obvious, even among trucks which have rather conventional design. The pictures also reveal that large size does not necessarily mean poorer visibility. For example, the 150-ton Terex (Figure 1.4-3) has more restricted forward and right side vision than its big brother, the 350-ton Terex Titan (Figure 1.4-4). As another example, despite its monstrous size (28 foot width and 43 foot length), the 250-ton V-CON Model 3006 Rear End Dump Truck (Figure 1.4-5) had an unconventional divided frame design that allowed the operator to see the ground directly in front of the right front wheels and provided him with a partial view to the rear. (This experimental truck has now been dismantled, but was on trial in at least one surface mine: Cyprus-Pima near Tucson, Arizona.)

The more conventional truck design is represented in Figure 1.4-6, a sketch reproduced from the Employment and Community Safety Manual, Eagle Mountain Mine, Kaiser Steel Corporation (January 1973). This sketch gives an idea of the shape and magnitude of the typical blind areas. The size of the blind areas varies greatly, but even for the smaller haulage trucks visibility constitutes a major problem ("Beware of Big Trucks," World Mining. p. 37, May 1974).

In retrospect, it is not surprising that the advent of 100-ton and larger trucks with decreased visibility has resulted in accidents where the operator simply could not see the smaller vehicle, or person, or obstacle that he struck. A number of countermeasures have been tried with varying success. These countermeasures are of two general types: attempts to provide the operator with greater visibility, and steps to make external objects more visible to the driver of the large truck. Some countermeasures are partially effective, such as requiring all small vehicles to have brightly colored flags on tall (6 ft) flexible staffs (such as at Cyprus-Pima mine), or requiring a dumpman on the ground to direct truck backing, such as at the Kaiser Mine at Eagle Mountain, Californa. (In some cases, the dumpman may be in danger if too narrow a left-side mirror is used, as is brought out by K. L. Prothero.* Prothero mentions

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*Prothero, K. C., "Haulage Truck Safety Visibility Problems," Presented at the 49th Annual Converence of the Lake Superior Mines Safety Council, Duluth, Minnesota, May 23-24, 1973.

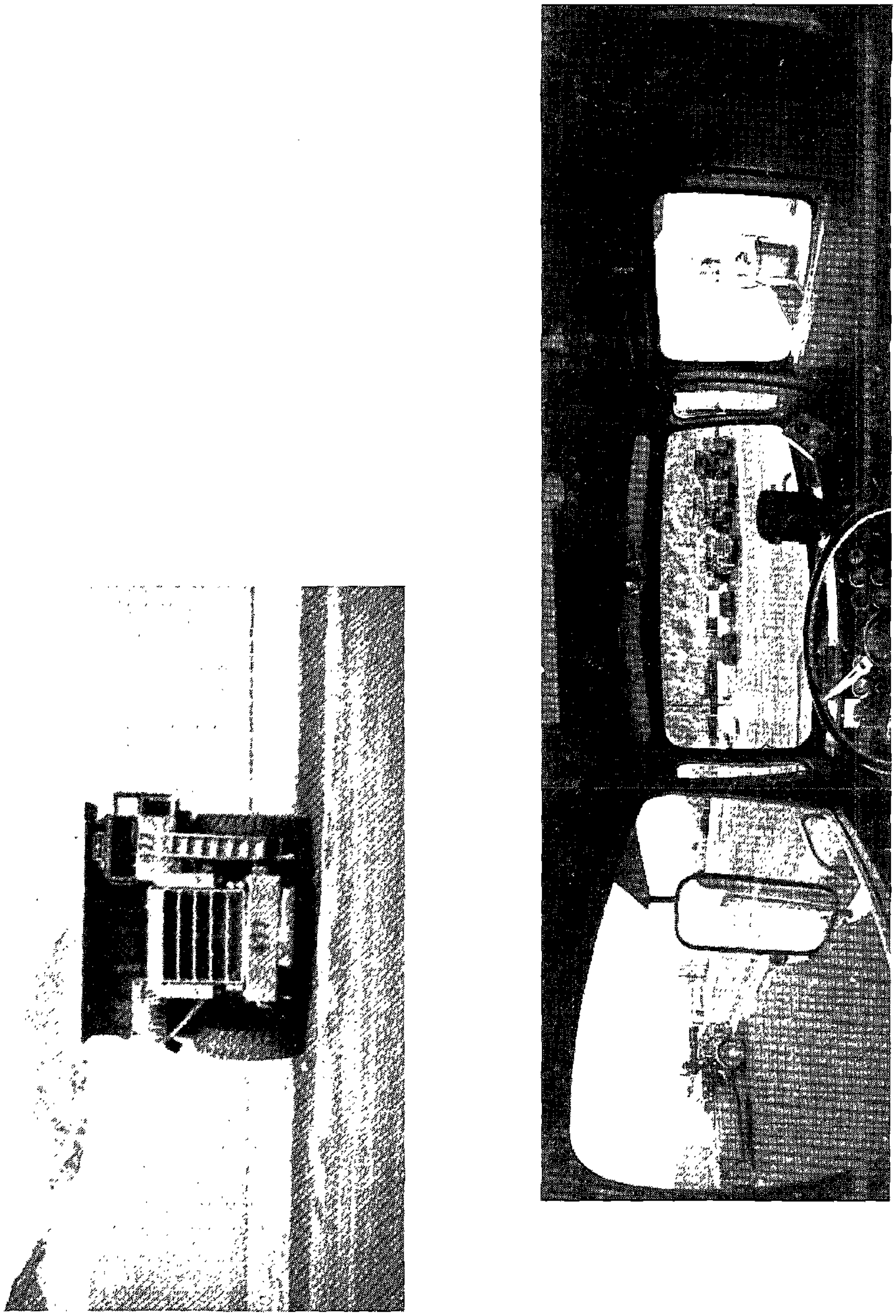

FIGURE 1.4-1
DART 110 TON

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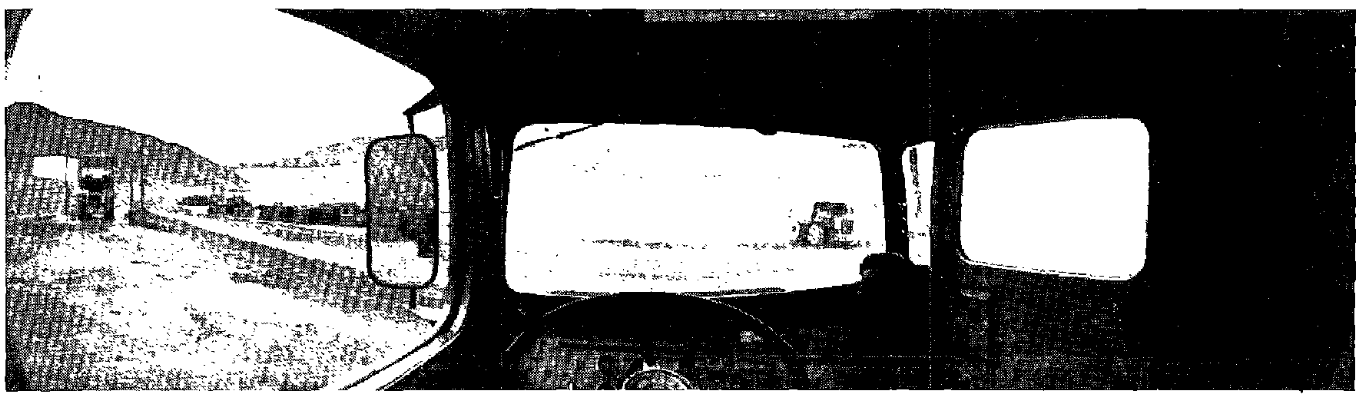


FIGURE 1.4-2
DART 150

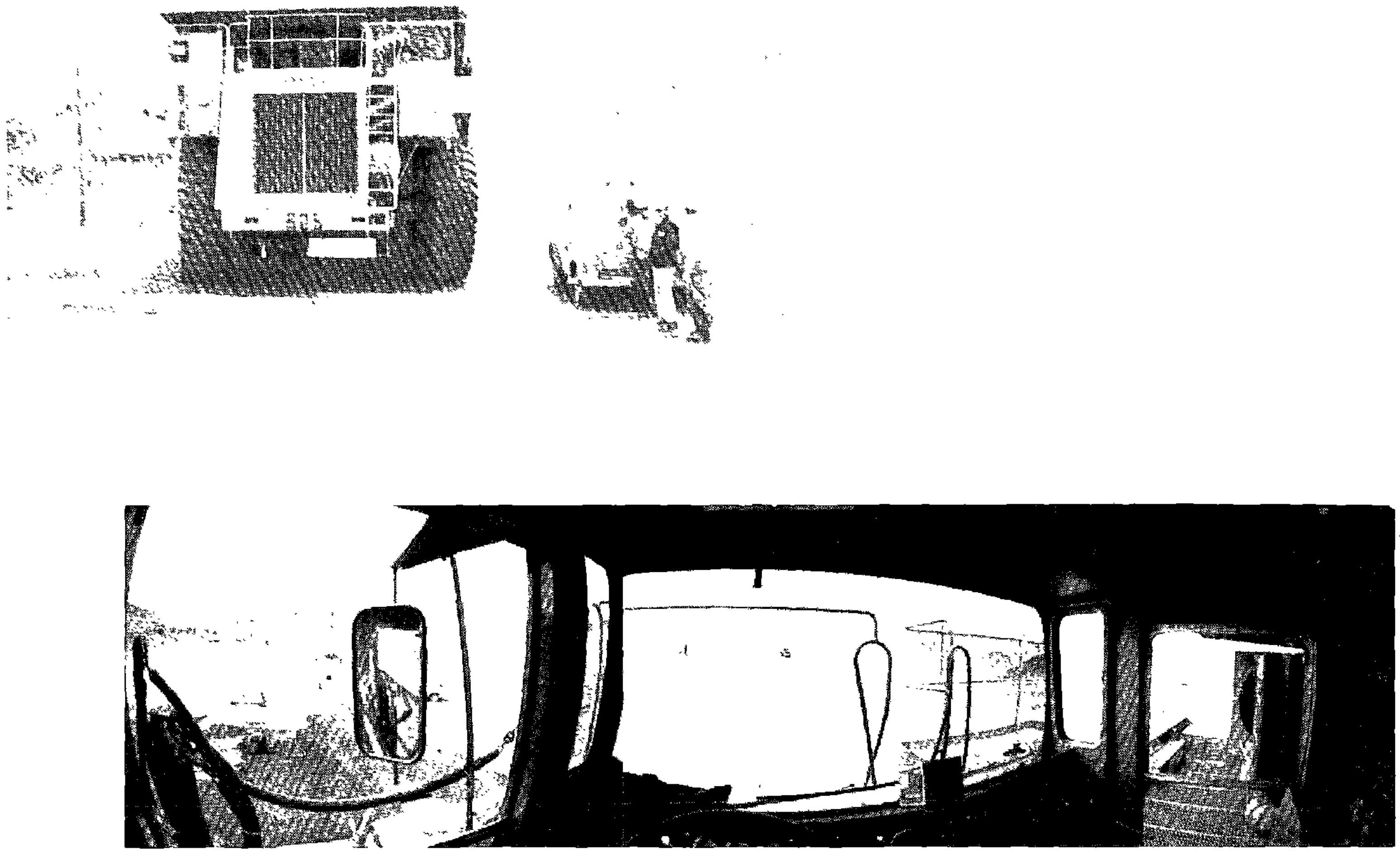
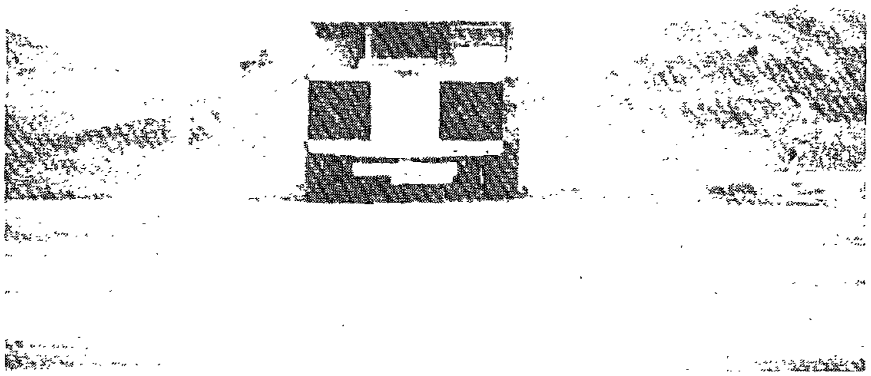


FIGURE 1.4-3
TEREX 150



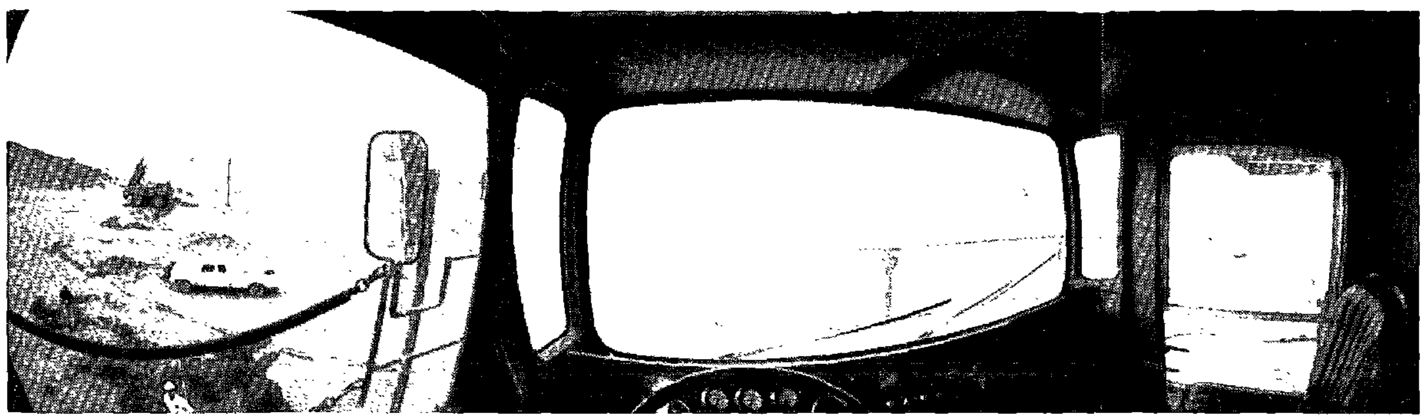


FIGURE 1.4-4
350 TON TEREX TITAN

FIGURE 1.4-5
V-CON 3006

KEEP A SAFE DISTANCE
FROM ALL HAULAGE TRUCKS

STUDY THESE PICTURES, THEY
MAY SAVE YOUR LIFE

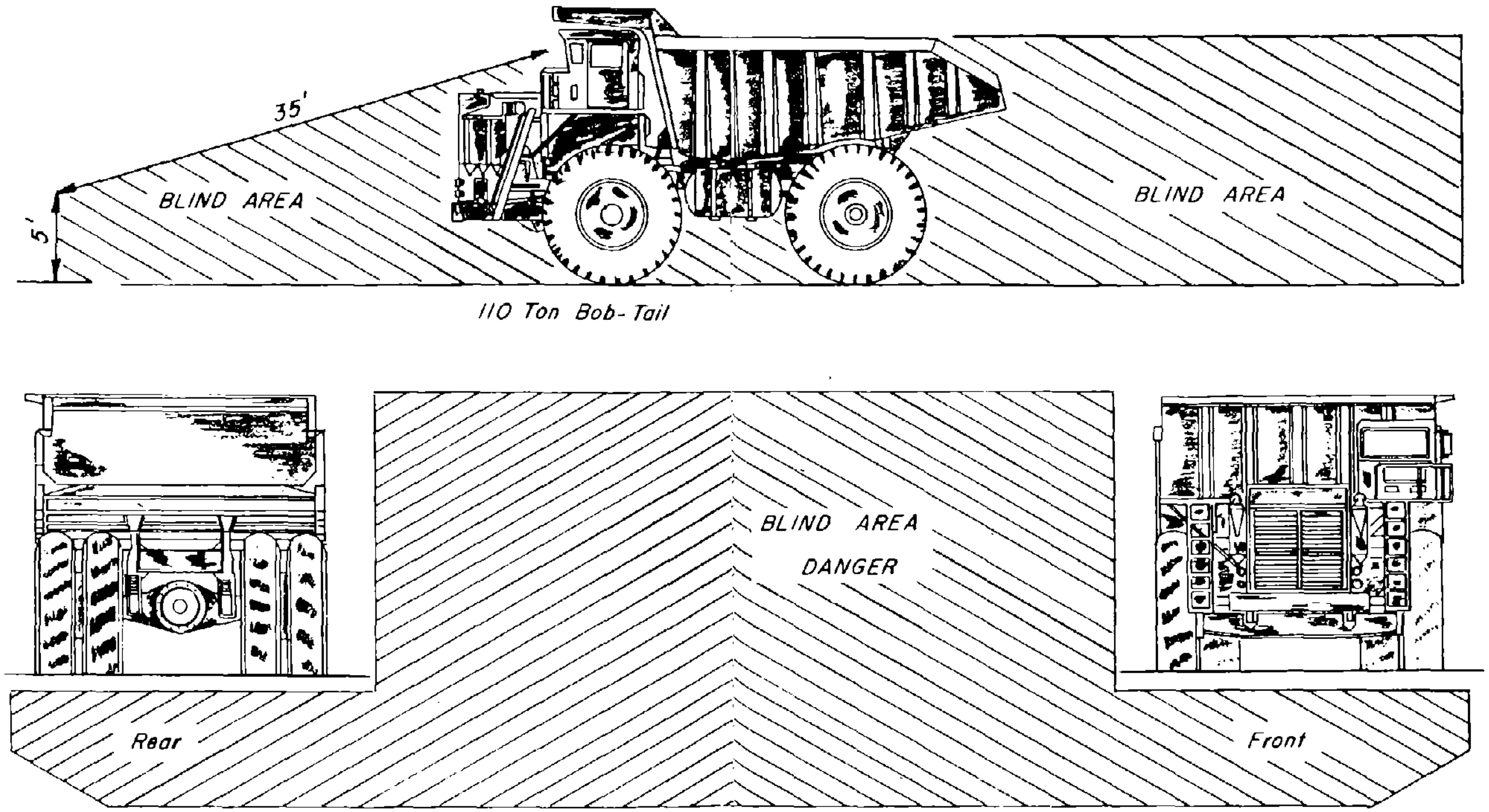


FIGURE 1.4-6
TYPICAL BLIND AREAS FOR LARGE HAULAGE TRUCKS

adding a small convex mirror to the left-side plane mirror in order to widen the left field-of-view and help reduce the danger of not being able to see the dumpman as he gives hand signals for backing to the edge of the dump). As another example, for nighttime work, personnel can be required to wear high visibility clothing, such as is being introduced at the Eagle Mountain Mine and as is mentioned by Prothero. However, if personnel or vehicles are in a blind area, they can't be seen regardless of what they wear, and they may not be aware that they can't be seen because these blind areas are quite large and extend forward and to the right, as well as directly to the rear.

Improved visibility has the potential of reducing accidents of various types such as occur at sharp right turns, at locations where large rocks can be run into (and over) causing vehicle and/or tire damage, backing up, and when starting up after personnel or smaller vehicles have entered into a blind area. Mining efficiency stands to be improved by increasing truck visibility becuase the operators can more quickly and accurately position themselves under the shovel bucket and at the dump. In addition, if the overhead blind spot can be minimized, operator fatigue can be markedly reduced because drivers won't have to strain into awkward positions to see where the bucket is being held. Nighttime visibility improvements also should reduce driver fatigue if glare sources and ambiguous lights are reduced in number.

2.0 HAULAGE TRUCK VISIBILITY ANALYSIS

2.1 VISIBILITY FROM LARGE HAULAGE VEHICLES. The study of the visibility from Large Haulage Vehicles involves the evaluation of the restricted field of view from the operator's position. This includes restrictions to the downward angle of view and obstructions to view such as cab posts, mirrors, handrails, and the load bed. The blind zones, caused by the restricted view, create various safety problems during the operation of the vehicle. The basic modes of operation and performance of a haulage vehicle define when a blind zone can affect safety. It is clear that present mirrors are not adequate.

2.1.1 Truck Size and Visibility Trends. Rear dump haulage trucks with rated capacities of from 100 to 170 tons are becoming standard at many surface mining operations, and larger trucks are being used experimentally in a few surface mines. Generally,the size of haulage trucks increases with rated capacity; in addition, the use of larger load beds for low density material and coal haulage results in a large increase in truck width. The relative width of rear dump haulage trucks increases with truck capacity from 16 to 26 feet. The relative sizes of rear dump haulage trucks are shown in Figure 2.1-1. The load bed height and cab do not follow this trend because of other design considerations such as shovel dimensions.

The extent of the blind zones around large haulage vehicles is not necessarily related to truck capacity. The position of the operator's cab in relation to the engine hood, right deck, and right deck components varies among truck models. With increasing truck width, the effectiveness of the right side mirrors are not nearly adequate and left side mirrors should be larger.

2.1.2 Measurement and Comparison of Blind Areas. The visibility from haulage trucks is conventionally described by measuring the ground areas that are obscured from the driver's view with the truck parked on level ground. An example of such a blind area chart is shown in Figure 2.1-2.

The blind areas of various haulage trucks have been measured by the Health and Safety Analysis Center (Wayne Miller), several mine operators, and by truck manufacturers. Only a small, though representative, sample of truck blind area charts exist. The use of these charts must take into account the following factors:

- The position of the operator's eyes has not been standardized for these charts. The operator's eyes can vary as much as 6 inches in height due to operator and seat differences. The operator also can rotate his head, move from side to side, and seats can be adjusted forward and backward.
- Even on the same model truck, modification can change the visibility pattern. New components on the right side deck, shields over the engine hood, optional tire sizes, and design changes on newer models can change the blind area size and shape.
- The difference in height between a loaded truck and an empty truck can be as much as 6 inches.

The blind areas can be measured in a few convenient ways. The most common method is to place an average size operator in the cab of a truck parked on level ground then survey the limits of the blind area as seen by him. This method takes into account head swing and would be more valid if the eye height and head position were recorded with the blind area chart. Another method involves hanging a high-intensity light bulb in the cab of a truck and mapping the shadow cast by the truck at night. This method would define the visibility from a single eye point. One final method involves plotting an eye point on truck layout drawings (front, side, and top view) and determining the blind areas by measuring the distance and height of view

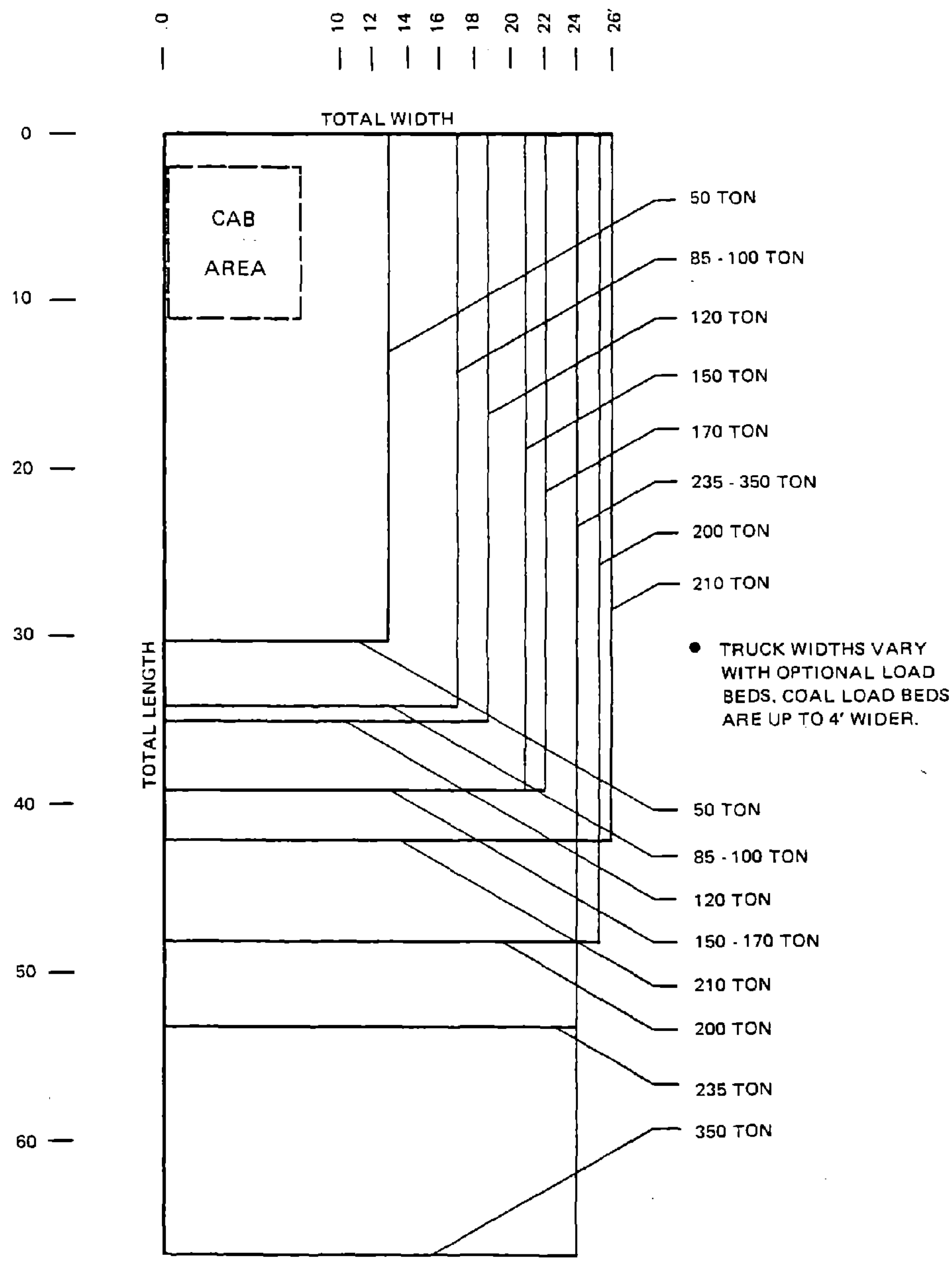


FIGURE 2.1-1
RELATIVE SIZES OF REAR DUMP HAULAGE TRUCKS

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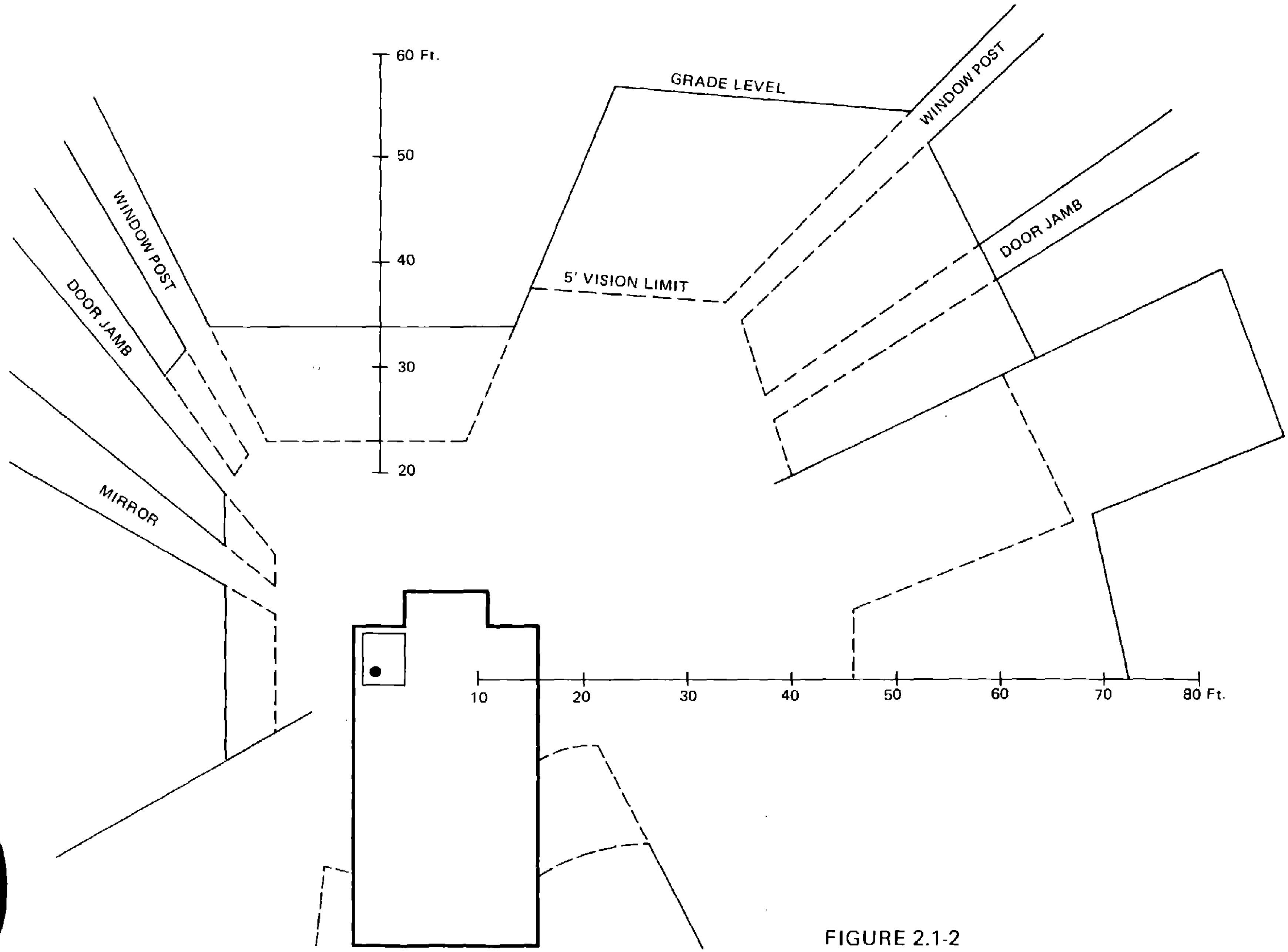

FIGURE 2.1-2
BLIND AREA CHART

obstructions, relative to the eye point. The problem with all blind areas measurements is that a standard eye point or eye range which would show what is seen by 95 percent of all truck drivers has not been established for large haulage vehicles. The blind area charts are adequate, however, for illustrating visibility problems and for developing visibility aids.

In Figure 2.1-3, various blind areas are shown for an assortment of different rear dump haulage trucks. The blind areas compared are those caused by obstructions to the downward angle of view. The variability of these blind areas especially to the right indicates that the truck design factors (which define these blind areas) are necessary to understand the patterns of these blind areas.

2.1.3 Visibility and Truck Design. All large rear dump haulage trucks have certain design similarities which determine the visibility from the cab of the vehicle. These design similarities are as follows:

- The operator's cab is mounted on a deck which serves as a wheel fender on the left side of the vehicle. The height of this deck depends on wheel suspension requirements and the engine height. This deck is mounted from 6 to 24 inches below the engine hood.
- The engine hood extends forward from the cab to the front bumper. The cab is located somewhere between the front of the engine and the front axle based on a trade-off between visibility, collision safety, and overhead protection. No mirror system was adequate to remove this blind area.
- The right deck, opposite the operator's cab and at the same height as the cab deck, also serves as a right wheel fender. Often drive system components are mounted on this deck, creating large blind areas no mirror can help reduce.
- The left, or operator's window of the cab, is located within two feet of the left side of the haulage truck so that the operator can look to the rear along the side of the load bed by leaning out the window, except in some truck models.
- All of the truck cabs surveyed had two window corner posts and two door-jam posts in the forward view of the operator.
- All truck cabs surveyed had a rear window that was of limited use to the driver except when the bed was raised.

There are few exceptions to these design similarities. Even tractor units on tractor trailer type trucks are designed similar to smaller rear dump trucks. Only a few new tractor trailer trucks are becoming large enough to have blind areas as extensive as large rear dump trucks. The two notable exceptions to these design similarities are the Kress Carrier and the Terex 350-ton truck. The Kress Carrier is a unique non-articulated bottom dump vehicle with the engine mounted in the rear. The cab is forward of the front wheels, with no engine hood obstruction and a minimal right deck. On the Terex 350-ton truck, the cab is mounted higher in relation to the engine hood than on most trucks and part of the right deck is cut away. The rear window was more useful than on the other trucks. These design features result in blind areas less extensive than on many other large haulage vehicles.

Blind area diagrams are useful to describe visibility. A generalized blind area diagram has been developed as shown in Figure 2.1-4. This diagram shows the parts of the blind areas that are defined by specific truck design features. For example, the front and left blind areas are defined by the window sills of the cab. The operator

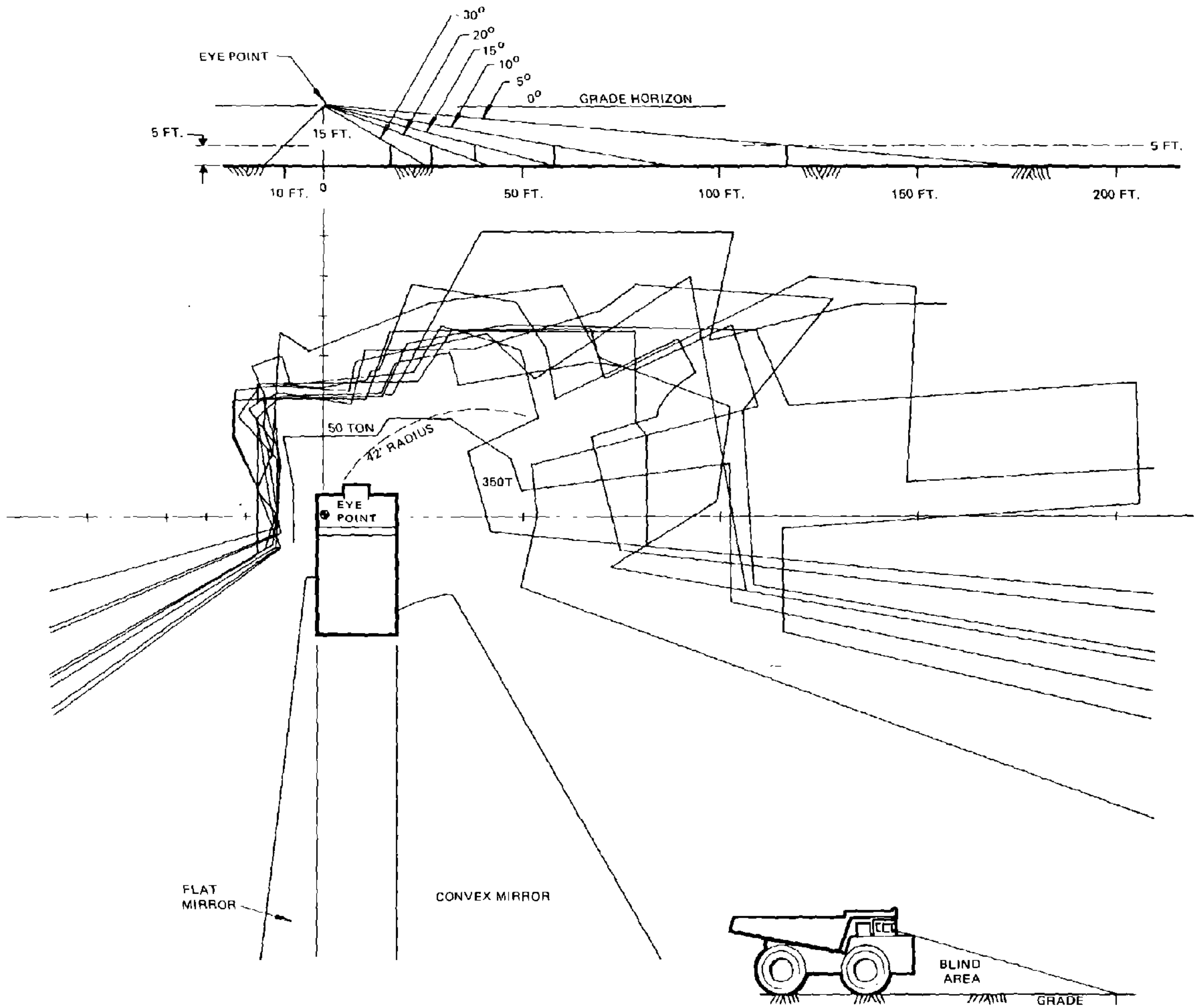

FIGURE 2.1-3
BLIND AREA COMPARISON

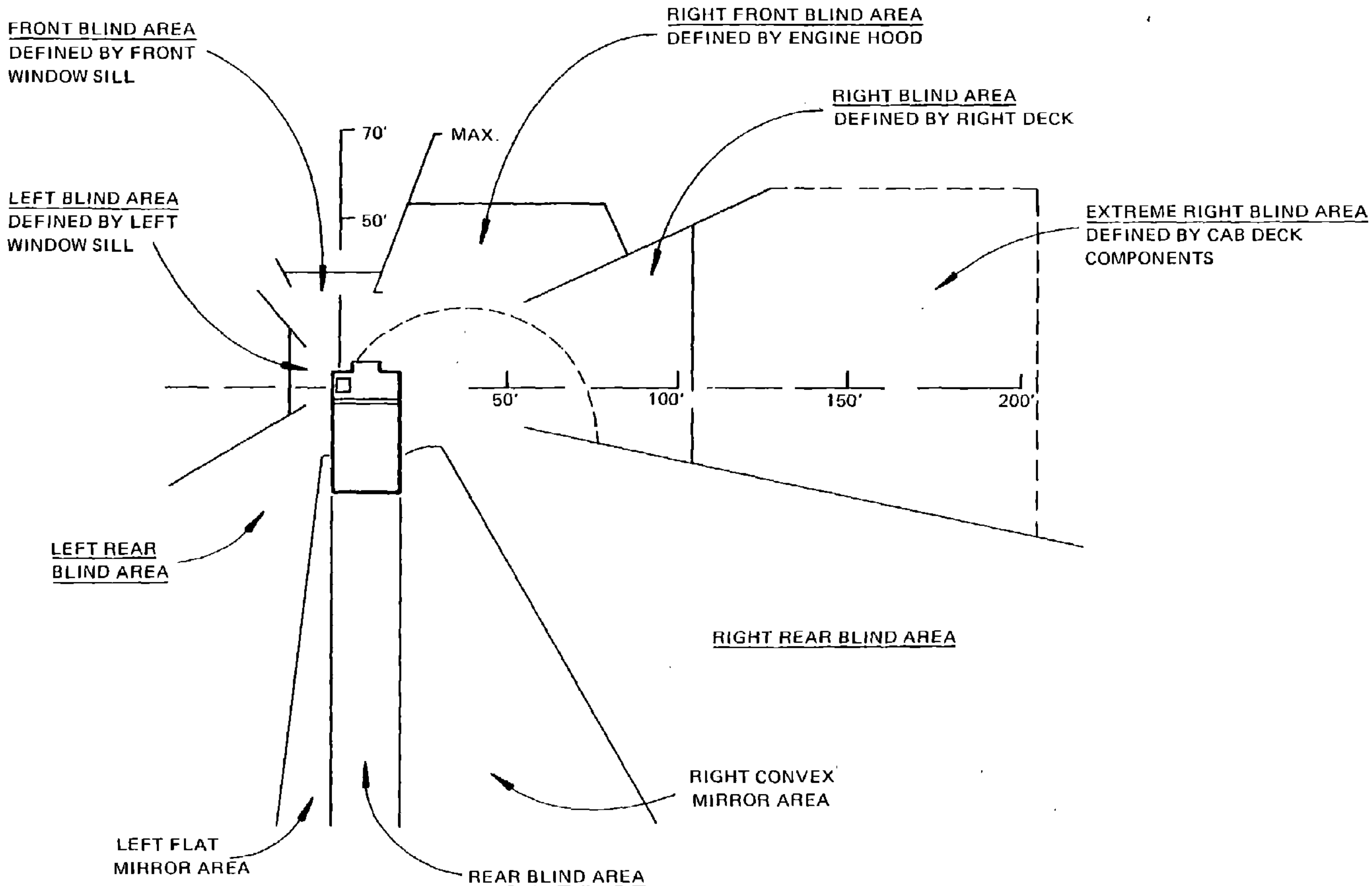

FIGURE 2.1-4
HAULAGE TRUCK BLIND AREAS

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must move his head considerably before the cab deck itself blocks his view. The front window sill is positioned in relation to the operator's console. This console is positioned according to the recommended design standards shown in SAE Article J898.

Concerning the right side view, the mounting of large components on the right deck is a common practice when no other mounting location is conveniently available. Although no trend is evident, the majority of trucks mount components such as motor cooling fans, air cleaner, electrical control boxes, or fluid reservoirs on the right cab deck. On about one third of large haulage trucks these components are in a position forward of the truck operator. This situation is also common to the tractor trailer trucks that were observed and it creates large blind areas.

The relationship between operator height and his downward angle of view is another way to describe visibility. The downward angle of view is the critical aspect of the operator's field of view which defines the shape of the blind area. Figure 2.1-5 shows the relationship between the eye point, truck obstructions and a vertical slice of the blind area. The operator's eye height varies from 13 to 18 feet on large haulage vehicles. This compares to eye heights of from 10 to 12 feet on haulage vehicles of less than 100 ton rated capacities.

On most large haulage vehicles the eye height falls between 14 and 16 feet. Because there is a small height variation and there are major design similarities among haulage trucks, the operator's downward angles of view can be generalized as in Figure 2.1-6. Nearly all obstructions to the downward angle of view are within 48 inches below the operator's eye level. These obstructions create blind areas in which vehicles (pick-up trucks, carryalls, etc.) and personnel can be completely hidden from the truck operator's view.

2.1.4 Visibility Aspects of Truck Operation and Performance. The basic operation of large haulage vehicles (without regard to traffic or road configuration) reveals the dynamic aspects of visibility. The basic operation of a vehicle includes speed of travel and maneuvers such as braking, start up, turning, and backing up. The performance of large haulage vehicles during basic operation is considerably different from over the road vehicles and the visibility aspects are more critical.

The speed of travel defines the time that the wheel path of a large haulage vehicle is in its blind area and the time that other hazards are in the blind area. For example, an average large haulage truck traveling at 20 mph has about a one second lag between last visual contact and vehicle arrival (on a relatively straight path). As shown in Figure 2.1-7, low speed operation allows more time for situations to change in the blind areas and the operator must remember more information about his path options. At high speeds, a truck's committed zone is well ahead of his blind area.

The speeds of travel which can be expected are as follows:

• Level Ground		18-30 mph
• Upgrade	Empty Loaded	8-15 mph 6-12 mph
• Downgrade	Empty Loaded	10-18 mph retarded 8-15 mph retarded
• Maneuvers and Rough Ground		0-10 mph

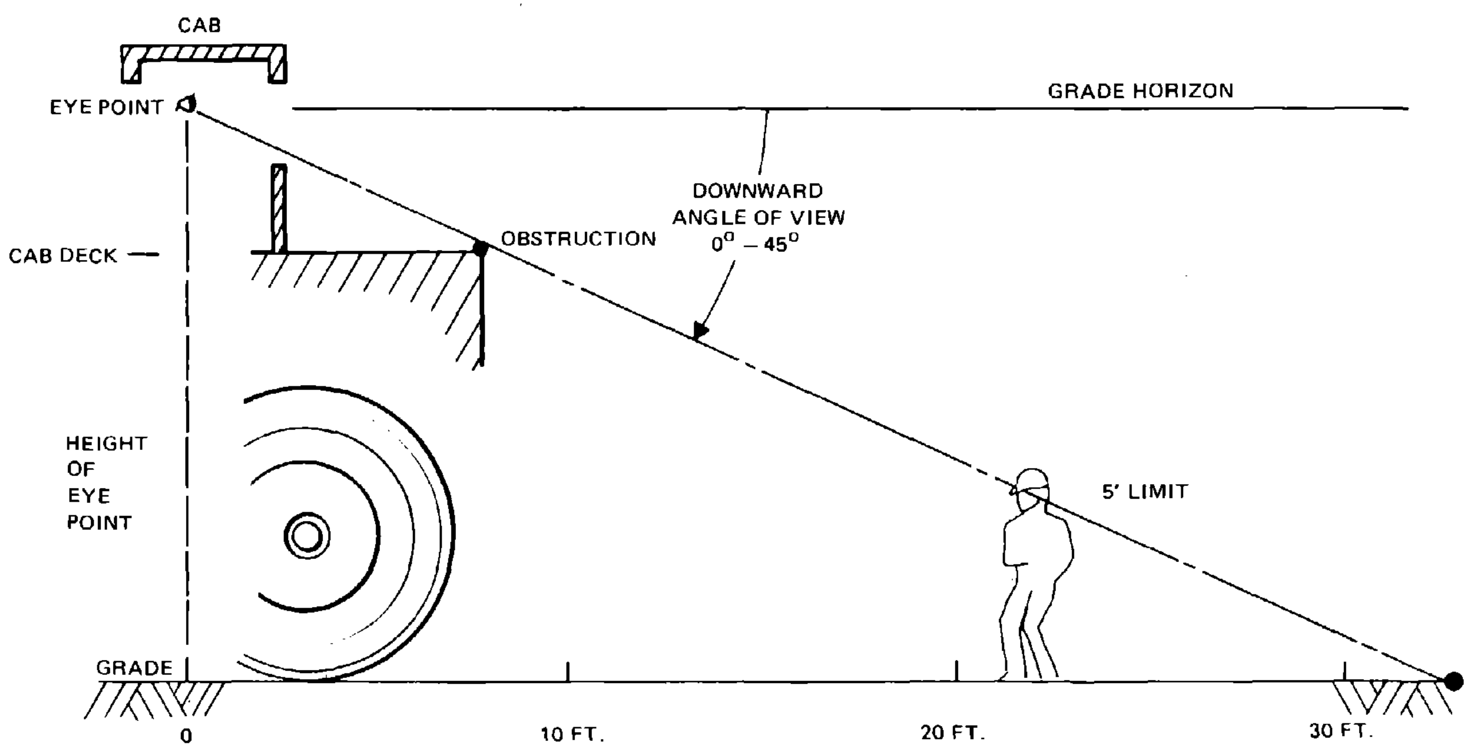

FIGURE 2.1-5
GEOMETRY OF HAULAGE TRUCK DOWNWARD VISIBILITY

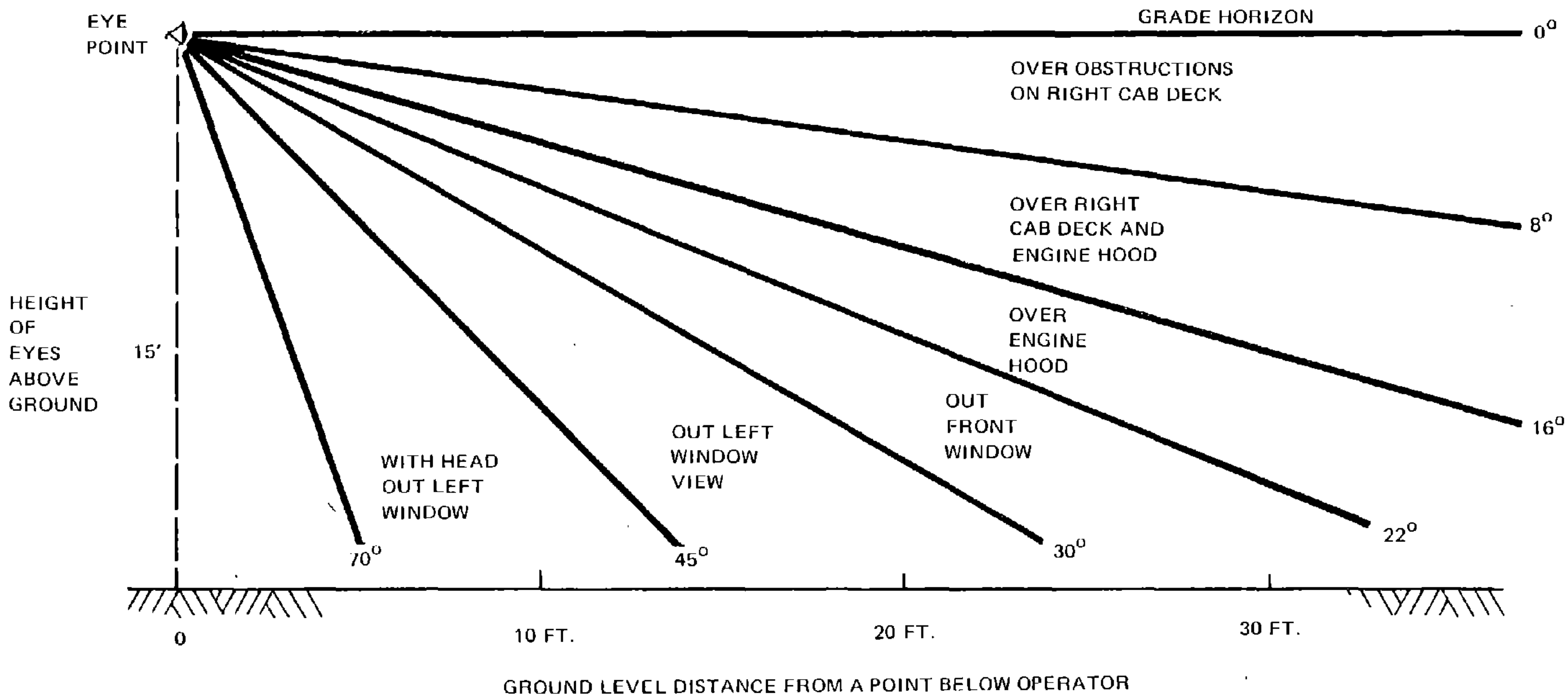

FIGURE 2.1-6
DOWNWARD ANGLES OF VIEW FROM HAULAGE TRUCKS

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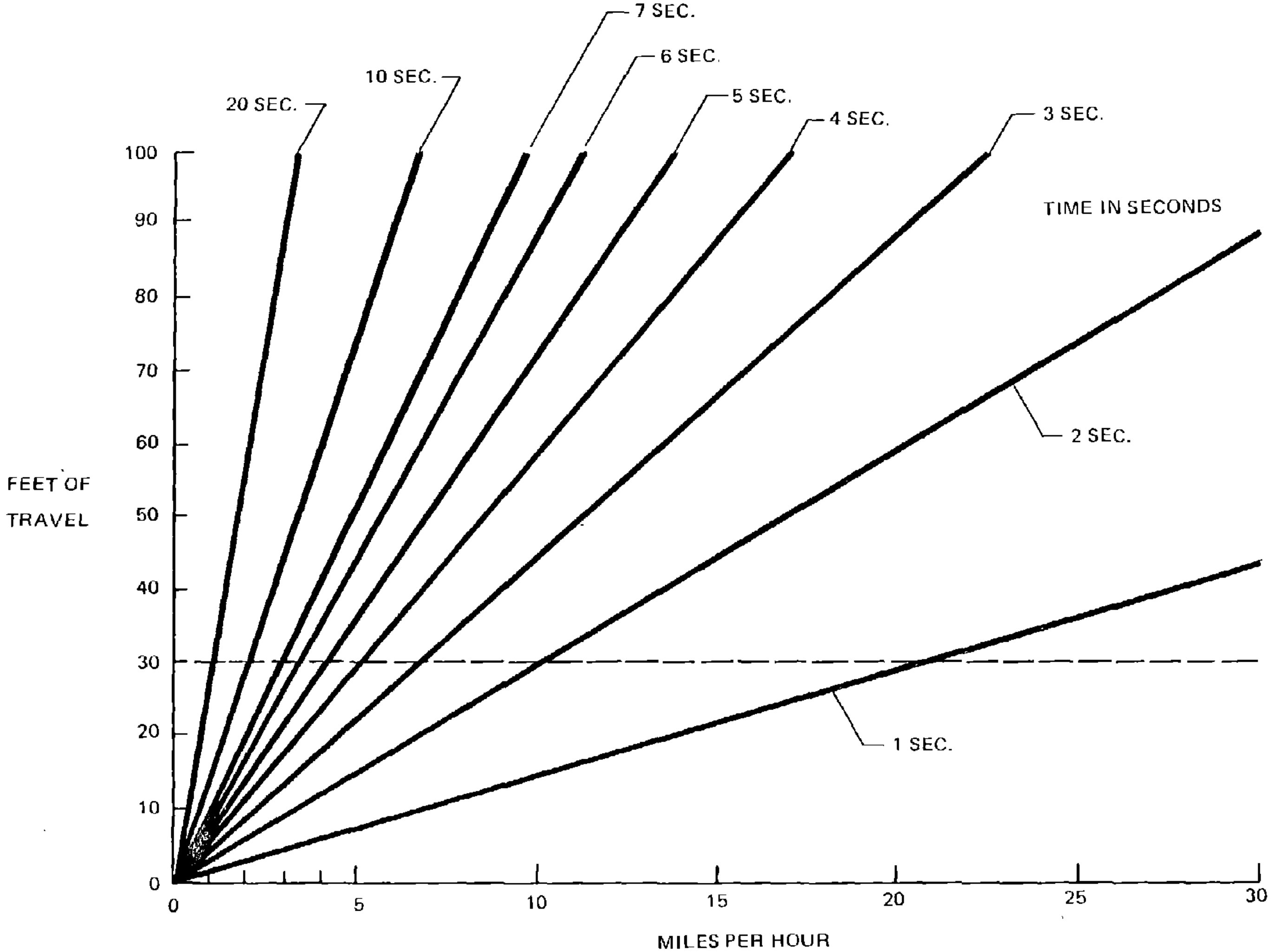

FIGURE 2.1-7
TIME, SPEED AND DISTANCE RELATIONSHIPS

As an additional consequence of moving on imperfect roadways, a truck operator's downward angle of view can change up to $\pm$ 5 degrees due to the grade of the road.

Because the distance between a person's eyes is from 2.1 to 2.8 inches, vertical obstructions less than two inches wide in the operator's field of view will not create a significant blind area. The effect of cab posts, handrails, and other view obstructions is reduced by the dynamic action of the haulage vehicle.

Hazards hidden by forward handrails do not remain hidden for more than a moment since the operator view sweeps the area as the truck moves. For a hazard to remain hidden behind a cab post or other vertical obstruction while the truck is in motion, it must converge toward the truck on a constant relative bearing. This is not a common occurrence, but it may be one factor in some hazardous situations.

Braking is a function of reaction time, vehicle performance, speed and grade. An alert driver requires a nominal two seconds to react to an unexpected situation. Drowsy, sleepy or new drivers require more time. There is an additional time lag due to the operational characteristics of dynamic retarders. This varies from one to two seconds. At speeds less than five mph (higher speeds in emergency situations), friction brakes can be applied without this time lag. Stopping distances vary considerably according to speed and grade. On downgrades and at high speed on level ground, stopping distance is well ahead of the forward blind area. On steep upgrades and at very low speed, stopping distance is within the blind area. Braking distance can exceed visibility due to external obstructions such as road crests and blind curves, equipment and structures.

Starting up from a parked or stopped condition allows stationary hazards to remain undetected or traffic to enter blind areas. The length of time since the operator has seen the ground included in his blind areas is critical. The operator initially inspects his blind areas by walking to or around his vehicle or driving to a stopping point. Once in the cab seat, inspection of blind areas requires some effort and is not a common practice. From the time the operator is in the cab seat, until start up, an awareness of activities in the area is required. The expectations of surrounding personnel and traffic is also a factor in this situation. When turning, various hazards can be hidden in the blind areas. The turning radius of the average large dump haulage vehicle is approximately 40 feet. The larger haulage trucks and those with tandem rear axles have larger turning radius. With such a tight turning radius, a rear dump truck operator can turn right 180° and never see the wheel path. This is critical in a start up situation.

When moving along a road, a blind area can conceal an overtaking vehicle prior to turning. Except for the start up situation, the turning area is generally viewed well in advance for evaluation of hazards and activity. On the approach to a turning point, a preview awareness of overtaking traffic and other activity is an important factor as is the expectations of other traffic in the area. For a left turn the visibility is better, however, right turns are preferred by drivers (in low speed maneuvers) for safe outside clearance of equipment and berms as well as for positioning prior to backing up. Visibility aspects of turning are illustraged in Figure 2.1-8.

Backing up presents both the possibility of hazards in the blind areas and a need for precisely positioning the vehicle. As with turning, the back up area is generally viewed just prior to the backing operation, during the approach to the area. When backing up, hazards can be hidden in the rear and right rear blind areas. The right rear view mirror is seldom used except for an occasional glance; the operator guides by looking directly to the rear or looking into the left flat mirror. A sharp left turn while backing quickly brings the vehicle across ground previously seen in the left

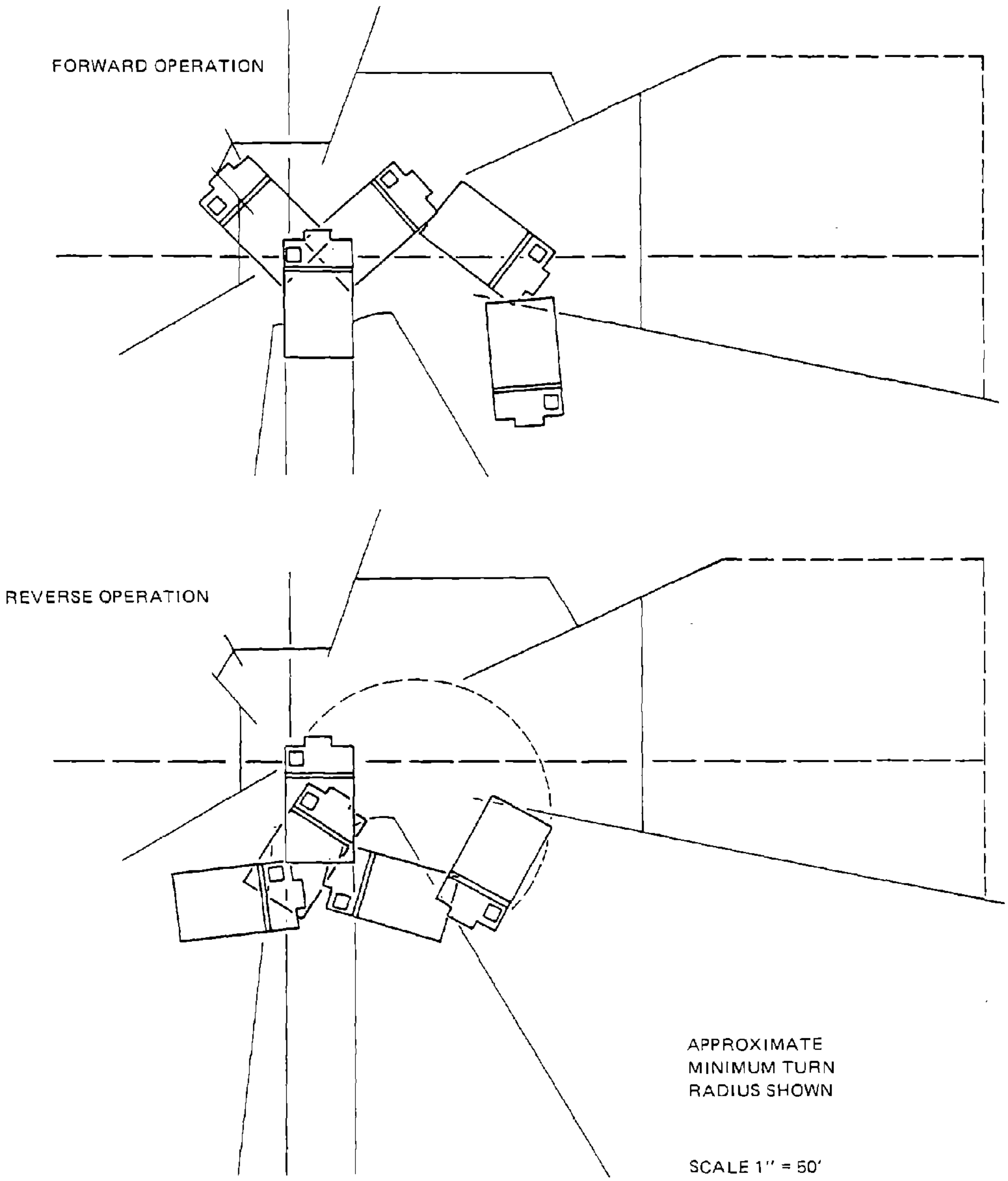

FIGURE 2.1-8
VISIBILITY WHEN TURNING

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rear view (see Figure 2.1-8). At the same time, the right front of the vehicle swings out into what was the right rear blind area. When backing up to a berm or shovel, orientation and depth perception are important to position the truck properly. A slight upgrade on smooth ground can make vehicle control easier, especially when the operator is leaning out the left door or window as is required in one mine that was visited.

From the above considerations, it can be concluded that maneuvers performed immediately after a normal traveling speed approach are safer than maneuvers performed from a parked condition when the maneuvers are performed according to uniform established procedures and in locations where such maneuvers are done as a convention. Start up situations should be limited to established locations and according to uniform procedure. Any change in a maneuver pattern at start up, especially in congested areas, should require a ground attendant. An example of this situation occurs when a line of trucks waiting for a shovel are directed elsewhere because of a shovel breakdown. Then, one or more haulage trucks attempting a sharp U-turn to the right, when maintenance and other vehicles are approaching, is a common occurrence. This non-scheduled situation has resulted in many accidents where visibility is a primary factor.

2.2 VISIBILITY ASPECTS OF MINE LAYOUT AND OPERATIONS

2.2.1 Mine Layout. Geological, topographical and economic constraints determine the configuration of a surface mine. Haulage roads are developed to fit these constraints. In deep open pits or in mountainous trerrain, available haul roads are limited, intersections can become complex and traffic circuits cannot be isolated. Another constraint to road layout is the availability of road construction and surfacing materials. For economic reasons, road materials must be available either on the road site or from a nearby source. In a typical deep open pit, one main haulage road connects the shovel access roads to the dump and shop access roads. Often this main haulage road is 8-10 percent grade. In shallow surface mines and coal surface mines, a single haulage circuit between a shovel and dump, with minimal cross traffic, was observed in a few cases. Occasionally one way haul roads are used. As surface mines develop, haulage roads are continually changed and traffic rerouted. In three of the mines visited, all traffic drove to the left. For these mines, left hand traffic had certain advantages:

- Because of haul road layout, traffic complexity at intersections was reduced. Stopping and yielding situations were reduced, especially for loaded haulage vehicles.
- A traffic crossover from right hand to left hand traffic at shovels and dumps is eliminated.
- The following of the road edge and berm on the left side is easier than on the right.

Haulage road width varies from 20 feet to over 100 feet. The trend for two way haulage roads is for widths greater than 80 feet. A few one way haulage access roads were observed with widths as narrow as 20 feet. Wide haulage roads reduce the complexity of traffic situations associated with two way traffic, passing, and avoiding parked or broken down vehicles. The complexity of traffic situations also depends on cross lane traffic at intersections, the crossover to left hand traffic at shovels and dumps and the effects of blind curves and road crests. Traffic complexity increases the visual information needed by the truck oeprator to make driving decisions. The use of road edge berm is common practice. The visibility and traffic aspects of berms are as follows:

- Any size berm serves to delineate the road edge especially in reduced visibility environments (night, bad weather).
- Berms interfere with road drainage increasing problems with mud or ice.
- At intersections high berms can interfere with the visibility from small vehicles as they approach and enter the intersection.
- A solid berm can promote the use of the road edge lanes during slippery road conditions.

The right-of-way conventions observed varied from intersection to intersection. The right-of-way was vague in some situations. In contrast to highway traffic rules, the right-of-way is assigned in some intersections to loaded haulage vehicles or to the truck with the blind side (left truck has right-of-way). The use of stop and yield signs is common, however, their utilization is not thorough, consistent, or uniform. One night time problem with signs and road delineators is that standard retroflective signs, coatings, and tapes do not work well when the haulage truck operator is seated 10 feet or more above his lights.

An evaluation of shovel loading areas shows wide layout variations in continuously changing shovel loading areas. Traffic patterns in the shovel area are similar and shovel area layouts reflect this. In over 95 percent of shovel area observations, shovel docking involves a 30° to 180° right turn followed by backing up either straight or to the left into loading position. A left turn approach to the shovel was observed in isolated instances. In even fewer isolated instances, shovel loading of rear dump haulage trucks involved positioning the truck at the rear of the shovel without any backing involved. Shovel loading area layouts for both single side and both side loading are shown in Figures 2.2-1 and 2.2-2 respectively. These scale diagrams show representative layouts developed originally with the equipment drawn on individual transparencies. The shovel shows a 50 foot loading radius and a 40 to 70 foot range is indicated for various shovel models. This loading radius can be conveniently adjusted from truck to truck a nominal 10 feet. Many 8 to 12 cubic yard shovels with small dumping radius were observed loading iron ore, copper ore, and overburden, while 15 to 20 cubic yard shovels with longer dumping radius were observed in coal loading operations.

Continuously expanding waste dumps vary widely in size and shape. In all cases a left hand approach was observed, with a right turn if needed prior to backing to the berm. A left turn while backing is standard practice to align perpendicular to the berm for final approach. Often a dumpman on a bulldozer is used to assist the final positioning of the haulage truck by signaling when to stop. A representative layout of a waste dump is shown in Figure 2.2-3.

Both right and left turns prior to backing were observed on the approach to the permanent dumps such as those at crushers (see Figure 2.2-4). Traffic patterns around crushers are extremely variable and the method of approach is a matter of operator choice in many operations. Truck ready lines and maintenance parking also varies from operation to operation. In observations of shop and utility areas, the best installations with regard to visibility, included drive-through-type loading bins, fuel depots, and tire shops.

2.2.2 Truck Operations. In over 95 percent of observations, large haulage trucks were used to haul mine material from a shovel to an established dump. The number of loads carried per eight hour shift varied from 10 to 30 depending on the individual haulage circuit. Waiting lines at shovels and permanent dumps were commonly observed. Other haulage uses include dam, road and plan site construction; and tailings, ash and coal fire disposal. Operation of large haulage vehicles also involves travel to ready lines, fuel depots, and service or maintenance areas.

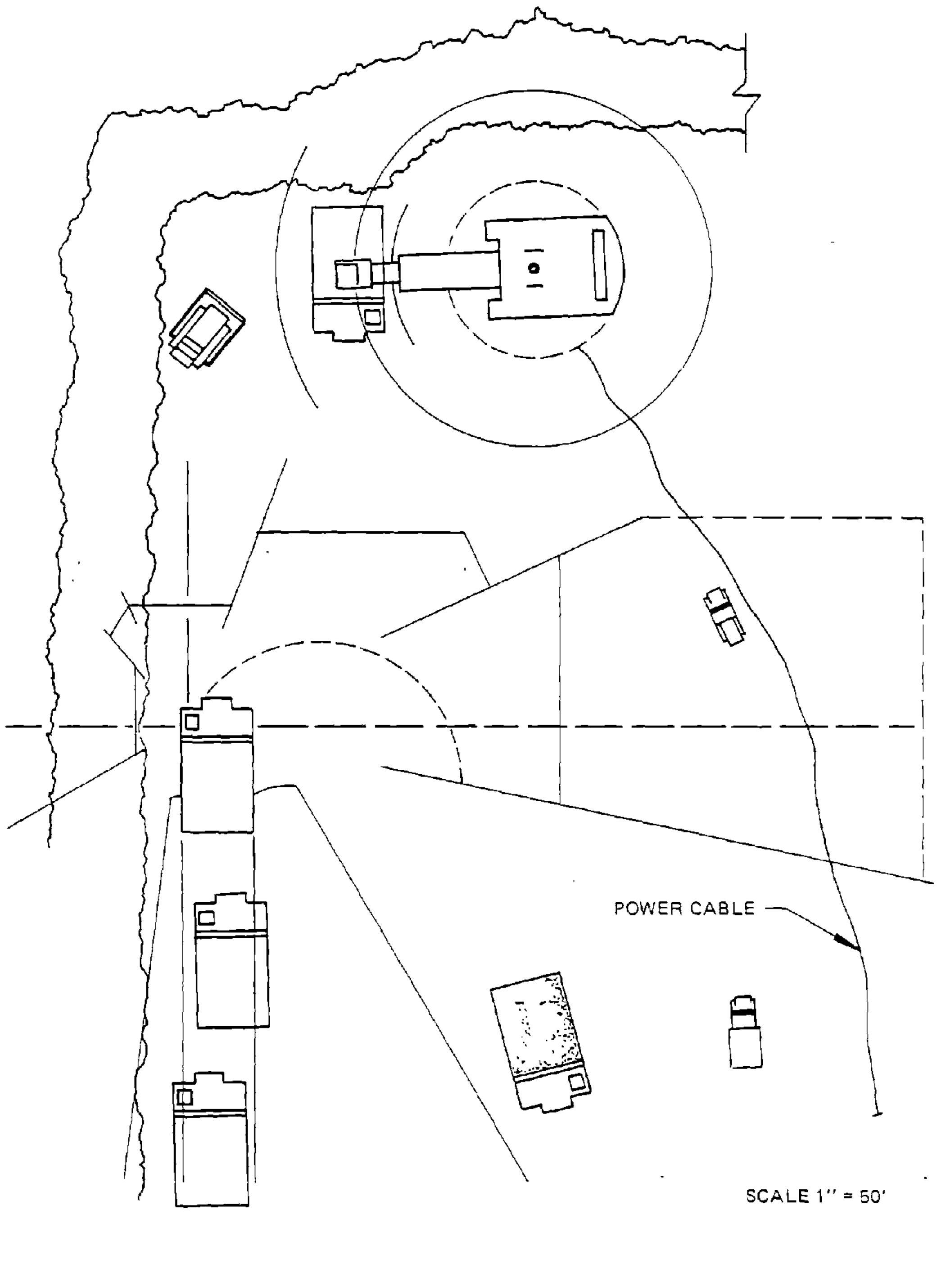

FIGURE 2.2-1
SHOVEL LOADING AREA (Single side)

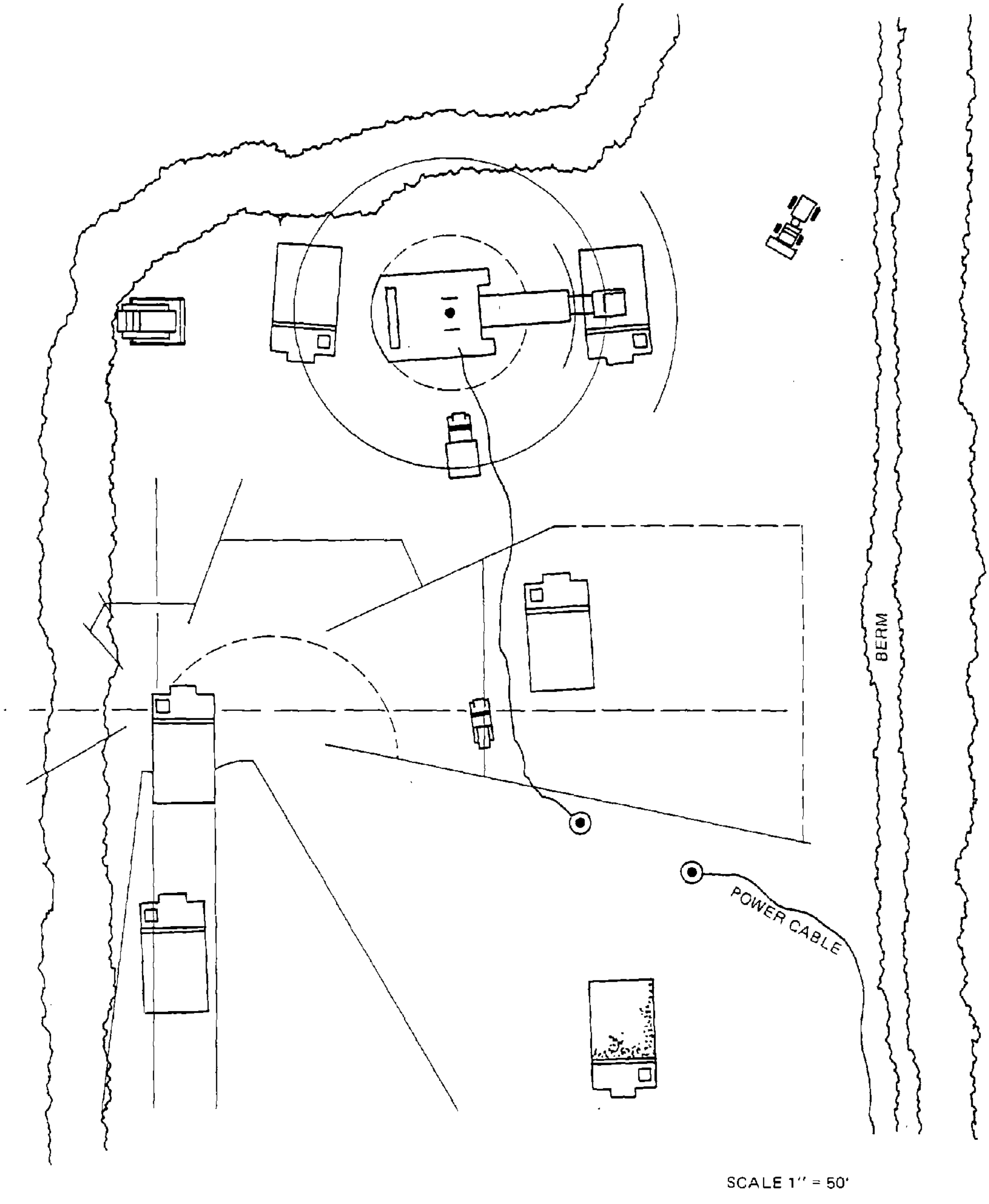

FIGURE 2.2-2
SHOVEL LOADING AREA (Both side loading)

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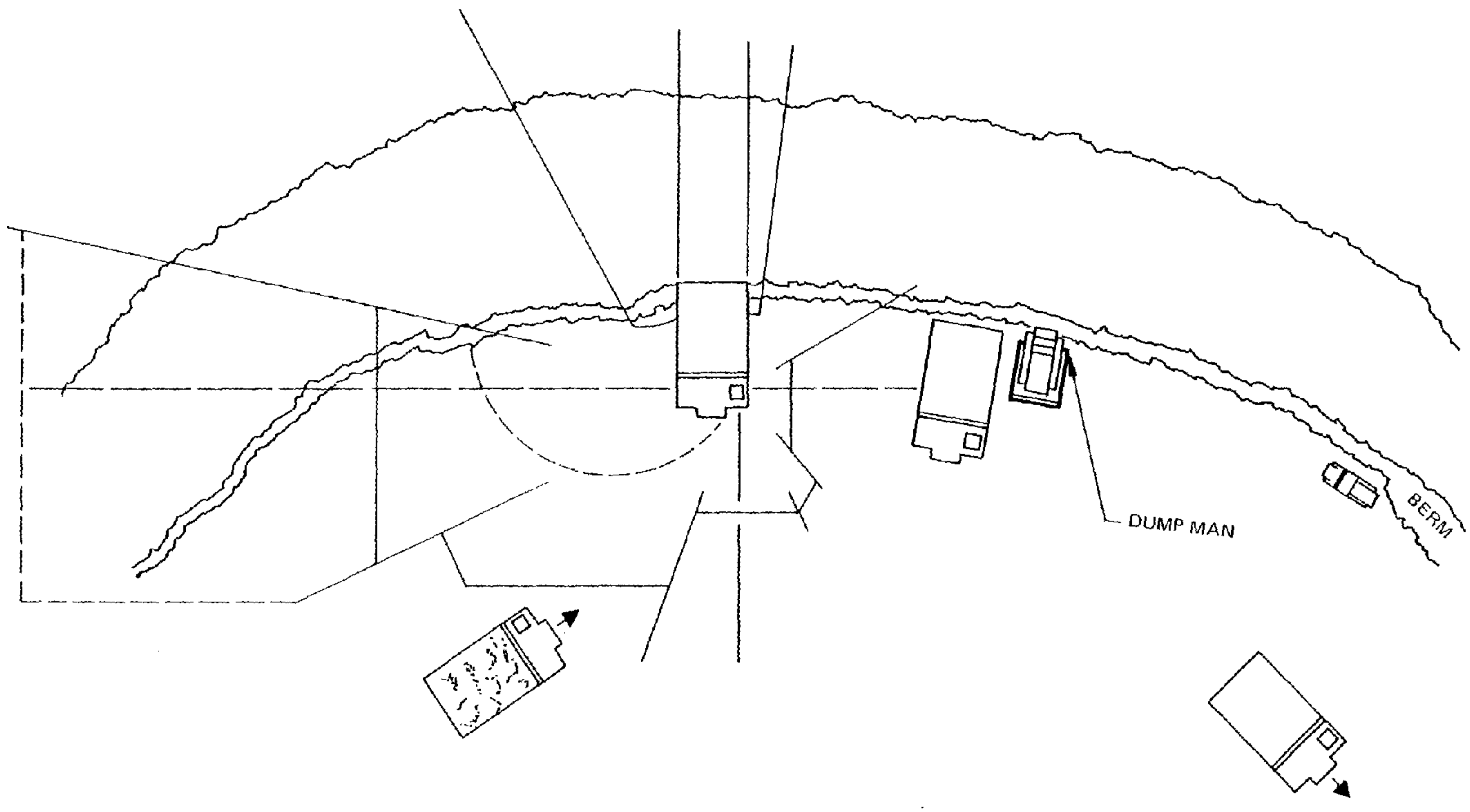

FIGURE 2.2-3
WASTE DUMP LAYOUT

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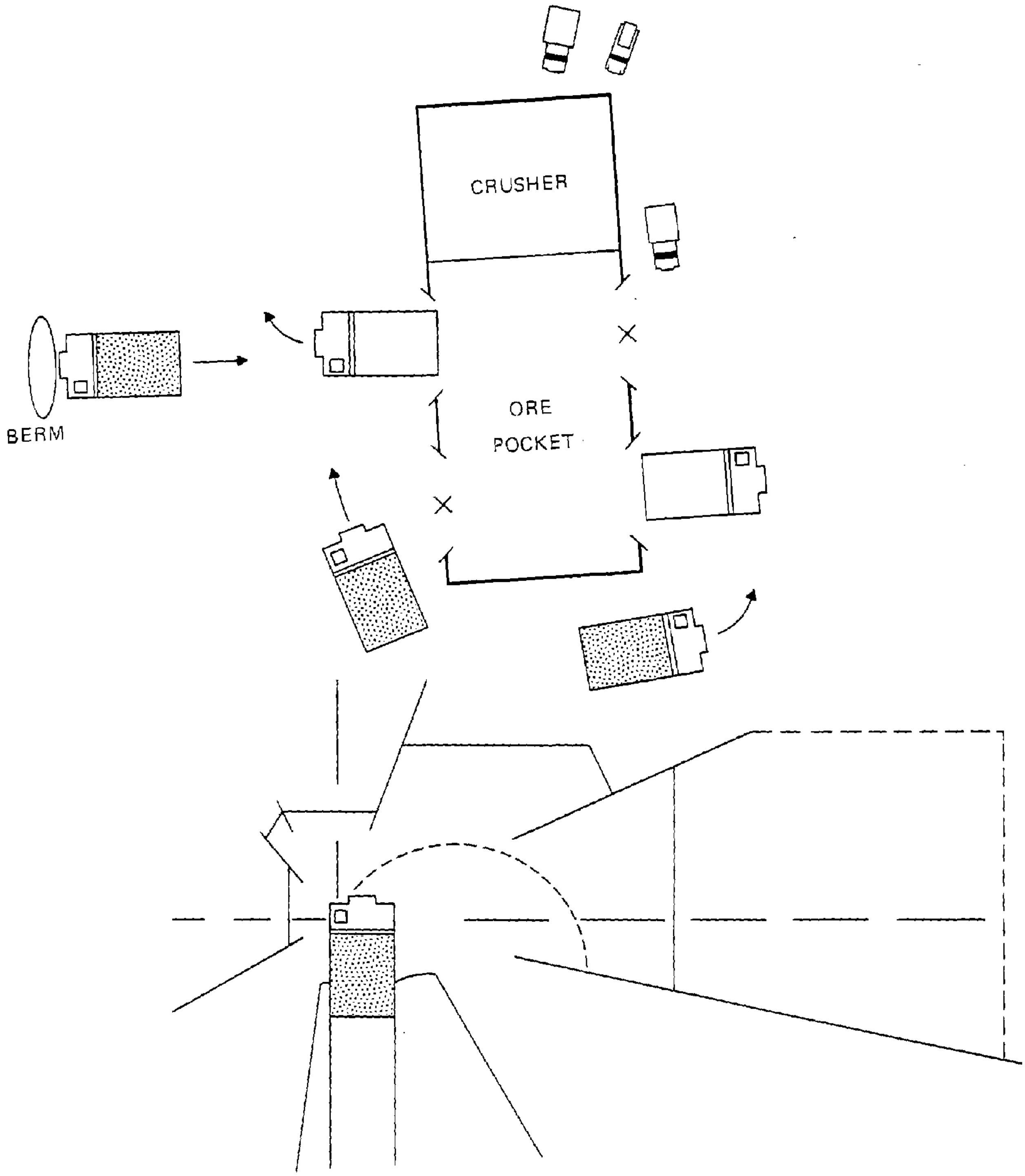

FIGURE 2.2-4
CRUSHER AREA LAYOUT

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Each truck operating location has its own visibility demands and hazards for truck operators. The basic visibility aspects and tasks for most truck operations are similar in the surface mines observed. The extent of visibility problems vary from location to location depending on traffic situations and traffic convention conformity. The basic visibility aspects with repsect to truck operator's visibility tasks are presented in Tables 2.2-1 through 2.2-5. It must be remembered that traffic conformity was not 100 percent at any mine vistited and truck operators had considerable latitude as to operating procedure at many mines. Often, driver expectancy was being substituted for visual alertness, and the drivers often tend to follow the truck ahead blindly. At one mine, a loud warning horn had been installed to "wake up" the drivers as they approached the crusher.

Driver alertness is especially difficult to maintain on the slow moving upgrade (loaded) portions of a haulage circuit that may be repeated during an entire work shift. Reduced alertness, combined with large blind areas and repetitious truck routing, creates serious hazards. It is clear that existing mirrors are not adequate to give the driver the visibility he needs to operate safely.

2.2.3 Climate and Mine Environment. Climate conditions affect visibility in both direct and indirect ways. The climate directly affects the visibility distance and the natural illumination levels. Indirectly, the climate determines the amount of moisture in and on haulage roads. Depending on the permeability and drainage, precipitation frequency and surface evaporation rates determine the degree of control possible over mud and dust. Climatic conditions vary from the mild dry winters and hot, dry summers in the southwest to the wet summers and cold wet winters in the Great Lakes areas. The weather condtions and their effect on visibility are as follows:

- Fog and dense haze reduces visibility distance and interferes with mine and vehicle lighting. Fog occurred only a few days a year in the mines visited. Haze was common in the mines visited in Minnesota and Michigan and its main effect was the increase of glare around stationary lighting systems.
- Overcast conditions reduce the natural illumination intensity. In the daytime the only effect is a reduction in contrast. At night the natural illumination from the moon and stars is reduced to the point that vehicle and equipment illumination is the only source. Overcast conditions are less common in the southwest.
- Precipitation can have the same effect on visibility as fog, haze, and overcast conditions. Depending on conditions, moisture from rain or drizzle suppresses dust or produces mud on the haul roads. Precipitation on mirrors and windows also reduces visibility.
- With snow conditions, mud conditions are sometimes delayed long enough for removal of the snow and ice. Snow on the ground can increase nighttime visibility by reflecting available light for increased illumination in the mine area.
- Temperature and humidity determine the evaporation rate from haulage roads. High temperatures and low humidity with windy conditions can dry out roads rapidly. Low temperatures and high humidity can result in extended mud problems and the retention of water in road materials. Cold temperatures also reduce the practice of leaning out the left window or door to view the left rear blind area. Problems with frost or dew were not considered common or serious in discussions with truck operators.

TABLE 2.2-1

VISUAL TASKS ON HAUL ROADS BETWEEN INTERSECTIONS				
	CONTROL PROCEDURES			
LOCATION AND TRUCK OPERATION	POSITION AND SPEED CONTROL	SITUATIONAL	BLIND AREAS, REDUCED VISIBILITY CONDITION	NAVIGATIONAL
				TRAFFIC CONTROL DEVICES
Driving on haul road General	Visual cues Road edges Berms Lane & road features Roadside features Road condition Traffic control devices	Road and traffic conditions compared to driver's expectancy: Converging traffic Changing road conditions Slippery, wet surface	Traffic convergence in blind area Delineation of road features and unlighted vehicles at night is needed	Informal landmarks well ahead General area orientation
Alone Level Upgrade Downgrade	Orient on path for smoothest ride	Rough road surface Rocks & Debris Landslides - ruts Overtaking traffic likely Runaway traffic possible, (braking ability) critical	" Visibility can be less than braking ability	Beginning or end of grade for advance response
Opposing traffic	Orient for clearance	Abrupt converging or crossing path possible Passing traffic in path possible	Night: Vehicle identification from headlight and clearance light patterns is needed to judge traffic patterns	Early awareness of traffic situation
Following a vehicle	Maintain distance	Evaluate vehicle actions, possible situations Vehicle may stop or turn Is vehicle ahead aware of follower		Compare desired path to path of vehicle ahead
Being followed	Maintain orientation and allow passing room	Vehicle behind may pass	Vehicle may be in blind area, be passing, or may have gone	
Haul truck passing Small vehicle passing	Orient to allow passing room Maintain distance from road edge	Long passing distance with possibility of opposing traffic and converging road width Vehicle in mirror view for only a short period of time before passing vehicle could pass on wrong side if space is allowed	Haul truck passes through large blind area when passing right Small vehicle may not be seen until passed	Evaluate road widfh and path ahead
Passing a vehicle Passing breakdown	Orient for adequate clearance	Evaluate passing distance traffic road width	Determine when to pull in front	Early awareness of traffic situation
Passing a grader		Evaluate remaining road width, traffic Evaluate road & lane width, traffic choose side to pass or stop	Night: May not be lighted Night road feature being changed	

TABLE 2.2-2.

VISUAL TASKS AT INTERSECTIONS					
	CONTROL PROCEDURES	SITUATIONAL			NAVIGATIONAL
LOCATION AND TRUCK OPERATION	POSITION AND SPEED CONTROL	DRIVE RIGHT	DRIVE LEFT	BLIND AREAS, REDUCED VISIBILITY CONDITION	ROUTE SELECTION GENERAL ORIENTATION
Drive through large flat area may be up or down grade	Smoothest path in general direction	Traffic conventions not clearly defined Rough ground and obstructions common		Convergence of traffic in blind (rt) area possible	Use reference features for direction Night: Lighted features or reflectorized guides needed for direction
Intersections (general) Simple Complex	Optimum lane not well defined for position control Speed control on approach can sequence traffic through intersection	Yield conventions	- Traffic sign - Loaded right of way - Blind side right of way		Traffic signs can give general area orientation Route uncertainty can result in unexpected traffic activity
Approaching a Y Driving to left leg Driving to right leg	Speed must be reduced during turns to reduce load spilling	Evaluate traffic Follow yield convention when crossing lanes			
Merging roads Driving in on rt. leg Driving on lf. leg		Follow lane and yield convention - freeway type merging possible		Traffic on left leg can converge in blind area, berm can hide traffic view from smaller vehicles	
Crossroads 60-90° Driving through Rt. turn Left turn	Passing up grade requires judgement of differential speed and when intersection will be reached	Cross traffic from right side must be detected before reaching intersection Traffic in right side blind area must be detected before reaching turning point			
Switch Back Driving through Rt. turn Left turn		Turning traffic may use more than one lane to clear corner		Convergence of traffic in right blind area is possible Stationary mirrors can be used	

TABLE 2.2-3

VISUAL TASKS IN SHOVEL LOADING AREAS				
	CONTROL PROCEDURES	SITUATIONS		NAVIGATIONAL
LOCATION AND TRUCK OPERATION	POSITION AND SPEED CONTROL	ADAPTING TO CONDITIONS, TRAFFIC AND HAZARDS	BLIND AREAS, REDUCED VISIBILITY CONDITION	ROUTE SELECTION GENERAL ORIENTATION
Approach to shovel area	Select smoothest path in general path or follow tire tracks (unless he is first truck in)	Awareness of traffic and activity in shovel area	Maneuver areas observed in advance which gives some confidence	Approach route sometimes not well defined
Switchover from righthand to lefthand pattern	Sharp turns at low speeds	Switchover point and right-of-way frequently not well defined	May be heavy dust, rain, fog, snow, etc.	May be routed to an unfamiliar shovel or dump site
Stop in waiting line		Assume truck ahead will not back up	Guide on cable support structure or cable guard	Reduced visibility causes disorientation
Start up	Sharp turns at low speeds	Support vehicles and personnel may have entered blind areas	Support vehicles and personnel can move into blind area during this maneuver or during extended waiting periods	May be pulled out of waiting line by dispatcher, or by shovel breakdown
Left or right turn to prepare for backing	Guide on shovel body, the bucket, and tire tracks	Recent direct view of area gives confidence but moving small vehicles easily can enter blind zone after it passes from direct view. Shovel body clearance can be misjudged		
Backing up to loading position	Guide on mirror image or direct view of bucket, shovel treads, or on previous tire tracks		Right rear tire can run up shovel bank	
Left side			High intensity lighting on the shovel greatly improves mirror scenes at night, but veiling glare on windshield is a problem	
Right Side	Guide on shovel bucket teeth or tire track			
Driving forward from shovel				
Leaving shovel area			Rocks may have fallen in front of tires	
			Shovel maintenance personnel and clean up equipment in area	
			Avoid sharp rt. turns	

TABLE 2.2-4

VISUAL TASKS AT WASTE DUMPS

	CONTROL PROCEDURES	SITUATIONS		NAVIGATIONAL
LOCATION AND TRUCK OPERATION	POSITION AND SPEED CONTROL	ADAPTING TO CONDITIONS, TRAFFIC AND HAZARDS	BLIND AREAS, REDUCED VISIBILITY CONDITION	ROUTE SELECTION GENERAL ORIENTATION
Approach to Dump area	Usually low speeds upgrade loaded	Be aware of other activity in the area		May be routed to one of several dump sites
Switchover from righthand to lefthand pattern	Select switchover point and smoothest path	Be aware of "the traffic pattern" and stay in it		
Select dump spot	Slowing for dumping maneuvers	Locate bulldozer and groundman (if any)		Judgement of turn radius and location of parked vehicle and activity need
Left or right turn prior to backing		Remain clear of parking areas		
Stopping to begin backing	Stopping and waiting to go into reverse	Detect any indications of landslide at edge of dump	Look for landmarks to go by	
Backing	Slowing as near the berm Alignment at right angle to curved berm	Stopping before striking berm	Lack of visual contrast between berm and surface	
Dumping	Prevent vehicle movement	Know signals from bulldozer operator on alignment for clearance	Stationary illumination should be to left of truck	
Startup to clear area	Waiting until bed is down or nearly so	Be aware of unexpected movement	May be some dust from other trucks arriving and dumping	
Leaving area	Begin turn into traffic path Higher speed (max) level or downgrade empty - avoid overspeed	Inspect areas for signs of imminent slide conditions Maintain drive left traffic pattern	Glare from illumination sources a problem Avoid sharp right turns Watch for slow or stopped haulage vehicles - especially in reduced visibility conditions	Have route in mind at least to "call point"

TABLE 2.2-5

VISUAL TASKS IN SHOP AND UTILITY AREAS				
	CONTROL PROCEDURES	SITUATIONS		NAVIGATIONAL
LOCATION AND TRUCK OPERATION	POSITION AND SPEED CONTROL	ADAPTING TO CONDITIONS, TRAFFIC AND HAZARDS	BLIND AREAS, REDUCED VISIBILITY CONDITION	ROUTE SELECTION GENERAL ORIENTATION
Maneuvering in close proximity to structures, parked haulage trucks, small utility vehicles, and personnel	Position control often involves guiding on structures and parked vehicles when ground is not visible	Personnel, moving vehicles and unscheduled activities in area	When guiding on structures and tall vehicles, small vehicles parked in between may be undetected hazards	Routing can involve paths around obstacles which are not seen when in the cab
Driving onto apron forward	Right side clearance is difficult to judge		Drivers may assume there is nothing inbetween due to past experience in the area	
Driving into shop or utility area	Guide on structures and pads			
Backing out of shop or utility area	Guide on door frame	Small vehicles frequently park in front of shop doors on apron	Rear view inadequate Assistance from manpower on ground in left rear view advisable	Safe route to better visibility area must be selected
Starting Up		Personnel, moving vehicles and unscheduled activities in area	Awareness of activities in blind areas advised	Routing can involve path through blind areas

- Freeze thaw conditions result in extensive mud problems with many road materials. Freezing conditions result in the storage of water in or on the road as ice. Thaw conditions, melting snow and road salt, can produce very extensive watery mud conditions. A frozen base, temperature near freezing, and high humidity can extend muddy conditions and cause icing in subsequent freezes.
- Wind removes more humid layers of air just above haul roads increasing evaporation rates. In dry, dusty, haulage road condtions, wind can both help and hinder visibility. Wind can pick up dust as well as remove it from operating areas. Wind is a factor in the delivery of dust and mud flung by the tires to mirrors and windshields.

Mud and wet conditions are a seasonal problem at most surface mines. Spring and winter freeze thaw conditions and spring rains can produce extended periods with muddy roads. Intermittent rain and dust control watering can cause minor mud problems. The effect of mud on visibility is the fouling of mirrors and windshields as a result of truck operation on haul roads with wet surfaces or covered with watery mud. At moderate to high speeds the tires of haulage vehicles displace and fling considerable quantities of mud both tangently and axially. Fan exhausts and wind contribute by creating turbulent air conditions below the vehicle. As a result of wind conditions and the turning of the front wheel out from under the fenders, mirror and cab window fouling occurs. This fouling often occurs randomly or repeatedly on sections of the haulage circuit where conditions are unfortunate.

Dust problems inevitably occur because of the difficulty involved in maintaining moisture in haul road surfaces when large volumes of relatively dry air pass over them. A low moisture content in the material being mined complicates this problem. Dust control was the major problem observed in western coal mines and lesser dust problems were observed in both iron and copper operations. Dust tended to slowly decrease the visibility through mirrors and cab windows. Any precipitation or moisture on mirrors or windows creates problems similar to mud. The cleaning of abrasive type dusts from plastic, glass, or polished steel mirrors can result in scratching if inadequate amounts of cleaning solutions are used. Dust clouds have been observed to obscure rear mirror views only in isolated instances.

Reduced visibility situations other than those created by fog, precipitation, mud, or dust, include glare and reduced illumination levels. In the daytime, low levels of veiling glare (on windshields) are not a serious problem, and the problems of low sun angle are obvious. One benefit of low sun angles is long shadows which can aid in detecting obstacles. At night, mines, equipment, and vehicle lights can produce both direct and veiling glare. The placement of lights in mining situations involves trade-offs between illumination and glare.

Reduced illumination levels due to overcast skies lower contrast levels between colors and surfaces. Low contrast levels in the right rear view mirror make detecting possible hazards behind the vehicle much more difficult. At night, visibility is often limited to headlight range or stationary light sources. Under not too infrequent conditions, only the lights of traffic can be seen in direct view or through the rear view mirrors. Illumination in mine situations is reduced by dark colored mine surfaces such as coal or taconite. There is much room for improvement in illumination of the blind areas and also the increased use of clearance lights on the trucks.

2.2.4 <u>Truck Maintenance</u>. Haulage truck availability was reported to be between 60 percent to 90 percent. Routine maintenance included servicing at intervals corresponding to approximately 100 to 200 hours operation and then a more thorough maintenance check at 1000 to 2000 hours intervals. Actual maintenance schedules can be expected to vary widely. The maintenance factors which concern visibility are as follows:

- Truck washing by high pressure hose was observed in several mining operations. Cold weather may interfere with this.
- Field maintenance personnel were observed in all mining operations.
- Electronic repair for radio communications was delegated to a factory service agency.
- Truck operators frequently had cleaning solutions and rags in their cab for cleaning windows and mirrors.
- All truck shops had a fabrication capability adequate for the mounting and alignment of any visibility components developed by this study.
- The maintenance of new or unfamiliar equipment often suffers from the lack of the diagnostic and repair procedure skills that are developed by experience with specific equipment. The successful maintenance of new devices depends in part upon initial trouble shooting and maintenance ease.
- A lack of component standardization can lead to problems with locating the proper size part or require additional fabrication steps. Such problems can lead to long repair delays for simple repairs such as cab window replacements.

2.3 TRUCK CHARACTERISTICS AND PERFORMANCE

2.3.1 Driver Characteristics. The drivers surveyed had from six months to over fifteen years of experience as drivers in the surface mines. At a typical location, some drivers could be young men or women who had recently been trained, others could be much older men who had worked in the same location for a number of years, and still others could be men who had been driving in other parts of the mine and then been transferred to the present run - perhaps to operate a different type of truck. Four drivers were women, and one was so small in stature that she needed portable pedal blocks to reach the accelerator and brakes. However, supervisors reported that women drivers performed well, and gave even greater attention to safe practice than many of the male drivers.

At the mines surveyed, all drivers were recruited from the ranks of existing employees. To qualify, these men had to be capable of operating the large haulage trucks, and they had to pass a medical examination in which they were checked for normal vision and the absence of any disabling health problems. These employees had typically worked at least one year at entry level jobs, and all were familiar with the various truck missions that are performed in the layout of haulage roads. However, they had not had any experience aboard the trucks.

Once selected, these men then went through a course of company training. This consisted of classroom training followed by behind-the-wheel practice. At each level, some screening was done by the company so that if a man satisfactorily completed his classroom training, he was then permitted to progress on to training in an actual truck, and if he performed satisfactorily there, the man then became a new truck operator.

When assigned to a particular mine location, the new drivers then become subject to a variety of mobility and turnover factors which will affect their permanence on that job. Some drivers will continue to drive the same truck over the same run for a long time. Others may bid for newer trucks or for work in other mine locations. Still other drivers may eventually move up to higher level jobs and leave the driving occupation completely. And, finally, some drivers, for medical reasons, may have to move into a non-driving job.

There was a high degree of maneuvering skill exhibited by most of the several hundred drivers who were observed. In fact, these large vehicles are so maneuverable and easy to drive, that many drivers were observed making what appeared to be excessively rapid maneuvers - particularly at dump sites. There is a good deal of excessive wear and tear on these trucks (especially when loaded) when they are operated in such "cowboy" style driving.

2.3.2 Driver Training. At the mines surveyed, the drivers were always trained at the mine by the safety supervisor or one of his assistants. This generally started with classroom training in which the trainee was asked to learn the company's driving rules and was familiarized with how the truck is constructed, powered, and controlled. Some attention is usually directed to the braking systems and the electrically controlled power train. Included with this material was also some safety information concerning large truck visibility problems and hazardous maneuvers. If the trainee appears to have made satisfactory progress in memorizing company driving rules and large truck operating characteristics, he will then be considered ready for some behind-the-wheel training.

Initially, the trainee rides as a passsenger with an experienced senior driver who explains the art of driving during each of the various maneuvers. The quality of familiarization provided can vary considerably among senior drivers, and some of these drivers object to training new drivers unless extra pay is given for serving as a driving instructor.

As soon as the training supervisor believes they are ready, the trainees are encouraged to try out their skill by operating a truck. Usually there is opportunity for the new driver to drive the truck, empty, in an open, level area before he attempts any part of an actual mission. Then, if the trainee does well, he operates the truck with the senior driver or safety supervisor as a passenger until he is judged competent to begin solo operation on a day shift. This total training effort typically requires one week to ten days and occurs on the day shift.

A few trainees had previously been over-the-road truck drivers, but most had only driven passenger cars or small trucks before learning to drive the large rear dumps. The actual driving of these large trucks is relatively simple, due to the electric motor power system and power assisted steering and brakes. Most trainees do become drivers, but about two to five percent either disqualify themselves or are told by supervisors that they can't perform skillfully enough, or with enough confidence to warrant their assignment as drivers.

2.3.3 Problems Affecting Driver Performance. The driver of a large haulage truck commonly drives his truck in a repetitive load and dump cycle. He becomes very familiar with the haulage route and the traffic on that route. His familiarity and his day-in, day-out, truck operation experience results in various expectancies regarding what is likely to be hidden in his truck's blind areas. This, coupled with traffic ambiguities, visual perception problems and driver alertness, creates potentially hazardous situations.

Usually, a driver is required to haul a certain number of loads per shift, and any stoppage due to a driver's performance problem, or his leaving the cab too frequently to check blind areas, would interfere with production goals. Driver visibility aids would reduce the hazardous situation potential due to drive performance problems. Visibility aids would also increase the driver's responsibility for safe defensive operation of his truck.

2.3.4 Driver Expectancy. In many situations, a haulage truck driver is reasonably sure, or assumes that his path through his truck's blind areas is clear of hazards. This clear path expectancy can be based on a rational awareness of activity in the area or over confident familiarity. A rational awareness adds a degree of certainty or predictability to the situation. For example, when a truck driver enters a dump area, he surveys the entire area as he enters it, to determine if there are any other vehicles or pedestrians in the area. He then mentally notes their location, choses a "safe" dump spot and makes his maneuvers while maintaining surveillance around his truck as best he can without leaving the cab. When it is time to leave, he can then be reasonably assured that there is no person or vehicle in the blind areas of his truck because he has watched the dump area ever since his arrival to detect any persons or vehicles that have entered, subsequently. In this situation, the truck operator can drive out with a high degree of safety with an awareness of the location of all potential hazards.

A problem arises, if a truck operator has been inattentive and he has not maintained a continuous surveillance of the area around him. In this situation, he cannot be really certain that another vehicle or person has not moved into his vicinity. To be sure, he would then have to get out of his cab, and examine his blind areas to make sure that he is still clear. In many locations, he would not expect a hazardous situation and assumes his path is clear.

Interviews with drivers regarding driver expectancy, revealed a tendency of drivers on a regular haulage circuit route, to assume that their path through their blind areas is clear. Another tendency is to assume that if another large haulage truck or structure is visible nearby, no other smaller vehicles are in between. In an extreme case, smaller vehicles and personnel were expected to stay clear of large haulage vehicles and the visual responsibility was not required of the haulage truck operator. The human element defeats this approach to safety. Haulage truck drivers also develop expectancies concerning road conditions, dump conditions, traffic patterns and other driver's reactions. Improved visibility aids can replace blind area expectations and assumptions by a high degree of certainty that the formerly blind area is free of hazards.

2.3.5 Traffic Ambiguities. Traffic on a haulage circuit tends to follow a pattern based on mine conventions. When this pattern is disrupted, potentially hazardous situations can develop. The accident potential of these situations, can be reduced by improved visibility aids and an improved visual environment. With respect to truck blind areas, it is an occasional event for other vehicles to enter these blind areas sometimes without regard to truck traffic patterns. Even if a small vehicle driver respects the truck operator's traffic pattern, the truck operator may depart from this pattern due to an unexpected event. A haulage truck's traffic pattern can be disrupted by a number of common circumstances such as; mining equipment breakdowns, maintenance problems, supervisor communications, work breaks, and driver initiative. Due to continually changing mine layout, traffic ambiguities concerning right of way can occur at some intersections.

Still another operational problem affecting predictability is that of the new driver who is assigned on a particular run. In a sense, drivers tend to form a close knit group in which each driver has a pretty good idea of how other drivers in his group will react, and what their driving performance will be like. When a new driver appears on the scene, some of the drivers who have been working in that area for some time may be at a loss to predict what the new driver will do in situations where they maneuver in close proximity.

The drivers of large haulage trucks often initiate changes in their route and style of driving to relieve the boredom of the repetitive haulage cycle. In mines with central dispatcher control (with an optimum observation point) more uniform traffic patterns were observed.

2.3.6 Visual Perception. In daylight conditions, visibility can be degraded by a lack of cleaning and maintenance of cab windows and mirrors. In dusk, dawn or overcast conditions, brightness contrast levels are reduced, making perception of low contrast objects more difficult, particularly as seen through mirrors. Another daytime problem is glare from reflected and direct sunlight.

At night, visual perception becomes even more difficult. When there is no natural illumination, the driver, using his headlights, must adapt to a lack of roadway delineation features and a few scattered sources of ground illumination. A truck driver is often located 10 feet above his headlights and the part of the illuminated roadway he can see is 30 feet to 50 feet ahead of the truck. Therefore, the illumination value of haulage truck's headlights is significantly less than that of an automobile or highway truck. Because the truck driver is so out of line with his headlights, standard retroreflective tapes and delineators are not effective. When driving on most haul roads, only the low contract road features or berms are available as guides. With repetitive runs and familiarity, truck drivers partially adapt to these poor visibility conditions.

In addition to poor roadway delineation at night, other traffic presents a problem on haulage roads. As other traffic is approached, headlights, taillight and clearance light patterns are often the sole source of vehicle identification. As other traffic is approached at a 15-50 mph closure rate, an evaluation of the other vehicle's speed, direction and lane position must be made quickly. This situation requires alertness since the roadway orientation of the other vehicle cannot be determined directly in some cases. The possibility of a false interpretation is high. In some cases, haulage trucks and small vehicles have similar light patterns and were mistaken, with some accidents and many near misses occurring. This problem with vehicle delineation and identification is compounded by frequent occurrences of burned out lights and, in a few instances, by lighted delineators being shifted to a different location on the haulage truck. This problem is similar to visual maritime navigation at night. Improvements in vehicle delineation, roadway delineation, and haul road illumination would improve the nighttime visual environment safety considerably. At shovels and dumps, lighting is frequently adequate for the standard maneuvers. The haulage truck creates a shadow on one side at these locations and the illumination of dump berms sometimes was inadequate. It was noted that a few trucks had re-aimed their backup lights in order to illuminate the berm as they could see it in their left mirror view. In well-lighted areas, cab windows frequently act as mirrors reflecting images which obscure the direct view of truck surroundings. Poorly aimed lights and atmospheric conditions can also produce a masking glare.

When leaving a lighted area, the driver's eyes must adapt to lower light levels. In adapting to low light levels, a temporary loss of visual ability occurs. This problem becomes worse with drivers suffering from night blindness and visual adaptability worsens in drivers from age 45 on.

Nighttime visual perception problems are worse in climates with frequent cloud cover, haze and precipitation.

2.3.7 Driver Alertness and Fatigue. All types of human activity and performance are degraded by so-called "fatique" effects. The word fatigue is so broad in meaning that it covers many conditions of physical and mental capability. Several international conferences on the topic of fatigue have been held; and one conclusion that all experts agree upon is that there is no single satisfactory definition of the word fatigue. Therefore, each study must create a specific definition of what the researchers are actually studying and how they created fatigue or what work or play activities they observed in their study.

In the case of drivers of large haulage vehicles, there are several types of fatique effects that are acting to cause truck accidents in surface mines. Based upon our recent studies of large haulage truck operation in more than twenty surface mining operations through the United States; and relating this information to over twenty years of research interest and activity on the topic of sleepy drivers, the following causal factors are listed below but not in any particular order:

- Loss of sleep before reporting to work.
- Boredom due to the task of driving.
- Physical tiredness due to overexertion before reporting to work.
- Mental stress due to personal life situations.
- Mental stress due to work related conflicts.
- Physiological effects due to shift changes.
- Inherited tendency to fall asleep while driving.
- Physiological stress due to noise, temperature, ventilation and vibration conditions.
- Drugs, alcohol, medication and hangover effects.
- Vision fatigue due to glare or reduced visibility conditions e.g., fog, snow, dust, etc.
- Illness of any type and elevated boby temperature.

This list of eleven factors has come to light during our opportunities to meet with drivers, supervisors, safety engineers, managers and union stewards to discuss the many causes of large truck accidents in surface mining operations. This topic (sleepy, bored drivers) repeatedly came up even though our prime concern was to learn about the visibility problems (blind area accidents) of large haulage truck operation. These same factors are reported in the resently completed survey of this surface mining problem by Dr. Bruce McDonald.(1)

The essential nature of the problem of unalert drivers of large haulage vehicles is that there are several types of unalertness such as follows:

- Common form of drowsiness

  Driver gradually becomes sleepy - and his eyes close and his head nods in repeated episodes lasting several seconds. He may go sound asleep eventually and not awake until he crashes or is physically shaken.

  This is usually due to either lack of sleep or a mild degree of narcolepsy.

- Sudden loss of consciousness

  Driver is awake one moment and only semiconscious the next, without warning. Sleep episodes may last minutes.

  This is typical of prolonged loss of sleep and/or use of drugs. Cold remedies with antihistamines can cause this. Also, some stimulants have this effect when they "wear off." Brain damage and other neurological trauma may also cause this sudden loss of awareness.

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(1)McDonald, B. "Improved Truck Driver Alertness Technology" Technology Summary Report, March 1977, pp. 19, MIDWEST RESEARCH INSTITUTE.

- Loss of awareness with head errect, eyes open while performing routine driving tasks.

  Driver appears alert, eyes are open, he can stay on the road but he may fail completely to detect a stalled vehicle in his path. Or he may perform an habitual maneuver without becoming aware that it is safe to do even though the hazard is clearly in his field of view.

  This behavior is due to the highly repetitive and undemanding nature of the task of driving these large, slow moving vehicles on wide roads with few stops and little traffic. This loss of awareness may become habitual and may be caused by preoccupation with personal life problems.

  Sometimes this stage of semiawareness precedes an episode of common drowsiness.

Improved visibility of the terrain, other vehicles and personnel can help to offset these tendencies for drivers to lose alertness. If the driver has to make an effort to see into a blind area, this extra effort can help to keep him alert. However, if a driver has to make an extra effort to check a blind area, he is less likely to do so in an inattentive fatigued state. If moving objects appear in his improved visibility aid devices, they can attract his attention, whereas formerly they wouldn't be able to "wake him up" because they would have been in his blind area.

Visibility aids may also reduce driver fatigue because he can see where he is going and drive with confidence. The stress of constantly "driving blind" can be a major source of work induced fatigue.

2.3.8 Factors Affecting Use of Visual Aids. A driver's desire to use a visual aid is basically dependent on the problems he has been having in the driving situation and his expectation of help from the visual aid. A new, inexperienced driver who has been having some difficulty in the driving situation, may expect that the aid will help him, and he will start out using this aid on a regular basis. An older, more experienced driver, who has already learned to cope with the driving situation, and who has developed some well established scanning and surveillance patterns in his driving, may find the new visual aid a distraction and disruption of his driving performance. In addition, the experienced driver may not have the same expectation that the visual aid will help him. In this situation, the experienced driver may not use the visual aid very much at the beginning.

However, after the visual aid has been in use for some time, both the new driver and the experienced driver will develop new expectancies concerning this visual aid as the result of their experience with its performance. If drivers have found the visual aid to help them and reveal potential accident situations that they might otherwise have missed, their use of this visual aid will increase. However, if the visual aid has not been providing useful information, or requires frequent maintenance, drivers will tend to use it less and less, and they will give more of their attention to other means of observing their driving environment, and the visual aid will eventually fall into disuse. To summarize, a visibility aid will be used if it provides a degree of certainty pertinent to the detection of hazards, safe clearance of obstacles or the positive control of the vehicles path. Often present mirrors are inadequate and poorly maintained, which results in disuse. At night, lack of illumination, or glare can prevent visibility aid from being useful in some circumstances.

2.4 VISIBILITY FACTORS IN HAULAGE TRUCK ACCIDENTS. The primary purpose of analyzing visibility related accidents was to determine the frequency distribution of accidents by types of large truck operations. This information would answer the question of where in the various existing blind zones there would be a payoff for overcoming the visibility restrictions with one or more visibility aids. Secondary purposes of the accident study were; time of day relationships, and the relationship of driver experience to accident frequency.

2.4.1 Data Sources. Based upon MESA regulations relative to accident reporting, it was fairly clear that property damage only accidents will seldom be reported to the Health and Safety Analysis Center (HSAC). Furthermore, injury accidents with no loss of work time will likely not be uncovered in a computer file search of the HSAC data. In addition, some past recording difficulties in pre-1975 data nearly precludes a reliable file search of pre-1975 data. Thus, only 18-20 months of readily accessible data could be resonably expected from the HSAC division of MESA. It was therefore necessary for the project staff to solicit accident data from those mines visited by the project team. A total of six mines responded by providing their own accident records. The number of these records varied from 3 for one mine to 30 for another mine. Of the total of 92 accident records received, 73 of these came from three mines. Another 3 accidents were verbally described by mine personnel to visiting MBA project team members.

Of the 95 accident descriptions provided by the mines, the vast percentage were likely never reported to HSAC as there were few disabling injuries, although two reports had resulting fatalities.

A three-day visit to the HSAC facility in Denver, Colorado, was preceded by a HSAC conducted file search of their 1975-1976 records. Because large haulage truck accidents cannot be directly retreived, two basic codes were used to obtain a file listing which would contain such accidents for both coal and metal/nonmetal mining operations. There was an "aboveground" mining operation code coupled with a haulage code which involved automobiles, gasoline, or diesel trucks and tractor trailers. These file listings produced in excess of 1000 accident listings which were microfilm accessible via a HSAC document number. Using mine ID numbers which corresponded to some 25 mines with (or possibly with) large haulage truck operations, the HSAC file listings were hand-screened to form a sub list of accident document numbers, the reports of which were microfilm viewed.

2.4.2 Data Screening. Once a file of large haulage truck accidents was obtained, these records were analyzed and those records where the primary accidents causes were not visibility related were discarded. Reasons for discarding included drivers falling asleep, truck failures (brakes, steering), excessive speed, etc.

The results of this screening process produced 53 restricted visibility related accidents from the 95 received from the mines and 9 such accidents from the HSAC 1975-1976 data.

Before proceeding with the results of the 62 visibility related large truck accidents, a few remarks need to be made relative to types of accidents not contained within the aforementioned 62 accidents.

The first is an individual who walks in the path of the rear wheels of a moving haulage truck. This can be likened to a small dog instantly appearing next to the rear tires of a slowly moving automobile. Such behavior is not the responsibility of the automobile driver, nor the large truck driver. Providing visibility enhancement for large trucks to protect against such individual behaviour is not considered cost effective by itself. However, most visibility aid concepts reported in the study will help reduce these types of accidents.

Rear-ending of large haulage trucks by other large haulage trucks in haul road operations is not considered a visibility problem, but rather an informational transfer problem which is easily solved, but is external to the project scope.

2.4.3 Locational Analysis. Of the accidents analyzed, they locationally occurred as follows:

- 35.5% in shovel area
- 34.0% in the dump area or dumping operations
- 14.5% in the shops or parking area
- 8.0% in the haul road operations
- 8.0% in the crusher, loading bin, or unknown area

The foregoing reveals that roughly 70 percent of visibility related accidents are occuring in loading or dumping areas.

2.4.4 Daylight Versus Darkness Accidents. The daylight/darkness frequency of accidents was impossible to determine as it was not noted on all reports. Based upon known conditions it is approximately a 9 to 11 split in daylight vs darkness accident frequencies. Including dawn and dusk in the darkness category, the daylight frequency split is near 1 to 2.

2.4.5 Truck Operations Relating to Accidents. Of those accidents analyzed in detail, three primary truck movements contributed the following accident percentages:

- Fifty-eight (58) percent of the accidents involved backing movements of large haulage trucks.
- Twenty-eight (28) percent involved right turns (including 2 U turns) i.e., trucks turning right into their blind area.
- Fourteen (14) percent involved straight ahead truck movements.

Specific breakdowns within each category are discussed below.

- Backing through the dump berm naturally produces the highest likelihood of driver injury or fatality. Of the 14 reported accidents in this category, 6 specifically noted the right rear (blind side) wheel initially penetrated the dump berm. These statistics confirm the expressed apprehension voiced in truck driver interviews relative to dumping operations and their voiced difficulty in perceiving right rear tire location in backing maneuvers.

Figure 2.4-1 depicts the potential operational accident payoff in increasing truck visibility in each of four zonal areas. Zones I and II correspond to forward and forward/right turn operations while Zones III and IV correspond to backing maneuvers. The fatalities (total of 3) are all in Zone IV.

2.5 DESIGN CRITERIA FOR VISIBILITY AIDS

2.5.1 Visibility Needs. The visibility needs of large haulage vehicles are based on the interaction of the blind areas and vehicle operation. Analysis of truck visibility, truck operation, mine operation, accident and property damage indicates the following conclusions:

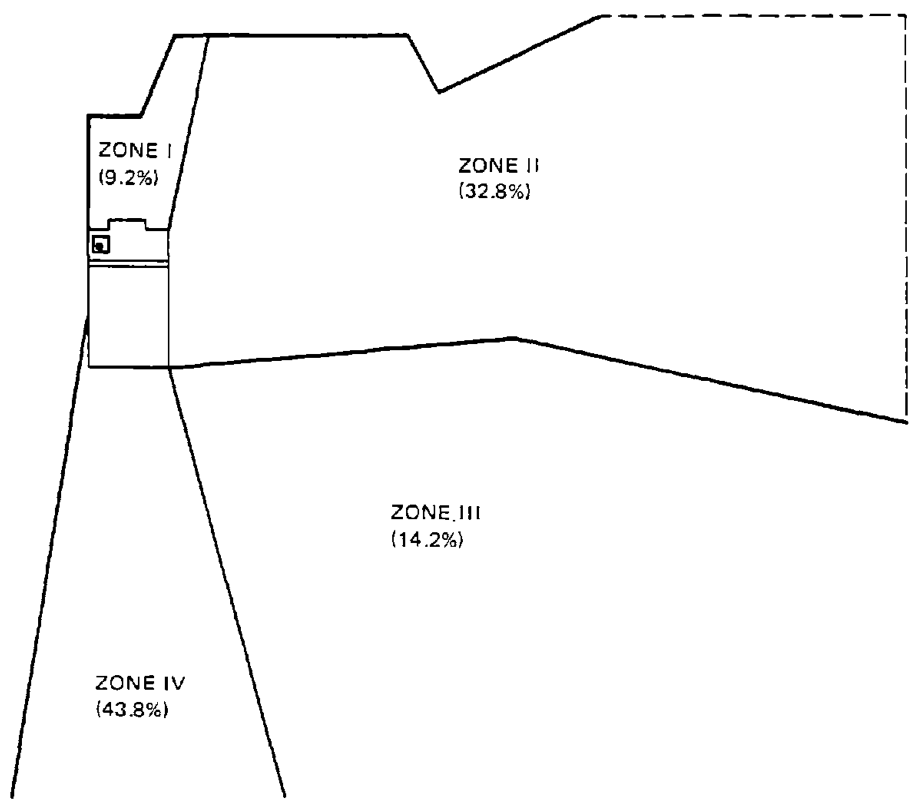


FIGURE 2.4-1
VISIBILITY RELATED LARGE TRUCK
ACCIDENT ZONES

3466-15379

- The detection of stationary and moving objects in the right front, right and rear blind areas is required for safety during start up situations and is necessary in some traffic situations at intersections.
- Visibility in the front right and right blind areas is required to within 20 feet of the haulage vehicle and visibility to within 0 to 10 feet is advisable.
- The detection of stationary and moving objects in the rear blind area and mirror view area is required for safety in start up situations.
- The detection of overtaking or converging vehicles to the rear is required for safety before lane changes.
- A view to the rear with good orientation, detail recognition, and depth perception is required for safety when docking at shovels and at dump berms.
- Visibility aids for other blind areas would be beneficial in start up situations.

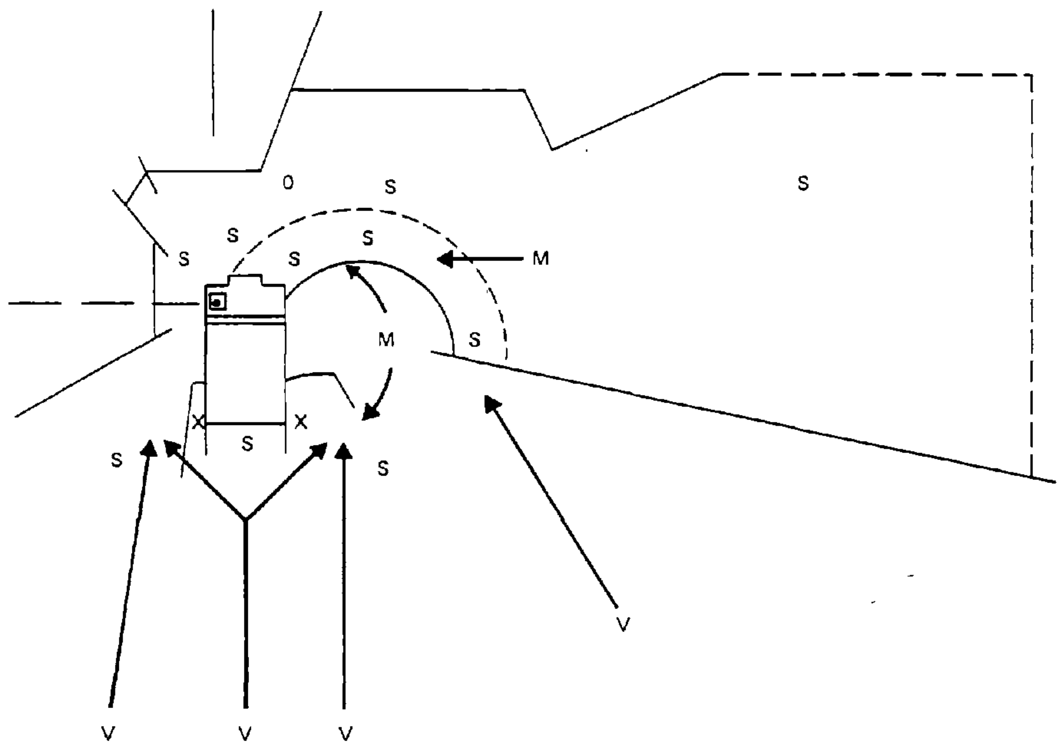
Visibility needs based on truck operation in mines with traffic show that the visibility hazards are different in startup and moving situations; and that turning right (in forward or reverse direction) when the maneuver area has not been viewed immediately beforehand is the most potentially hazardous situation involving visibility (see Figure 2.5-1). These sharp right turns and backing (right, left or straight) occur primarily in shovel, dump and shop areas which are the locations of all the visibility problem accidents investigated involving start situations.

The difficulty of proper orientation of objects (shovels, berms, dumptenders) in rearward views creates a considerable safety problem indicating a need for better view (clarity and coverage) of the rear area. The practice of drivers bodily hanging out of the open door or window to obtain a clear direct view (left, rear only) increases the possibility of their losing control of the vechicle because of their foot slipping or not being able to reach the controls.

Because of moving vehicles and personnel in the vicinity of haulage vehicles and because visibility aids would be viewed intermittently, near total coverage of right front, right and right rear blind areas is needed; to the rear, near total coverage of the rear blind area with good orientation is needed.

2.5.2 Capabilities. The ability to protect mine equipment and personnel from damage and injury depends on the visibility system. The capabilities of a visibility system will depend on the capabilities of individual visibility aids. These capabilities concern the view or the meaning of signals received by the driver of the large haulage vehicle. Capabilities for visibility aids are as follows:

- The field-of-view of an optical visibility aid must be wide enough to detect all stationary and moving hazards in the blind areas. The view should contain cues as to the location of objects relative to the motion of the large haulage vehicle. A wide field-of-view also reduces the number of visibility devices required for coverage. The driver will be viewing most visibility devices with his eyes gazing horizontally. This indicates that a vertical field-of-view of 90° is needed to see both the horizon and the ground immediately adjacent to the vehicle. The horizontal field-of-view needed depends on the area to be covered and the overlap with other visibility devices. The scan area for object detection sensors should cover all areas in the wheel paths.



VEHICLE SPEED	HAZARDS	CODE
START UP AND SLOW SPEEDS 1 - 10 mph	STATIONARY OBJECTS	S
	MOVING OBJECTS	M
	DUMP BERMS	X
HIGH SPEED	STATIONARY OBJECTS	O
	MOVING VEHICLES	V

FIGURE 2.5-1
VISIBILITY HAZARD SUMMARY

MBA
3466-15380

- Image resolultion is important for the recognition of personnel, equipment or hazardous features in the field-of-view. The recognition of pertinent objects in the field-of-view depends on the image size in terms of the angle subtended at the eye, the distortion of the image and the constrast of the image with its background. An image size equal to that seen in a direct unaided view would be desirable especially in views of the wheel paths. Image sizes reduced by a factor of up to ten would be acceptable for detecting close objects. It is obvious that distortion should be minimized and that contrast can be maintained by minimizing optical light losses. At night the detection of vehicle lights and flashlights would require no additional illumination; however, the detection of surface features and objects in the wheel path requires added illumination (truck mounted).

- Driver usage of optical visibility aids depends on their usefulness and driver safety consciousness. A driver can be expected to use a visibility aid when he feels a need to see a particular view. This means that with an optical visibility aid, safety will still be the responsibility of the driver. Operator usage can be encouraged by the ease in which the view can be oriented by means of the device's alignment and the features in the view. Sensor systems can indicate the presence of possible hazards independent of driver action. There are problems with sensor systems. For example, a sensor could fail without being noticed, but the failure of an optical visibility aid cannot occur without indication. The sensitivity and range of a sensor can also vary widely. Another problem is the false detection of hazards. In order for the driver to respect a signal of a hazard, false signals must be infrequent as compared to relevant signals. False signals and signals from detection of equipment and objects which are not immediate hazards in the driver's opinion can destroy the credibility of a sensor. This indicates a sensor signal must indicate the general area location of the object detected.

- The operating environment for a visibility aid ranges from the protected cab interior to the turbulent mud and dust underneath the vehicle. On the sides of vehicles, visibility aids must be protected from wheel thrown mud, soil aggregate, and rock spillage from the edges of the truck bed. Devices which are self-cleaning should be used when isolated from the cab deck or require cleaning more than three times per shift. For individual trucks the patterns of encrusted mud and load spillage give indications as to the needs for accommodating this problem. The front of a large haulage truck is not entirely free from mud and spillage and at the rear of a haulage truck the bed acts as a wheel fender. Mine temperatures range from -30 to 120 degrees Fahrenheit; fatigue inducing vibration is expected along with shockloads from shovel loading, shovel dipper contact and from rough road features, all are expected to be an intermittent problem. MBA's experience with the application of a wide variety of devices to vehicles with similar shock and vibration problems has been utilized to reduce fatigue effects and shock induced damage possibilities to levels acceptable for long component life.

2.5.3 Cost Factors. Mine operators are concerned primarily with purchase, installation and maintenance cost. The following is an estimate of the range of costs of present visibility systems:

	Unit Cost	Yearly Cost
Initial Installation (purchase and weldments)		
Mirror bracket-part of mirror	$25-50	$12-25
Mirror bracket fabricated	50-200	25-100
Mirror Unit		
Purchase cost	10-50	50-250
Labor cost	5-20	40-100
Flat mirror glass replacement		
Purchase	3-10	20-100
Labor	10-30	60-300
Total yearly costs		$62-500
Purchase parts		62-350
Labor		40-30

This estimate assumes a mirror mount weldment life of two years and variabilities in replacement rates for an average mirror life of two months, total systems costs similar to mirror costs would be acceptable,however, a system including many individual visibility aids will need to be considered on the basis of a cost-effectiveness ratio or as a percentage of a yearly truck cost.

For a cost-effectiveness ratio, the value of a visibility system in terms of elimination of a percentage of injuries and property damage would be needed along with estimates of increased productivity and employee morale, etc. These factors relating to cost-benefit concepts are discussed in the next section, 2.5.4.

2.5.4 Cost vs. Benefits. The concepts of "cost-benefit" and "cost-effectiveness" have come into increasing usage in recent years in an effort to justify (or attack) an existing or proposed safety program. As O'Neill and Kelley(1) point out in their informative paper, both of these concepts are often misunderstood and misused. Appendix A contains a discussion of this complex issue.

2.5.5 Benefits of Improved Visibility. The benefits of improved visibility would vary considerably at different surface mines due to the individual character of the mine. Each particular mine operator can best make an assessment of potential benefit based on a first hand knowledge of injury accidents, property damage and tire maintenance costs. Improved visibility for haulage truck operators would result in the following potential benefits by reducing or eliminating:

- Disabling Injuries and Fatalities
- Lost Time Injuries
- Haulage Truck Damage or Loss
- Small Vehicle Losses
- Damage to Shovels and Structures

(1) O'Neil, B. and Kelley, A.B., "Costs, Benefits, Effectiveness and Safety: Setting the Record Straight, "Society of Automotive Engineers Reprint No. 740988, 1974.

- Tire Damage
- Low Employee Morale
- Production Less - From Accidents
- Production Loss - Poor Visibility

These potential benefits can be realized in specific situations which are common in surface mining operations. The size and power of large haulage vehicles is such that even a minor accident can cause significant costly damage. Examples of situations where the benefit of improved visibility can be realized are as follows:

- Small vehicles parked or passing close to a stopped haulage truck can be detected by the driver before moving his haulage truck forward, backward, or to the right. A safe path certainty would result.
- When backing to the shovel, spotting position and shovel body clearance can be judged with more certainty and vehicle control. Tire damaging rocks could also be avoided.
- When backing to a dump berm, the location of the berm and its alignment could be more accurately judged while positive vehicle control is maintained.
- When maneuvering road hazards such as rocks, holes, and ditches can be avoided preventing tire damage and driver injury.
- In shop and utility areas, structures equipment vehicles and personnel could be detected and tight clearance maneuvers could be more safely accomplished.
- More certainty of a safe path would result in less stress to drivers and maneuvering around observable hazards would be expeditious for better time efficiency.
- Collisions with other haulage vehicles and embankments could be avoided if observed with an improved view.

Overall, it appears that the relatively low costs of improved visibility devices would be offset many times over by the benefits. However, it is difficult to document those accidents that never happened becuase the driver saw the hazard through his visibility aid. Over a period of time, the benefits would eventually show themselves if detailed and accurate records were kept of minor as well as major accidents; however, such is not the usual case. Therefore, a long term (one year) test program in several mines is recommended. In such a test, the drivers would be asked to report instances where they believe an accident would have happened if they hadn't seen it coming in their visibility aid device.

2.5.6 Mine Operator Apparent Selection Criteria. Mirror selection in mining operation primarily involves costs, safety opinion and driver acceptance. One of these factors is emphasized at every mine observed. Mirror cost becomes a factor when breakage is excessive. Safety opinion is different at every mining division and had more effect on selection of visibility systems than cost. Examples of safety opinions are:

- Larger left mirrors are selected because of visibility advantages.
- Higher cost systems would be selected if their safety value was obvious or demonstrated.

- Higher cost systems would be selected if they could be maintained.
- Giving the driver more responsibility for his actions means less reliance upon non-fail-safe safety devices.
- Promoting a safety attitude is as important as safety devices.
- Reliance on an inoperative safety device is more dangerous than no such safety device.
- Safety devices which become factors in work delays or stoppages are not desirable.
- Too many false warnings of danger can result in no response to such warnings.

Driver acceptance affects the maintainability and use of mirrors and the selection among several models of mirrors is done by informal driver survey in a few operations. Individual driver preferences are different and this can result in a wide variety of mirrors at mine operations.

Another factor mine maintenance personnel are concerned with is maintenance complexity. A one step replacement of a standard visibility device is preferred to locating or fabricating non standardized parts. Requirements for special parts storage, templates, and delays caused by delivery from or fabrication in outside shops is not desired.

2.5.7 Adaptability. The following factors would allow adaptability to any truck for a retrofit visibility aid.

- Mount bracket design for attachment to external surfaces by weldment.
- Field-of-view wide enough to minimize location restraints.
- Operating temperatures from -30 to 120 degrees.
- Minimal power requirements.
- Low weight to minimize structural support requirements.

Any optical device which is routed through a haulage truck's structure would require custom design for each model.

2.5.8 Component Selection. The availability and reliability of system components is a factor in the development of a visibility system which can be developed into a common usage item. The use of "state-of-the-art" components which are "off-the-shelf" or distributed widely is preferred. If such components will not conform to the specifications required, state-of-the-art components will be developed, thus a high probability of success and reliability is assured. Components with variable, nonstable, or unpredictable operating modes will be avoided.

2.6 ALTERNATIVE CONCEPTS. In terms of image recognition and orientation, direct vision is preferable to any visibility aid. Direct vision is not a practical approach to the viewing of most blind areas with the present design of haulage trucks. The use of visibility aids which must refract or reflect or transmit images around corners is an attempt to give the driver a view with the same information content as direct viewing. The extent to which a visibility aid approaches the capability of direct vision in the blind area considered, and with the coverage needed, is a good measure of the effectiveness.

2.6.1 Improved Direct Vision. There are areas of truck design where direct vision can be improved. These improvements would not be very extensive in a retrofit situation and radical changes in new haulage trucks would be difficult to substantiate. Concepts under consideration as well as comments as to their effectiveness are as follows:

- Cab design modifications can increase the downward angle of view (to the front and left) and minimize the effect of cab post obstructions. The window sills on the front and left side of the cab should be lowered considerably because of the height of the driver. This would require a radical change in console design. The deck outside the cab serves as a fender and could be constructed of expanded metal only if a lower fender was or could be constructed beneath it. This would not be practical on many trucks. The obstruction to view caused by the cab posts can be minimized by cab posts which block only 2.5 inches or less across the driver's field-of-view. Elimination of the cab posts would require curved glass shapes which would involve considerable purchase and replacement costs considering the amount of glass breakage in mining operations. Cab design must also be coordinated with acoustical considerations in order to comply with noise level requirements.

- Cab location can improve visibility and change the distribution of the blind areas. The positioning of the cab at the left edge of the haulage vehicle is considered optimum for viewing to the left and to the left rear areas. Moving the cab to the right trades one blind area for another. The forward position of the cab involves a trade-off between collision vulnerability and visibility over the engine hood. The elevation of the cab relative to the engine hood and to the right side can improve the downward angle of view a few degrees. The visibility to the right can be significantly improved by relocating the right deck components (if possible) and replacing the right deck with a fender which follows the curve of the right front wheels. The placement of the cab in a position under the engine has many field of view advantages, however, this low position would result in difficulty with severe mud fouling and increased window breakage in traffic situations. For this, the haulage truck engine must be raised approximately five feet to provide a right side view and allow equivalent ground clearance. A cab in this low position forward of the front wheels would be vulnerable in a collision.

- Pendant controls and remote controls were considered as possible visibility aids. Pendant controls would allow the driver to be anywhere on the cab deck in order to select the view needed. This would be extremely dangerous to the operator who would need both hands free to hold on to the vehicle on rough roads. For full advantage, the entire deck would need to be enclosed for adverse weather environments.

  Remote controls could give a truck operator optimum visibility, however, maintaining an operator in an optimum position for visibility and positioning the haulage truck would be extremely difficult over an entire haulage circuit.

- Shovel view ports cut into front of the load bed behind the driver would be useful in docking on the right side of shovels. Their utility is limited to the final approach to a shovel and their use would prevent adequate inspection of ground level activity in the shovel area.

2.6.2 Improved Mirror Systems. Mirrors have a proven capability to provide rear view vision along the sides of a haulage vehicle. Their utility in viewing areas forward of the driver is questionable because of problems with view orientation and limited areas of view. At night, headlights of other vehicles have caused driver confusion. With the possible exception of quarter sphere mirrors for direct downward viewing, the use of mirrors to view forward blind areas would be best reserved for special case situations.

Mirror systems improvements would allow larger mirrors, with better fields of view and image recognition. These improvement concepts include:

- Protective frames would prevent damage from load bed spillage by deflecting such from mirror surfaces.
- Cleaning system consisting of a wash spray and either a compressed air jet or an oscillating wiper will keep mirrors clean. (Right mirror only)
- A mirror with both plane and convex shapes combines the best features of both types of mirrors. These can be made to have a flat surface.
- A power drive system rotating a large flat mirror through a small arc ($10-30^{\circ}$) and back upon demand, would increase the effective horizontal field of view without reducing image size.
- The use of mirror surfaces (which can be replaced without tools) in rugged frames and brackets would reduce maintenance costs. This concept includes both a standardized "drop-in" mirror glass shape and a mylar film mirror roll dispenser with over 100 feet of fresh mirror surfaces stored in its dispenser.
- Mirror views need to be illuminated at critical points such as near the rear wheels. This is presently done on a few trucks by angling the backup lights to the side of the vehicle where they are useful.
- Remotely adjustable features for mirror alignment would aid in obtaining the desired view. The left mirror can generally be reached by hand but the right mirror view could be adjusted or panned remotely with a locking push pull cable.
- Convex mirrors (right side) with a rectangular, as opposed to circular, fields of view give a better view coverage and view shape. A 10 by 30-inch convex shaped rectangular section with a radius of 40 inches would have a vertical field of view of approximately 45 degrees and a horizontal field of view of 30 degrees. Image size would be increased and little of the view would be wasted. Other rectangular shapes also present possibilities.

Mirror systems have low costs, low light losses and work well when reflecting images through 60 to 180 degrees. Trade-offs between image recognition and field of view or problems with orientation and area coverage limit their use.

2.6.3 Optical Systems. The simple refraction of images through 0 to 90 degrees or through complex multiple refraction paths has certain advantages over mirror systems, if light losses are limited. The optical devices considered are as follows:

- Fresnel lens systems with a negative focal length are being marked for use as rear view aids on campers and vans. These lens can add 27 degress to the downward angle and have a horizontal field-of-view of 55 degrees. This can reduce the blind area to 30 feet from the lens. Orientation of the view is excellent, however, image size is reduced to provide the field of view. Because of view orientation, Fresnel lens are promising concepts for viewing blind areas forward and to the right of the driver. Because of the short viewing distances involved, the development of Fresnel lens with maximum downward angles of view from 45 degrees to 90 degrees are promising concepts for viewing blind areas closer to the haulage vehicle. For use in mining operations, the Fresnel lens must be mounted between two transparent plates in a protective frame because any contamination of the grooved lens surface by water or soil obscures the optical refractive properties of the lens.

- Periscopes with wide fields-of-view and low light losses require large enclosed optical paths and would be difficult to retrofit to existing vehicles. A periscope, which gives a wide horizontal view from a point beneath the haulage vehicle would have excellent coverage of blind areas except for areas blocked by the tires. The turbulent conditions such as mud and dust could be avoided by using the periscope only in low speed situations. The fact that rigid ladders cannot be maintained below the level of the front bumper creates doubts as to the survivability of a periscope in location beneath a large haulage vehicle. Other aspects of periscopes must be considered also. The driver must maintain a fixed position to view through a periscope and the optical components needed to provide a well- oriented wide angle view with minimal distortion are complex.

- A telescope which can be viewed without eyepiece contact is a promising concept for viewing mirrors or Fresnel lens to increase image size to the eye. A special low power telescope with large plastic lens would be mounted in the cab interior to give a magnified view for greatly increased object recognition while looking at smaller size wide-angle visibility aids mounted on the right side of the vehicle.

- Fiber optics can provide a very flexible optical path for transferring an image from a small remote lens to a viewer. Fiber optics are not an effective approach to the transfer of wide angle views at this time. The problems of high cost, fiber breakaege and severe light loss are being solved in data transmission applications; however, considering applications to systems of practical use to truck visibility, the problems are insurmountable at this time.

2.6.4 Optical Electronic Systems. The use of a Closed Circuit Television (CCTV) system can transfer a wide angle view from a remote truck location to the driver's cab with a comparatively large image size. No other visibility aid considered can give a comparable view of the blind area directly behind a haulage truck and the use of CCTV to view the areas on the right side are also promising. Image sizes larger than direct view size can be presented to the operator depending upon the field of view.

Although standard off-the-shelf CCTV components have been utilized on board large haulage vehicles for experimental periods of time, the use of CCTV for extended usage will require a protective enclosure. An enclosure fabricated from structrual steel shapes with a viewing window is being considered for protection from the abuse of the mining environment and shock loading. A remotely activated cleaning system will be needed to clean the view window when necessary. The CCTV Camera will be mounted between and above the center of the rear wheels and will have fields-of-view options from 60° to 90°. Cameras which adapt to low light levels without the blooming effect of headlights will be utilized. The monitor will be mounted in the cab, possibly in a location similar to that of a standard car's rear view mirror.

2.6.5 Obstacle Detection Sensors. In concept, obstacle detection sensors would be excellent for detecting objects within 10 to 20 feet of the haulage truck and alerting the driver. In considering the potential use of sensors, the following items of information were deemed relevant.

Collision avoidance or warning systems generally have two objectives:

- Prevent injury to operating personnel and pedestrain traffic;
- Prevent damage to equipment by avoiding collisions between vehicles or collision of vehicles with obstructions in the travel path.

Such systems can be divided into two basic categories:

- Cooperative systems - In this type of system, objects and personnel to be avoided are equipped with some type of device which makes their presence within a predetermined distance of the vehicles known, the device may be signal emitting or simply retro-reflective;
- Passive object detection systems - In this type of system, the intent is to give warning that there are objects and people in the vicinity of the vehicle which are not equipped with any special devices.

The following section describes, in some detail, several systems of each class. The strengths and weaknesses of each are pointed out based on practical experience of what can and cannot be expected of them.

2.6.5.1 Cooperative Systems. There are numerous variations of cooperative systems; however, they all fall into one of three basic types:

Type 1 - The vehicle carries a receiver unit only, usually it is an electromagnetic field sensor system, i.e., low frequency RF receiver of limited sensitivity with some type of loop antenna. The objects or persons to be avoided are each equipped with a small battery powered transmitter which emits either a continuous or periodic signal (beep). With such systems it is not possible to tell the exact distance of the transmitter from the receiving unit, however, with proper antenna design, orientation and placement, the transmitter location can be determined under nominal operating conditions to be within a given sector or zone. The short range type of system (under 50 feet) accuracy for locating a given transmitter that can be expected is approximately ± 3 to 4 feet of range and ± 20° in azimuth.

This type of system is generally used to protect people. Each person working in the area where the vehicle is operating is required to wear a belt or helmet mounted transmitter unit.

There are several problems associated with this type of system (aside from accuracy. These are:

- Difficulty in finding proper locations for receiving antennas on the vehicle, system performance is severely compromised, and costs increased by lack of suitable mounting locations.

- Difficult, if not impossible, enforcement of rules that all personnel in the operating area wear transmitters. This is particularly true of people who do not normally work in that area.

- Transmitter units are subject to damage or failure without the wearer being aware of it. This is particularly true of battery exhaustion or failure.

- Prohibited use of transmitters in some areas, particularly where explosives are being handled or used.

- The use of high powered electrical equipment such as power shovels, industrial battery chargers, etc., may interfere with operation of the vehicle's receiving systems.

Type 2 - This is the transponder type of system. The vehicle is equipped with both a transmitter and a receiver; the persons or objects to be avoided are equipped with a battery powered responder unit. These systems usually operate on two frequencies and the vehicle periodically transmits a pulsed signal on a frequency to which all of the receivers in the responders are tuned. When a responder receives a signal from the vehicle transmitter, it replies by transmitting a pulse on another frequency to which the vehicle receiver is tuned. Such a system introduces some additional intelligence into the system and allows for more precise location of the object relative to the vehicle. The signals involved may be of several types; radio frequency energy, light signals, infrared signals, ultrasonic signals or some combination of signals.

While this type of system is more accurate than the first type, it has all of the disadvantages plus it is more complex, hence, more susceptible to failure.

Type 3 - The retro-reflector or nonpowered responder systems allow a vehicle to transmit and receive. Persons or objects to be detected are equipped with a device which is not powered but which is designed to reflect or bounce back a large percentage of the energy it receives. If the energy being used is light or infrared, the target device would be retro-reflective tape or something similar. If the transmitted pulse from the vehicle is radio frequency, microwave or ultrasonic energy, then the target would be a resonant device. In some cases, the system is designed to alter the signal in some way to make it distinguishable from the vehicle's transmitted signal. Depending on exact design parameters, such a system may use a transmitter signal that is either pulsed or continuous wave.

These systems have one advantage over the first two types, that is, there are no batteries required to power the responder devices.

2.6.5.2 Passive Object Detection Systems. These systems transmit some form of signal then listen for the energy reflected back from objects in the path or area being scanned. They may use UHF radio signals, light or infrared beams or ultrasonic beams. Due to the very short distances involved, accurate ranging cannot be done with light or I.R. beams. The same is true of microwave systems using time base ranging. Microwaves may be used in phase modulation comparison systems in which the basic carrier is constantly being shifted slightly in frequency, and the phase shift of the echos are compared to transmitted signal, the difference being a function of the reflecting object's distance from the transmitter.

Echo ranging can be accomplished with an accuracy of a few inches using ultrasonic pulses, and the technology for ultrasonic obstruction detection systems is highly developed and is the most applicable for ranges under 50 feet and speeds up to 20 mph.

There are some problems which are basic to all systems which rely on reflected energy for object detection. These are:

- The effective reflective area of an object is not a simple function of size only. The composition and texture of the object's surface and its attitude relative to transmitted beam affect the returned echo strength greatly. To expect a minimum to maximum returned signal ratio of 1:1000 would not be unreasonable. Consequently, detecting obstructions close to the ground is very difficult. If the system is sensitive enough to reliably detect objects a foot in size at 10 foot distance, it will also detect some objects at 10 or more feet which are perhaps only an inch in size. The only real solution to this problem is to aim the transmitted energy well above the surface which will then result in missing or not seeing some objects that it might be desirable to avoid. This is probably the most difficult problem to overcome, i.e., arriving at a system sensitivity and area of coverage that is the best compromise between missed obstructions and false or unnecessary alarms.

- Some objects will be transparent or absorbative and will reflect little or no energy. It turns out that this is not generally a severe problem, but it should be kept in mind that it can occur. General experience has been that this is likely to occur only with man-made substances and is more likely to occur with infrared or light beam systems than with ultrasonic or microwave systems.

- Smooth flat surfaces are often not detected or give range readings that are false, owing to the fact that the transmitted energy may be reflected off at an angle and little or no energy reflected back to the receiving unit. In general, if a surface has a general roughness equal to 1/4 wave length or more of the transmitted energy, this will not be a problem. For I.R. and light, this means the problem would only occur with smooth, highly-polished surfaces. For microwaves, any surface smoother than $\pm$ 1/2 inch roughness can be a problem, and for ultrasonic systems, any surface smoother than $\pm$ 1/16 inch may produce this effect.

- All such systems are subject to outside interference or jamming. The best defense against this is to use a relatively low sensitivity receiver system and the highest obtainable transmitter power. In this respect, the ultrasonic systems have a distinct advantage as peak pulse powers of a kilowatt or more are obtainable.

2.6.5.3 Conclusions. Microwave systems are not practical for ranges under 50 feet. The complexity, cost and low power would rule them out for the application being considered.

I.R. systems using pulsed or modulated solid state light sources are practical and will work well over the 1 to 10 foot range. Time base ranging is not practical in this range, however, zone ranging based on source and sensor location or geometry is practical and fairly reliable.

Ultrasonic echo ranging systems are practical for ranges from 5 to 50 feet. It is not recommended to utilize the commercially available doppler shift intrusion alarm systems. These systems have insufficient power output and will detect only objects which are moving relative to the system. In addition, they are sensitive to air current motion (wind), thermal variations, etc.

The cost of an ultrasonic or microwave system development program is beyond the scope of this project and the ultimate unit cost of a successful system is beyond the feasible range for surface mining use. There is a high risk factor in embarking on a development program of this sort due to the fact that there is a high likelihood that no successful system would be forthcoming.

2.6.6 Improved Visual Environment. Increased contrast between vehicles and their background and increased delineation of road edge features are needed for a safer visual environment. At night increased illumination levels and reduced glare would increase the contrast levels for unlighted objects or vehicles and personnel with inoperative lights.

Haulage vehicle and utility vehicle should be painted with colors which contrast with the background areas and also with contrasts between different vehicles. A small vehicle of the same color as a haulage truck can be confused with truck features when parked nearby and partially obscured from the haulage truck driver. The painting of haulage truck surfaces visible to its driver a matte black color would assist in contrasting adjacent objects and reduce glare in a few situations. It would be a very effective, low cost, safety measure if the right deck, engineer hood, left deck, and cab window frames were painted a matte black color. The use of flags and lights mounted above small vehicles makes them visible in forward blind areas. The maintainability of such devices is not adequate for the mining environment and on many small vehicles these devices become inoperative or are not used in operations which supply such devices. Flashing lights which are visible in the daytime become blinding and annoying at night (multi-intensity, flashers are needed).

Lighting in mine operations is difficult because of the wide areas to be covered and the absorption in light by dark colored mine surfaces. Improved vehicle lighting is needed and is the most cost effective approach to complete effective illumination in conjunction with shovel and dump area illumination. Haulage truck headlights were observed which provided only minimal illumination (low beam) from 30 to 60 feet from the driver. Any reduction in the illumination levels seen by the driver from the application of polarization systems or antiglare coating is not recommended at present mine illumination levels. Nighttime glare can be more effectively controlled by light placement and lighting system design. See Section 2.6.6.1 for discussion of polarization.

The use of road edge delineators and obstruction marking is needed at certain locations in surface mines. For example, the delineation of the edge of a coal bench at night is very difficult. The minimal needs for delineators can be determined by riding haulage trucks on dark nights. More effective vehicle delineators are also needed.

2.6.6.1 Polarization. Considering the use of polarized filters that can effectively reduce glare, the trade-off to be made is how much light intensity can be lost without significantly reducing the information carrying characteristics of the driving scene. For the vehicle headlight glare sources, there is the possibility of crossed polarization of headlights relative to windows, windshields, visors, and mirrors.

Polarization of headlights and windshields has been a topic for study by Billings and Land.[1] The practical use of polarized filters in automobiles has not yet been discovered. One of the more recent studies[2] is concerned with visual guidance cues from the roadway as a function of system angle of the polarized headlight systems. They conclude that, "The visible distance to an obstacle of certain size standing on the road is longer at the system angle 0° compared with the system angles 45° and 90° when all other conditions are constant." In other words, the loss of light transmission reduced the distances that targets were deleted.

The system angle is the angle between the axis of the polarization sheet through which the driver looks (a visor) and the polarizer of the headlights. The polarizer used in these experiments was Polaroid Corporation filter HN38 which transmits about 38 percent of incident unpolarized light and about 0.5 percent when two crossed filters are placed at 90° to each other.

Major drawbacks of polarized systems are the loss of light and the loss of the "glow" that oncoming headlights cast in the sky at night. Some safety experts claim that this glow is an important advance visual cue when oncoming vehicles are hidden from direct line of sight around curves and dips in the roadway.

All of these factors and considerations were taken into account during the Phase II work when the nighttime working conditions were studied by the MBA study team.

As a result of the present Phase II work, the following conclusions have been reached regarding polarized materials and glare:

- Only one accident report involved glare; it is sun glare in the right-hand window.
- Some drivers mentioned glare of oncoming truck lights as annoying in dark (unlighted) sections of the haulage roads.
- The nighttime loss of illumination rules out any permanent installation of polarized filters on trucks (headlights or windows).
- Daytime glare can be alleviated by use of either a visor or sunglasses made from polarized material.
- Internal reflections in the cab are not reduced by polarized material.

These conclusions are supported by personal communication from Dr. Richard Schwab, U. S. Department of Transportation, Federal Highway Adminisntration, who, for over 15 years, has closely followed the possible benefits of the polarization of automobile and truck headlights.

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(1) Billings, G. H. and Land, E. H., "A Comparative Survey of Some Possible Systems of Polarized Headlights," J. Opt. Soc. Am. 38, 819-829, 1948.

(2) Helmers, G., "Visible Distance and Visual Guidance as a Function of System Angle of Polarized Headlight Systems," University of Uppsala, Report 126, 1972.

3.0 VISIBILITY SYSTEMS

3.1 IMPROVED VISIBILITY SYSTEMS

3.1.1 Visibility Aid Selection for a Visibility System. For the selection of concepts for consideration, the following criteria were used:

- Field of view capability
- Image size presented to driver's eye
- View orientation
- Costs

View orientation tended to limit the possible locations on the trucks where the concepts selected could be effective. The concepts which can provide near maximum coverage of blind areas are presented in plan view in Figure 3.1-1, with the vertical field of view coverage shown in Figure 3.1-2. The approximate cost estimates (ranges) and view capabilities for each concept are presented in Table 3.1-3. The concepts selected are for visibility systems that would provide the best coverage of the blind areas for the lowest cost. Several concepts have been selected for each blind area since no one concept can provide total coverage. Provisions for several different concepts will also provide flexibility for mining operations to choose a system best suited to their individual problems.

It is difficult to estimate the maintainability and yearly maintenance costs associated with each of these concepts. Initial costs will depend on the amount of protection and weather resistance needed in the final designs. For example, the design life of the weakest components (the electronic system) is at least five years and can extend to fifteen years. Driver abuse to trucks in mine operations may be reduced by increased visibility. Truck bed spillage, or mud problems varies widely on different trucks. The recommended concepts for development are as follows:

Front Blind Area Left Blind Area	none (see Section 3.1.1.1)
Right Front Blind Area Right Blind Area	system of 3 to 4 fresnel lens providing 50° down angle of view
Right Rear Blind Area	Improved rectangular convex mirror
Rear Blind Area	Fixed mount CCTV System
Left Rear Blind Area	Improved mirror system

Each selection will be discussed in the following sections.

3.1.1.1 Front and Left Blind Area Concept Selection. A lack of data concerning vehicles and personnel being involved in visibility accidents in this area indicates that the visibility in this area is approaching adequate downward angles of view. For increased visibility, the most cost effect system for detecting objects in start up situations would be small fresnel lenses mounted on the lower positions of the handrails. This would best be a spinoff from the development of other fresnel applications in the right blind areas. For future application the development of cabs with improved acoustical characteristics should include visibility improvements in downward viewing angles and smaller cab window post obstructions. The benefit of increased cab visibility in the left front area is not extensive enough to warrant development for the single objective of visibility.

AREAS 0 - 10 FEET FROM TRUCK

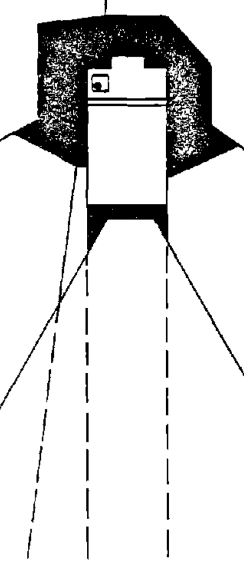
1. COOPERATIVE RESPONDER SENSOR
   - Wide field
   - Location indication
   - Predictable range
2. PASSIVE OBJECT SENSORS
   - Detects all objects

LEFT FRONT AREA

1. FRESNEL LENS
   - Field of view
   - Orientation
   - Low cost
2. PERISCOPE (Simple)
   - Image size
3. CAB DESIGN
   -
4. OBJECT SENSORS
   -

RIGHT FRONT AND RIGHT ZONE

1. FRESNEL LENS (3 Required)
   - Field of view
   - Orientation
   - Low cost
2. CCTV SYSTEM (Auto pan and tilt)
   - Field of view
   - Image size
3. MIRRORS
   - Low cost



LEFT REAR AREA

1. IMPROVED MIRRORS (Flat & Convex)
   - Image size
   - Field of view
   - Orientation
   - Low cost
   - Improved vehicle control
2. DIRECT VIEW
   - No cost
   - Orientation
   - Field of view
   - Image size

REAR AREA

1. CCTV
   - Image size
   - Field of view
   - Orientation
2. LEFT & RIGHT MIRROR ONLY
   - Low cost

RIGHT REAR AREA

1. CONVEX MIRROR & TELESCOPE
   - Image size
   - Field of view
2. IMPROVED MIRROR (Convex)
   - Field of view
   - Lowest cost
3. CCTV
   - Image size
   - Field of view
4. MOVING MIRROR (Flat)
   - Horizontal field of view
   - Image size
   - Low cost

FIGURE 3.1-1

CONCEPT SELECTION:
LISTING PRIMARY ADVANTAGES OF EACH

MBA

3466-15381

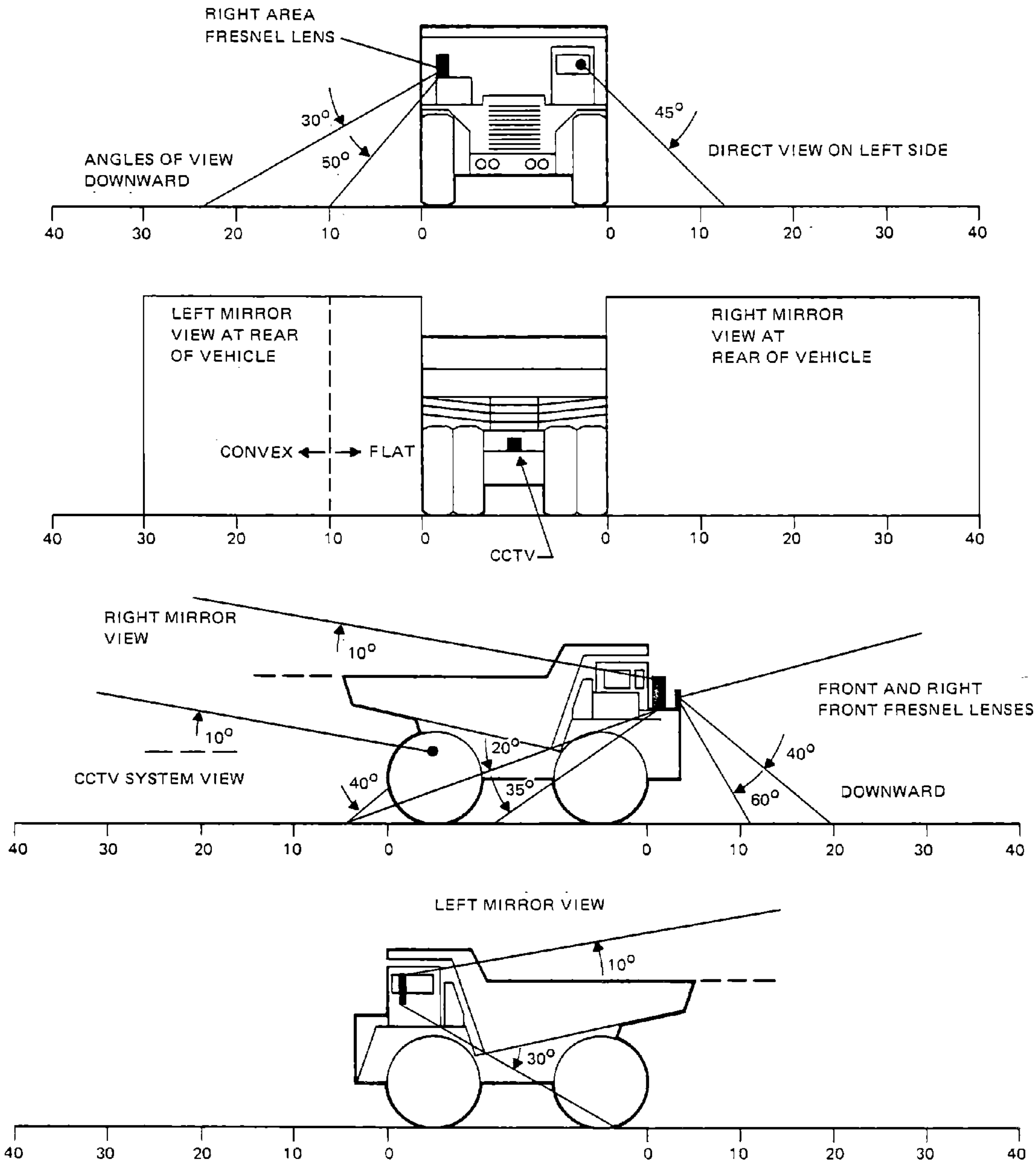


FIGURE 3.1-2
FIELDS OF VIEW FOR PRIMARY CONCEPTS

MBA
3466-15382

CONCEPT	Blind Area Coverage	Field of View	Image Size (Reduction X)	View Quality Orientation	Usage & Safety Potential	Reliability & Maintainability Potential	Estimated Price
Improved cab	Front, left	+20° D	Lifesize	Excellent	Excellent	Excellent	5000+
Relocated cab	tradeoff		Lifesize	Excellent	Poor		2000+
Improved left mirror	Left rear					Excellent	
Flat		H20°V 40°	Lifesize	Excellent	Excellent		200
Convex		H60°V 45°	6X - 8X	Fair	Good		200
Combination		H60°V 45°		Excellent	Excellent		210
Improved right mirror	Right rear						
Rectangular convex		H60°V 40°	6X - 12X	Good	Good	Excellent	220
Movable flat		H60°V 7°	Lifesize	Poor	Fair	Good	300
Combination		H60°V 40°	Mixed	Fair	Fair	Excellent	300
Fresnel Lens (2 - 3 Req.)	Front, right						
Single element		H60 D 27°	5X - 10X	Excellent	Good	Excellent	270 ea.
Multiple element		H60 D 70°	5X - 12X	Excellent	Excellent	Excellent	300 ea.
Telescope (Special eye piece)	Front right	NA	0X - 3X	Good	Fair	Good	100 - 400
(For viewing visibility aids)	Right rear						
CCTV System		H80°V 50°	Lifesize+				
Fixed mount	Rear			Excellent	Excellent	Good	1500 - 3500
Pan & Tilt	Right rear to left front			Good	Good	Good	1500 - 4000
Automatic cleaning devices					Good		50 - 100
Sensors	Adjacent			Indication only			
Passive object system		H20°V 20°			Poor	Good	1000 - 2000
Cooperative responder system		H180°V 180°			Fair	Good	1200 - 3000
Improved visual environment	NA						
Contrasting paint					Excellent		50 - 100
Truck delineators (lights)					Excellent		20 - 100
Stationary mirrors					Fair		50 - 200
Improved lighting					Good		

TABLE 3.1-3
VISIBILITY CONCEPT TRADEOFFS

3.1.1.2 Right Front and Right Blind Area Concept Selection. Fresnel lenses with downward angles of view of approximately 50 degrees are a simple optical system which can provide a well-oriented view with good coverage. Three or possibly four lenses mounted in a glass sandwich and protected by structural steel frames would be placed along the front and right edges of the engine cowling and right deck for total area coverage. On the basis of cost and view orientation, fresnel lenses are clearly superior to CCTV systems and periscopes for this view. Annual replacement cost would be less than for mirror systems which are more exposed to damage. In quantity, fresnel elements might cost $15 to $20 each.

3.1.1.3 Right Rear Blind Area Concept Selection. The selection of an improved convex mirror system for the right side is based on cost and utilization potential. A stationary convex mirror with no mechanisms, remote adjustments, or washdown systems, was selected on the basis of cost. Flat plane mirrors were rejected because of a very limited field of view. Remote adjustment and automatic panning features would create new orientation problems. The use of a telescopic viewing device to increase the image size in a convex mirror was rejected due to high cost and a low potential for utilization, and CCTV systems were rejected due to cost factors only. The following factors were considered for the selection of a convex mirror:

- A $30^{\circ} \times 60^{\circ}$ rectangular field of view gives greatly improved coverage of the right rear blind area.
- A larger than existing mirror size is needed to increase image size, however, a compact shape is required to minimize vulnerability to damage.
- Increased protection from rock spills is needed.
- The mirror element must be a standard, easily produced shape.
- Due to its size, shape, and the distance from the cab to the mirror, no adjustments are needed for individual drivers.

3.1.1.4 Rear Blind Area Concept Selection. The front element of a visibility aid for the rear blind area would need to be positioned approximately 40 feet directly to the rear of the driver. The only visibility aid concept which can provide this view with good orientation and field of view is a CCTV system. A CCTV system can give a very well-oriented view including both sets of the rear tires when approaching a dump berm. On trucks with wide bodies that obscure the tires from the side view mirrors, a CCTV has even more merit. Except where unusual circumstances exist, it is anticipated that CCTV will be a less cost effective visibility aid on trucks smaller than 170 ton capacity, merely because these smaller trucks cost less than the larger ones.

3.1.1.5 Left Rear Blind Area Concept Selection. The selection of an improved mirror on the left side is based on observations of both plane and convex mirrors on various vehicles. A plane mirror over 25 inches long and 8 - 10 inches wide is needed for a well-oriented rear view, with depth perception capability. An add-on rectangular shaped convex mirror section with a 30 x 60 degree field-of-view would give wide (near total) area coverage. A combination of these mirrors in a single protective frame with the specified fields-of-view would be very useful. The following factors were considered in the selection of this concept:

- Direct viewing, although superior, involves the possibility of a loss of control when the operator is leaning out the window or door to view rear areas. Direct view is also uncomfortable in cold or wet weather.

- The existing mirror systems observed gave either a narrow or extremely wide field-of-view, with no system giving a view with all the characteristics desirable. Most left mirrors used on haulage trucks were designed for highway vehicles.

- The large percentage of accidents involving rearward visibility indicates a need for a better view of all rear areas.

- For viewing to the left, rear mirrors have orientation and cost advantages over fresnel lenses and CCTV Systems respectively. The main disadvantage of a mirror system is the view obstruction it creates in the front left area.

- Mirror maintenance was in most cases accomplished by complete assembly replacement or glass replacement in the maintenance shop. Only one percent of the mirrors observed had frames designed to withstand abuse from load bed spillage.

3.1.1.6 Concepts for Blind Areas Adjacent to Haulage Trucks. The need for detecting the presence of objects within 0-10 feet from the haulage vehicle without information as to the location and orientation of such objects is not indicated by limited investigation of accidents. Detection of objects (rocks, vehicles, personnel) at short range would have utility prior to the movement of a stopped haulage vehicle. When moving, however, due to vehicle and driver response time, most such accidents would not be preventable. Because of the limited utility, unpredictable range response, probability of false or irrelevant signals and high unit costs, no sensor systems were selected as a viable concept. Visibility systems giving total area view to within 10 to 20 feet of a haulage vehicle would give an awareness needed for a defensive driving response. Sensor systems might give false warnings demanding immediate stops. Also features (rocks, dips) in the wheel paths of concern to drivers and damaging to tires could only be effectively detected visually.

3.1.1.7 Optical Cleaning System Concepts. The CCTV System will require a cleaning system consisting of a cleaning solution jet and a solenoid or motor actuated wiper. It is anticipated that fresnel lens systems will not required automatic cleaning in most situations. However, the development of a cleaning system which would retrofit to a fresnel lens system as an option, might have utility. A variety of components for conventional cleaning systems will be investigated for visibility aid designs.

3.1.2 Development of a Complete Visibility System. A complete visibility system was designed, fabricated and field demonstrated to prove and refine visibility aid concepts. As illustrated in Figure 3.1-4, the system consists of the following:

- 1 Improved left mirror
- 1 Improved right mirror
- 3 Blind area viewers (fresnel lens)
- 1 Improved CCTV System

The unique concepts and features are detailed in subsequent chapters. Except for the CCTV system, these visibility aids require no power and are designed to eliminate the need for frequent alignment adjustments. The unpowered visibility aids which are cost effective for trucks under the 170 ton load rating are shown separated from the CCTV system in Figure 3.1-5.

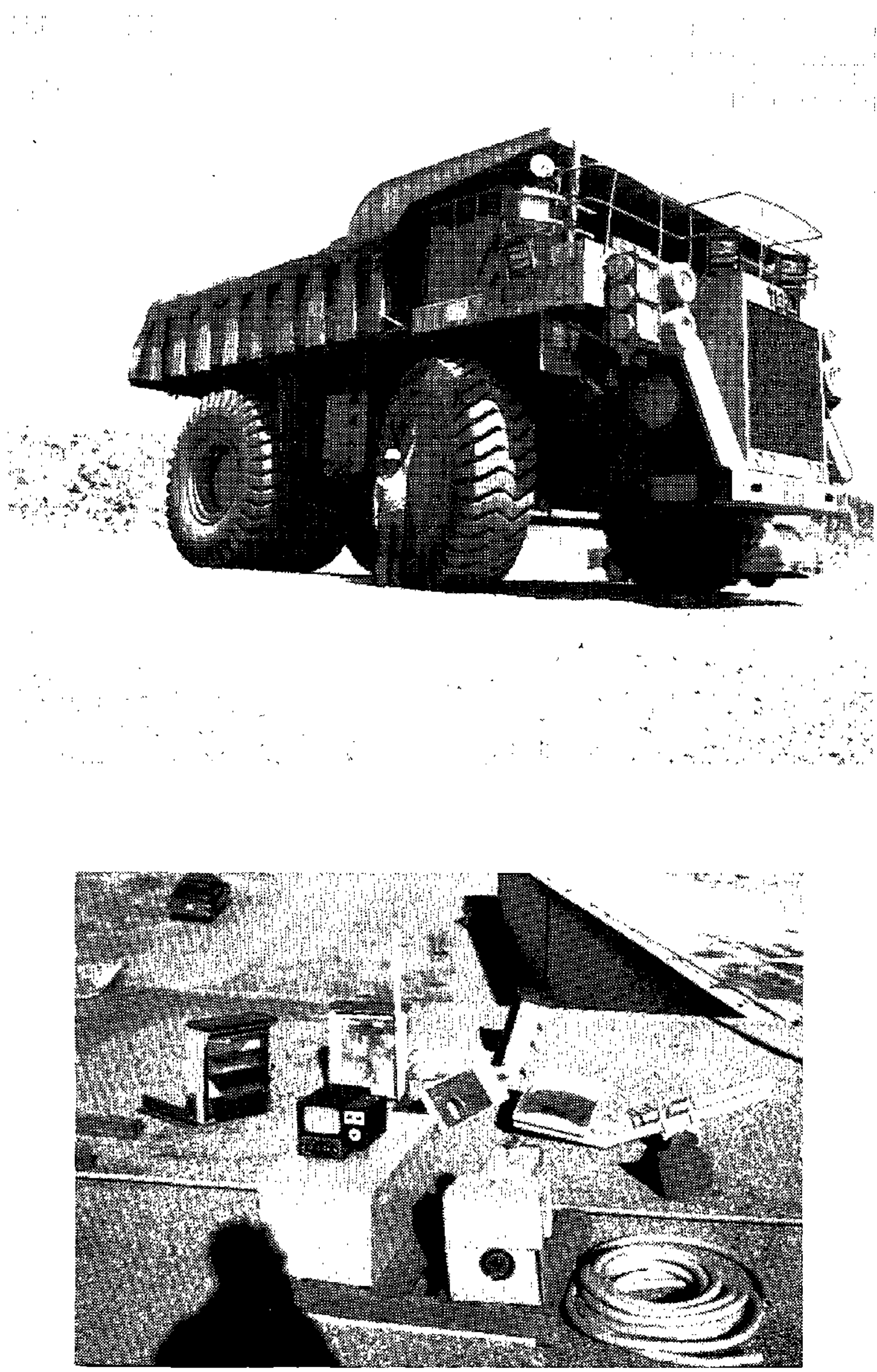
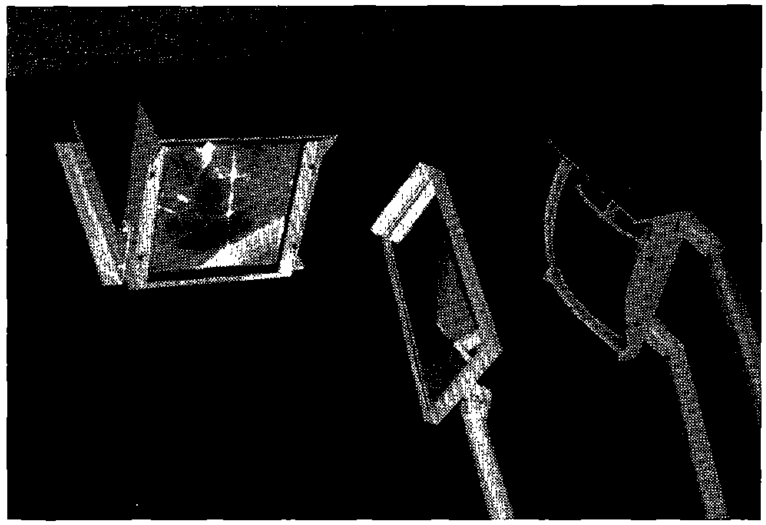
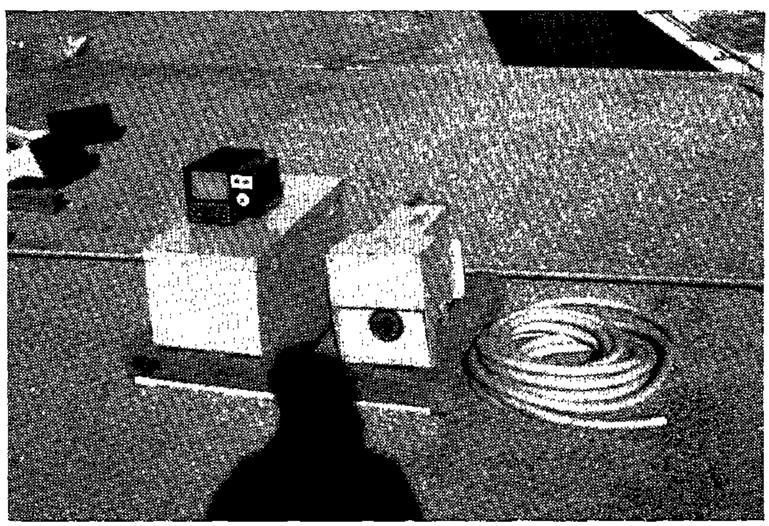


FIGURE 3.1-4
COMPLETE VISIBILITY SYSTEM



Stationary Unpowered Visibility Aids



Electrically Powered CCTV System

FIGURE 3.1-5
VISIBILITY SYSTEM ELEMENTS

The effect of this visibility system is best illustrated by referring to the blind area diagram in Figure 3.1-6 and then observing the improved visibility diagram in Figure 3.1-7. The blind area viewers reduce the blind areas to the front and right of the driver by over 80 percent. The left and right improved rear view mirrors give a field of view of over 100 percent greater than the mirrors observed in general use in mines. The CCTV system shows near total coverage (with wide angle lens) directly to the rear. No evidence of a significant safety problem was found in the remaining blind areas.

Each visibility aid can be used independently to create a visibility system tailored to the safety problems at individual mines with their particular trucks.

3.2 MIRROR TECHNOLOGY. For viewing the right and left rear blind areas, mirrors of specific size and shape were selected over all other concepts as the most effective approach in terms of view characteristics and cost.

Over 95 percent of the mirrors used on large haulage vehicles are designed for applications requiring a much smaller field of view. Most left mirrors used are designed for highway usage and the right convex mirrors are typically used in interior security and safety applications.

An analysis of existing mirrors reveals that mirrors with larger dimensions are needed, however, their size and the distance they project from the sides of the vehicle, increases their vulnerability to damage. Specific design parameters have been developed to maximize the effectiveness of improved truck mirrors and two prototypes have been fabricated and demonstrated. As a result, the optical paramenters have been established and the maintenance cost usage and safety factors have been estimated. Long term testing and evaluation is needed to refine this system for cost effective universal application.

3.2.1 Analysis of Existing Mirror Systems. Mirrors are reflective devices which must reflect or turn light 10 degrees to 180 degrees to provide a useful view. In almost all vehicle applications the view is reflected 60 degrees to 175 degrees and a portion of the vehicle is included in the view for orientation. It is also common practice to include the horizon or far away ground features in the view to aid in view orientation. The following factors are involved in the optical capabilities of mirrors:

- Field-of-View - Increased as the viewer is placed closer to the mirror. Increased by larger size mirror. Decreases as the mirror is rotated away from viewer. Increased by amount of convex mirror curvature in term of degrees of arc across the surface.
- Image Size - Increased as the viewer gets closer. Decreased as the object in view gets further away. Decreased by more convex mirror curvature in terms of a smaller radious of curvature.
- Ability to Detect Possible Hazards - Increased by larger field-of-view. Increased by larger image size. Decreased by low contrast situations, e.g., dust or fog. Increased by area illumination. Decreased by mirror surface distortion. Decreased by mud and dust on mirror surface. Increased by frequent intermittent use.

Of the various materials used in the construction of mirrors installed on haulage trucks, glass gave the least distortion in both flat and convex mirrors. Convex mirrors with polished steel surfaces are commonly used and clear plastic mirrors (interior surface mirrored) were observed in a few mining operations. All convex mirrors distort images by curving straight lines, however, polished steel mirrors viewed in the field often had wavy line distortion which becomes significant when pitting, scratching and denting degraded some portions of the surface (see Figure 3.2-1).

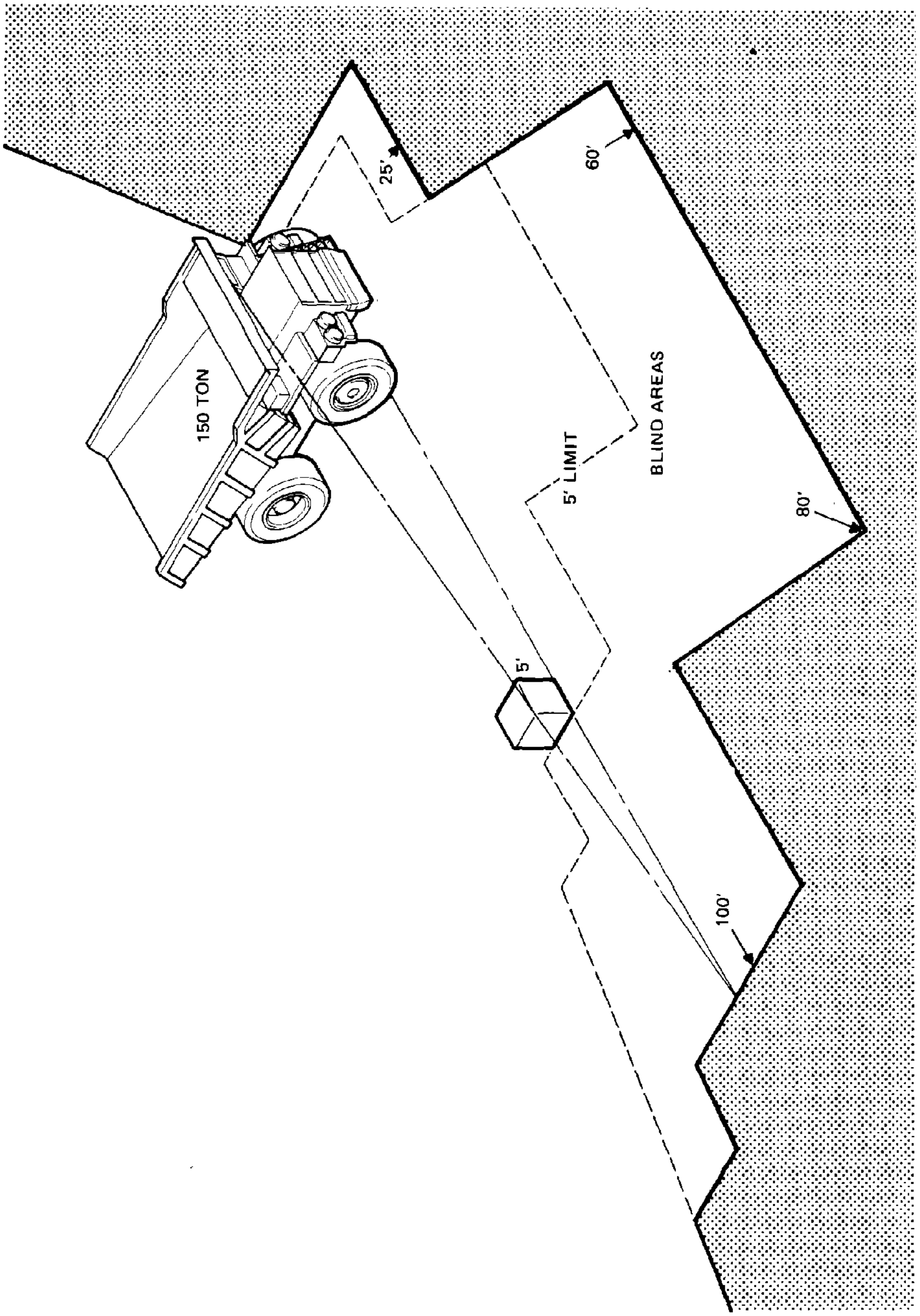


FIGURE 3.1-6
LARGE HAULAGE TRUCK BLIND AREAS

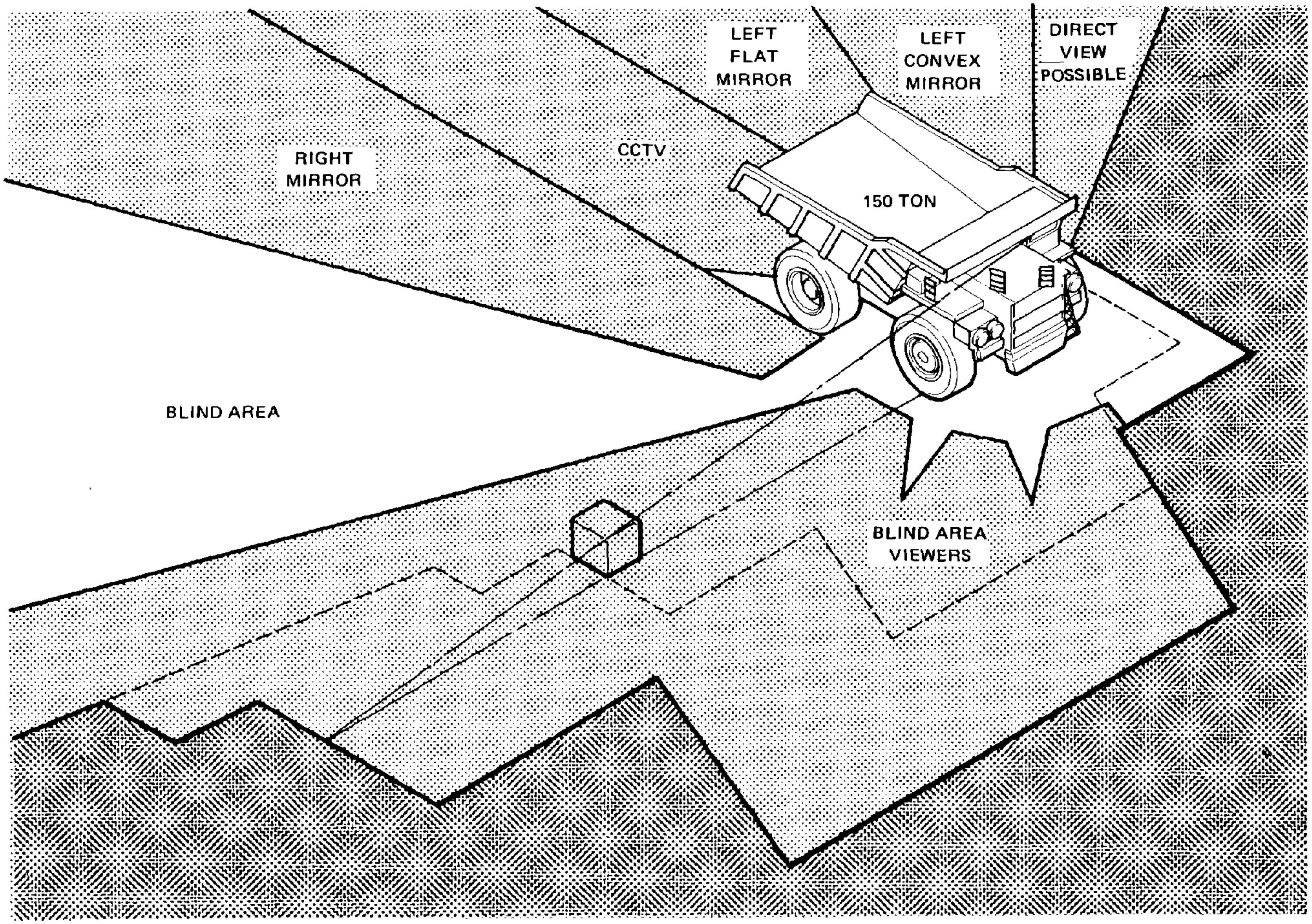


FIGURE 3.1-7
INCREASED VISIBILITY WITH IMPROVED VISIBILITY SYSTEM

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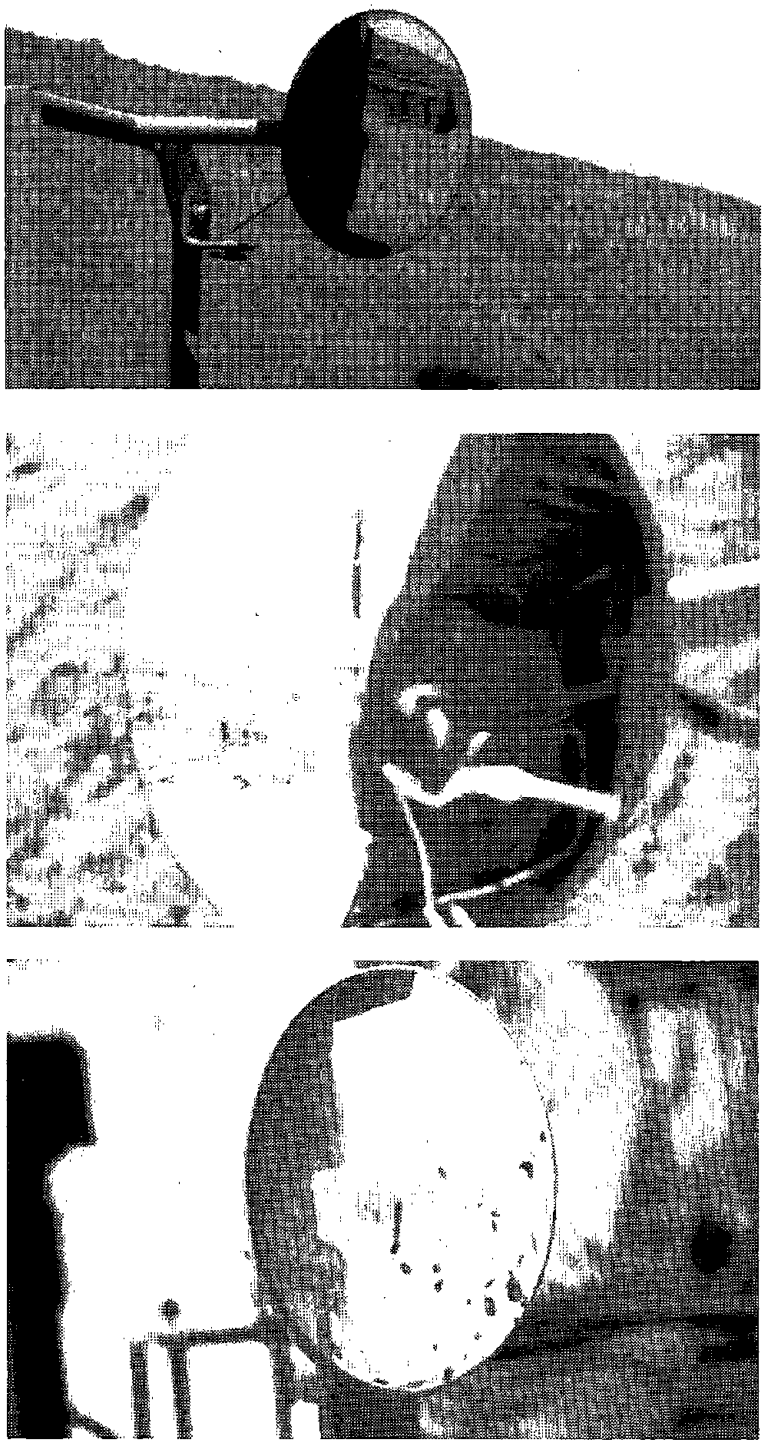

FIGURE 3.2-1
MIRROR DISTORTION AND MUD FOULING

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Polished steel mirrors can survive abuse from load bed spillage that would destroy a glass mirror. Clear plastic mirrors are vulnerable to scratching from load spillage and improper cleaning. At various surface mine locations the corrosion of mirror frames, deteriorations of rubber molding and the staining of mirror surfaces was observed in addition to dents, pits, scratches, and dirt.

A survey of mirror replacement rates showed that the average life of a mirror on a haulage truck ranges from one month to over a year. One mine reported as many as eight (8) 5 by 12-inch mirrors were replaced each shift where approximately 100 vehicles of all types were in use.

3.2.2 Left Rear View Mirrors. The left mirrors observed were mounted from 18 to 42 inches from the driver and were generally attached to the left cab door or the left side of the cab. A few were attached to the cab deck railing. In all cases the mirrors are mounted far enough to the left to give a view of the left side of the load bed. In general, left mirrors are positioned to give a view of the horizon and either a view of the ground at the rear tire or a view of the top edge of the load bed (see Figure 3.2-2). The horizontal field-of-view depends on the distance to the operator and the width of the mirror. The width of flat mirrors ranged from 5 to 10 inches with fields-of-view from 3 degrees to 20 degrees.

Image size in left flat mirrors is very slightly less than life size for the distances viewed. The vertical field-of-view of left flat mirrors directly depends on the length of the mirror. Lengths of flat mirrors ranged from 10 to 30 inches with the fields-of-view varying directly from 20 degrees to 45 degrees. Mirrors longer than 20 inches long can give a view of both the rear tire and the top edge of the load bed without requiring head movement. Head and body movements were commonly observed with shorter mirrors. Flat rear view mirrors on the left side can give enough depth perception, vehicle orientation references and image size to position a vehicle when backing up; however, the field-of-view frequently does not contain enough ground references for this task. Examples of left mirror view orientation are shown in Figure 3.2-3.

A few convex and combination flat and convex mirrors were observed in use as left rear view mirrors (see Figure 3.2-4). The convex mirrors had an effective field-of-view ranging from 30 degrees to 20 degrees along the horizontal center line. In one mining operation, five inch diameter round convex mirrors were used alone on the left. These mirrors were not used to position the vehicle, since the image size was small and depth perception was difficult. The wide field-of-view was useful in locating possible hazards. The combination mirrors were comprised of a 6 x 10 inch flat mirror and a 6 by 5 inch slightly convex mirror. Neither view is adequate alone and the views from both are oriented differently. Nearly all mirrors used on the left side were constructed of glass mounted in a metal frame. The costs for these mirrors are as follows:

Type	Mirror Assembly	With Mounting Brackets
5" x 14" Flat Mirror	$10-15	$20-$30
8" x 16" Flat Mirror	$20-$30	$30-$50
10" x 10" Flat Mirror	$40-$150	(Fabricated)
5" x Round Convex	$6	(Fabricated)
Combination Flat & Convex	$20-$30	$30-$50

The majority of mirrors used on the left side are purchased from distributors of industrial safety mirrors and highway truck mirrors which are not specifically designed for mine operations.

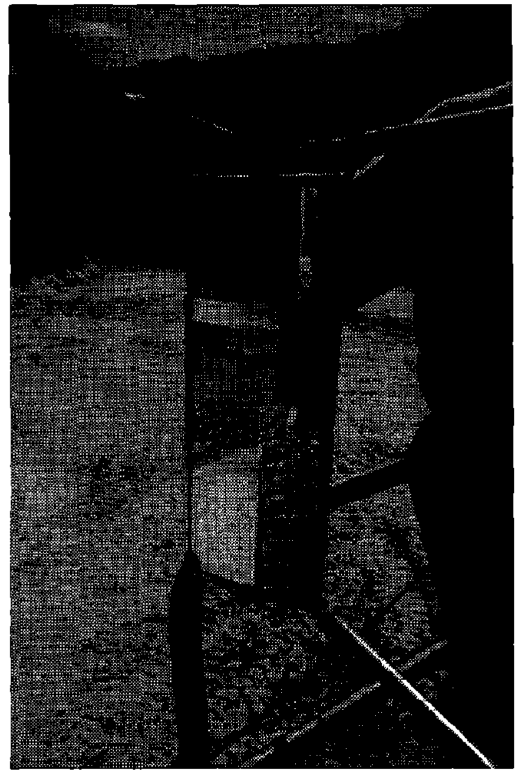

FIGURE 3.2-2
LEFT MIRROR VIEWS

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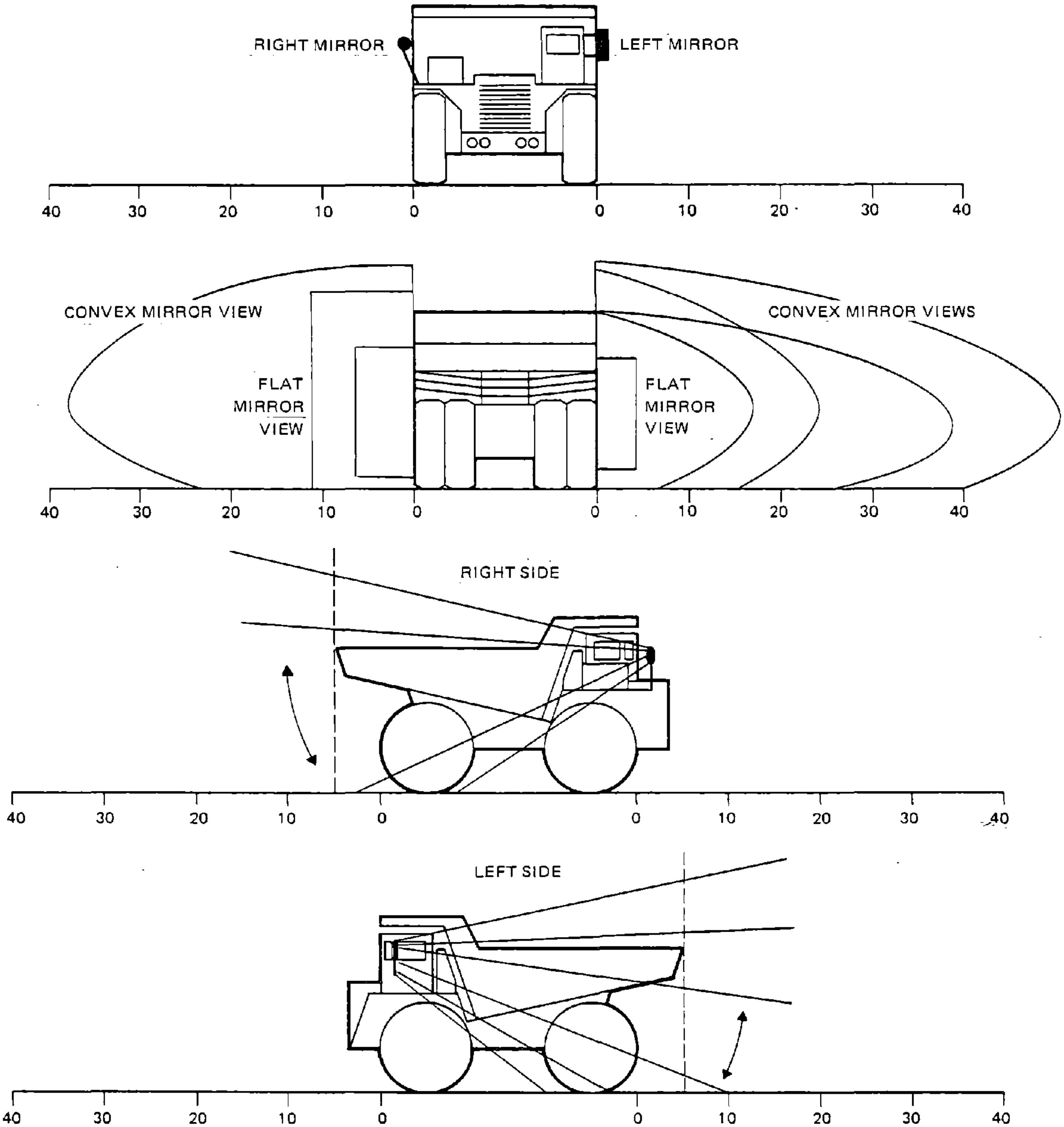

FIGURE 3.2-3
MIRROR VIEW ORIENTATION FOR TYPICAL MIRRORS

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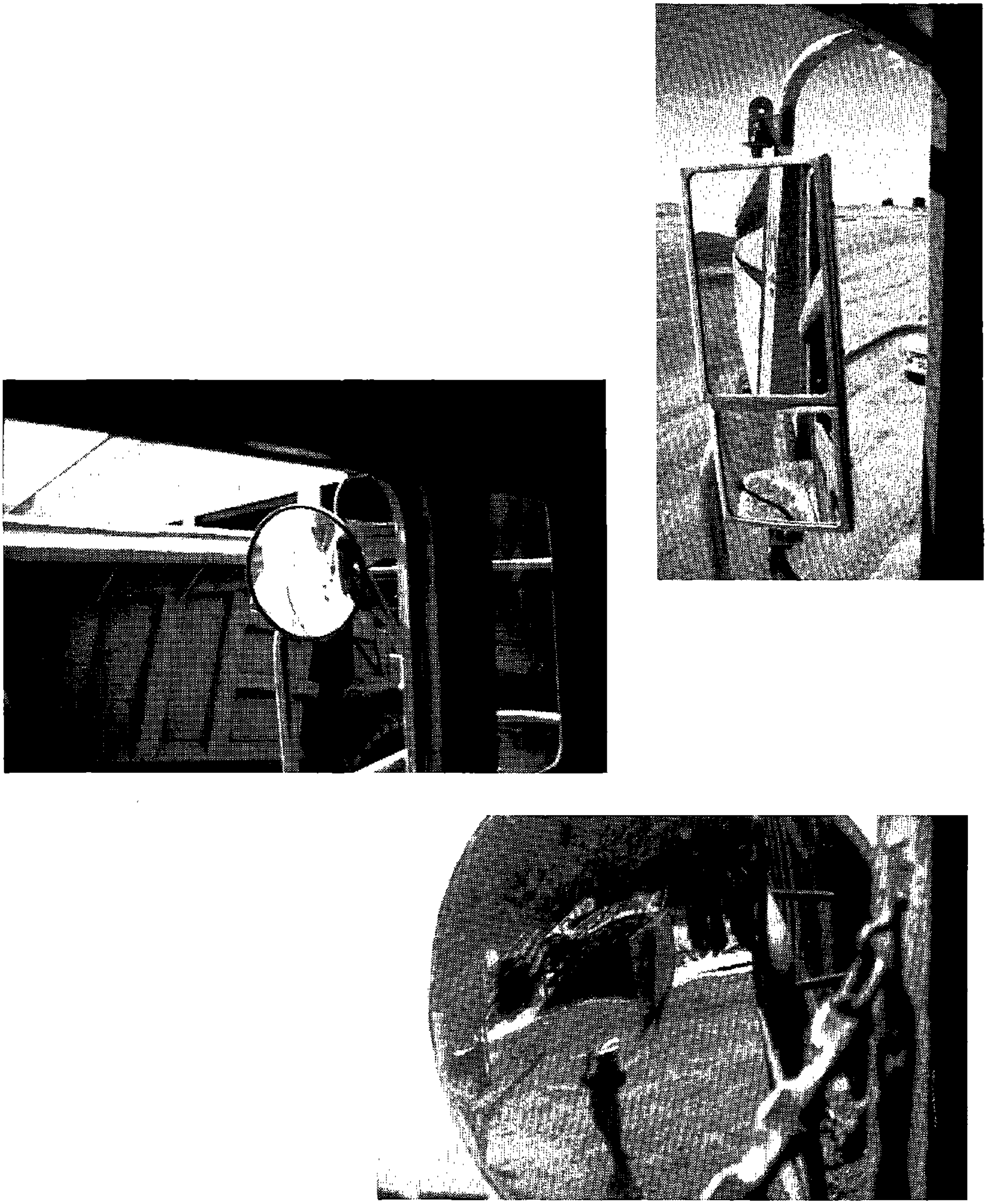

FIGURE 3.2-4
CONVEX AND COMBINATION
LEFT MIRROR VIEWS

Only one incident of injury from mirror glass breakage was discovered in this study and it involved only a minor laceration.

3.2.3 Right Rear View Mirrors. Over 90 percent of the right rear view mirrors observed on large haulage trucks utilized a nominal 12-inch diameter round convex mirror mounted from 13 to 24 feet to the right of the driver and 0 to 8 feet forward of the driver, depending on truck size. Exceptions included a 16-in diameter round convex mirror and some large size flat mirrors.

The convex mirrors observed had approximate radius of curvatures from 15 to 30 inches and the approximate degrees of arc across the mirrors ranged from 18 to 45 degrees. This degree of variation was not expected. This results in image sized 7 to 15 times smaller than direct view over the same optical path length.

In one test performed, the light from a slide projector located 15 to 20 feet away was reflected onto a wall by a representative sample of these mirrors. With the mirrors aligned for a maximum reflected angle of 90 degrees, an egg-shaped pattern (field of view) was projected on the wall. The vertical field-of-view projected corresponded roughly with the degrees of arc across the mirror, however, the horizontal field-of-view was nearly twice the vertical field-of-view. To simulate truck driver usage of convex mirrors, the maximum reflected angle was varied from 80 to 120 degrees. With this variation in alignment (similar to observed mirror adjustments on large haulage trucks) the projected field-of-view pattern changed shape when shifting. The field-of-view projected to the left of the 90 degrees reflection line (simulating the side of the truck) showed that the horizontal field of view available to a driver could not be predicted accurately with a range of from 20 to 80 degrees. Examples of the orientation of the view of convex mirrors is shown in Figure 3.2-3.

Examples of the view from these mirrors are shown in Figures 3.2-5 through 3.2-7.

Because of the reduced image size and the exaggerated distance perception cues presented to the driver, convex mirrors are very infrequently used for positioning a haulage vehicle when backing. Use of these mirrors for detecting the presence and location of objects is significantly hindered because of the distance between the driver and the mirror. The distance of the mirror from the object viewed and the image size reflected by the convex surface give the driver a mimimum of information for the recognition of smaller objects. Mirror distortion, damage caused distortion, reduced contrasts and mud splatters can degrade the effectiveness further.

Flat mirrors used on the right side range from 8 to 10 inches wide and are 24 to 36 inches long. The horizontal field-of-view does not exceed 3 degrees and the vertical field-of-view ranges from 5 to 12 degrees. The image size is equivalent to a direct view over a distance equal to the optical path. The small field-of-view limits the use of these mirrors because of the inadequate coverage of the right rear blind areas (see Figure 3.2-8).

A convex mirror with a 16-inch diameter was observed under ideal conditions at one mine (see Figure 2.5-8). The image size viewed by the driver was larger than for a 12-inch diameter convex mirror with the same field of view capability.

The costs of these mirrors are as follows:

Type	Cost (Less Mounting Structure)
Nominal 12" Diameter Convex	
polished steel surface	\$20-\$30
glass	\$20-\$30
Clear plastic	\$15-\$30
16" Diameter Convex (clear plastic)	\$30-\$50
10x30" Flat Mirrors (Glass)	\$40-\$150

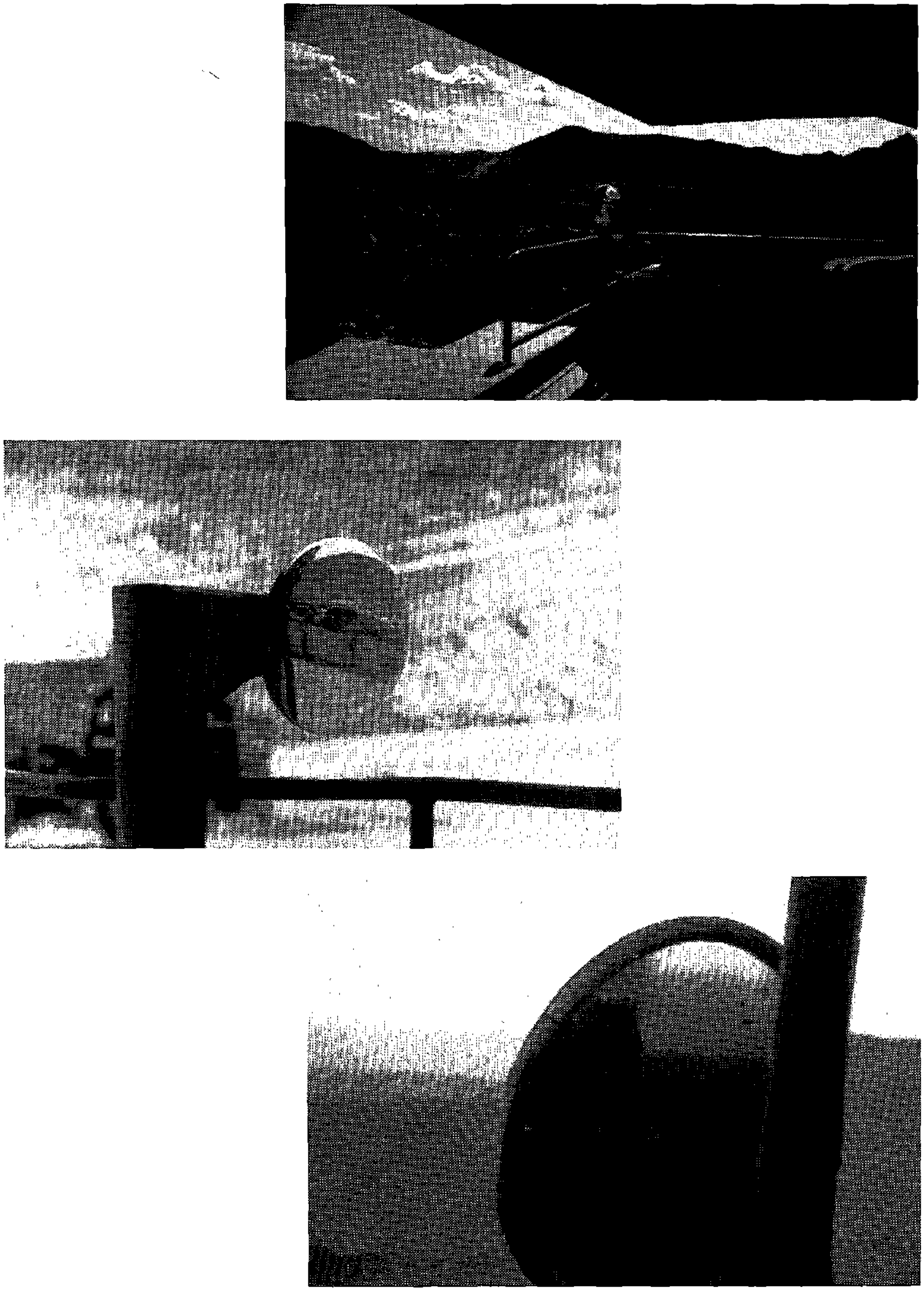

FIGURE 3.2-5
CONVEX RIGHT MIRROR VIEWS

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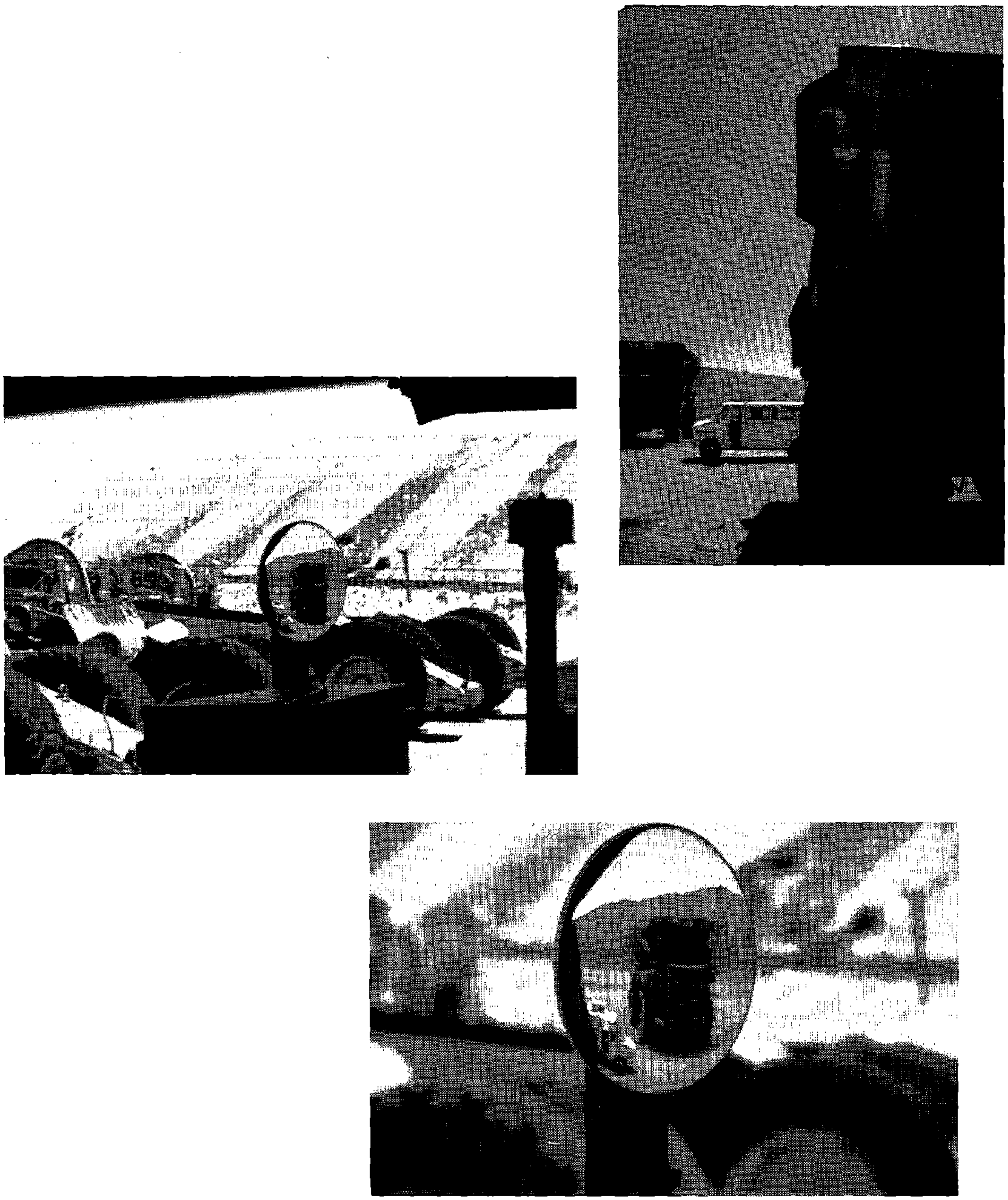

FIGURE 3.2 6
CONVEX REAR VIEW OF VEHICLES
TO THE REAR

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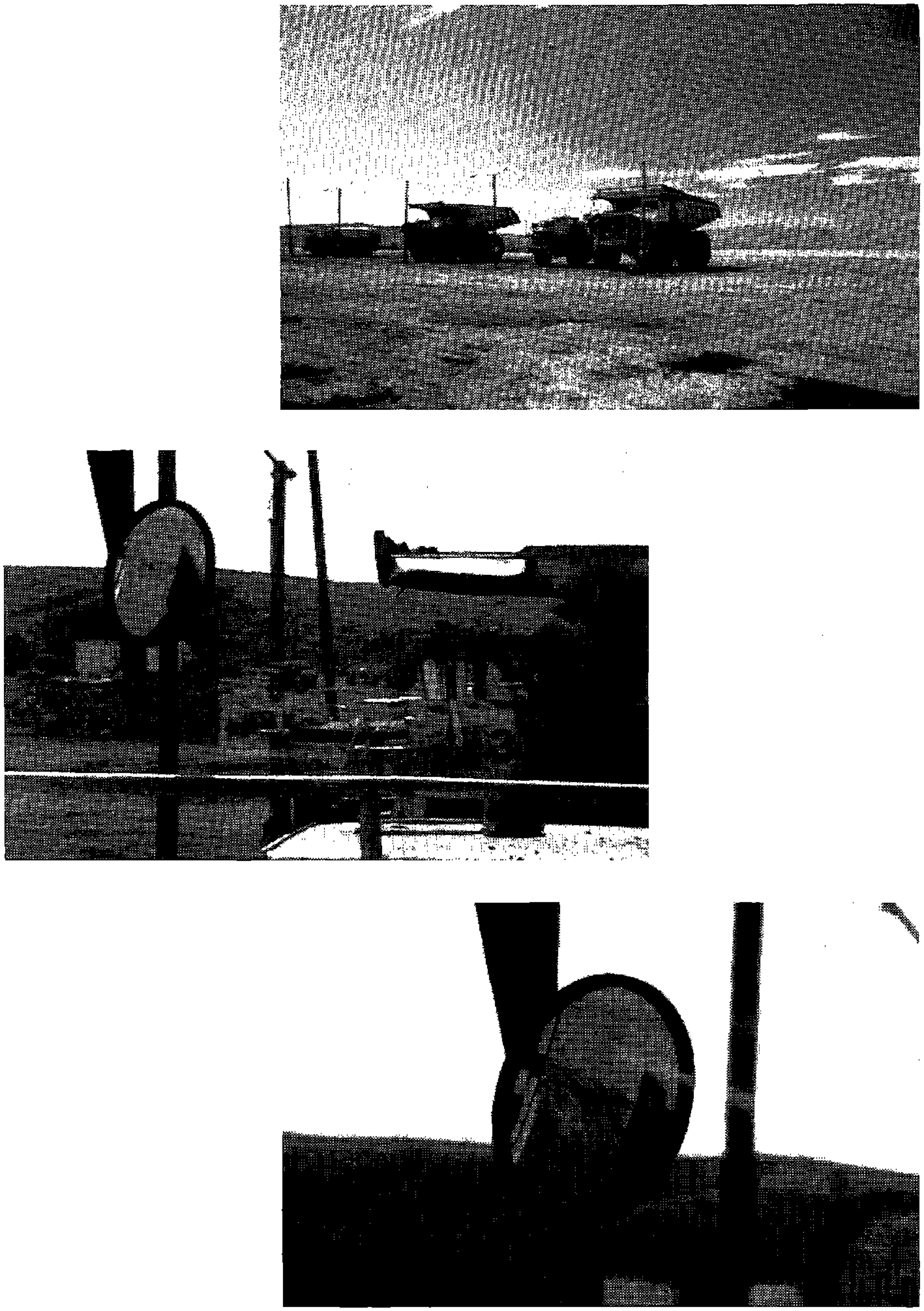

FIGURE 3.2-7
CONVEX RIGHT MIRROR VIEW
OF ADJACENT WATER TRUCK

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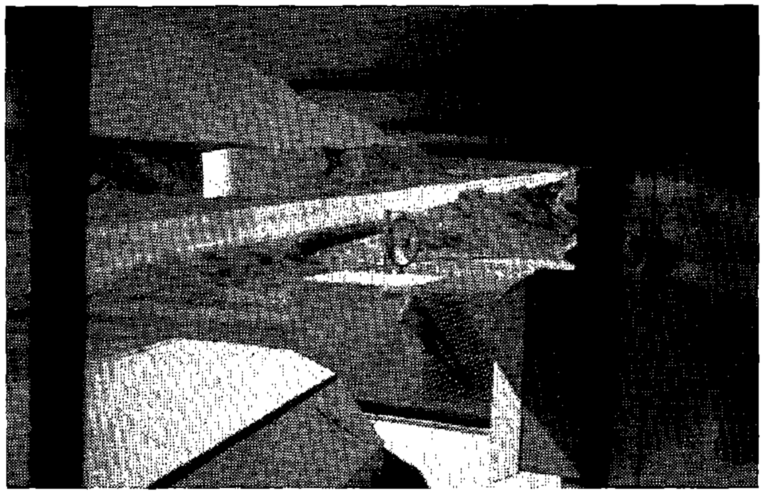
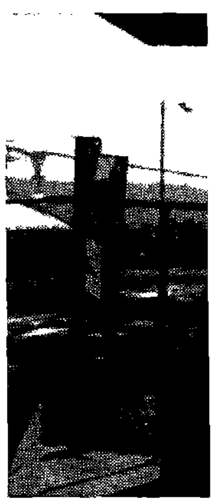


16" DIAMETER CONVEX



8" X 30"
FLAT MIRROR

FIGURE 3.2-8
UNCOMMON RIGHT MIRRORS

3.2.4 Other Mirror Systems. A quarter sphere mirror was observed on one truck which was mounted directly forward of the engine to give a downward view. This mirror showed a very distorted view of an area directly in front of the haulage truck vehicles to the right or left (within 20 feet of the truck) and slightly forward of the truck were visible. Personnel walking in front were detected by movement only. The strange shape of the limited effective field of view does not give adequate coverage of forward blind areas.

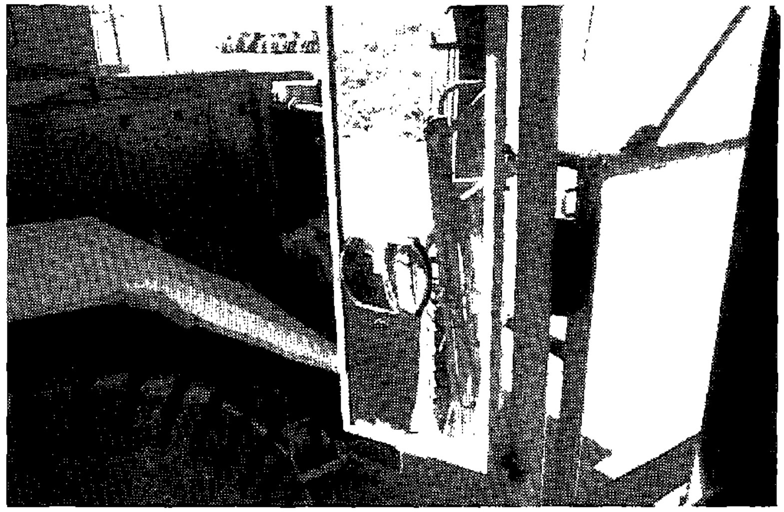
One mine observed used no mirrors on any haulage trucks. Accommodation of blind areas was entirely by procedures and traffic expectancy. View to the rear was exclusively by direct view of the left rear blind area. No factual evaluation could be made as the safety of this sytem, however, the distribution of visibility problem accidents as compared to driver error problem accidents is probably different. Traffic levels and haul road layout could not be directly compared to other operations.

Two mines reported experience with the use of convex mirrors mounted to give a view to the front of the vehicle. These front area mirrors were removed because of driver complaints. At night other vehicles' lights proved confusing to drivers looking into these front area mirrors.

3.2.5 Improved Left Mirror System. The left mirror system developed as shown in Figure 3.2-9 and Figure 3.2-10. It is a 9" x 27" plane mirror with a 3" x 5" rectangular convex mirror attached for a wide angle view. The mirror is framed in a rugged enclosure designed to withstand minor rock spills and to facilitate quick replacement of the mirror element. Although simple in appearance, this mirror contains a composite of concepts and features which are not evidenced or effectively utilized in existing left mirrors.

The left mirror system as developed and demonstrated has the following specifications and features:

- The field of view contains a view of the left side of the truck, including the top edge of the load bed and the bottom of the rear tire. No head movements are required to see this vertical field of view. The horizontal field of view of the plane mirror is sensitive to its distance from the driver, however, a small rectangular convex mirror is attached to expand this view to greater than 40 degrees.
- The view orientation can be maintained when glancing from the top to the bottom of the mirror because of the left side position of the convex mirror which does not interrupt the orientation features in the plane mirror. The convex mirror is field mounted in a position selected to prevent it from masking any significant view features.
- The plane mirror element is a standard glass mirror. The mirror assembly will accept glass mirror elements from 1/8" to 3/8" thick, including tempered and safety mesh backed mirror glass. The rectangular convex mirror is a standard hardware item mounted with silicon based sealant.
- The frame is of rugged construction and is topped with a 3/16" steel plate to prevent damage from minor rock spills.
- The left mirror is mounted with its right edge in line with the load bed for best view orientation.
- The mirror assembly is attached to the mounting structure using 3/8" bolts with rubber washers for positive alignment.



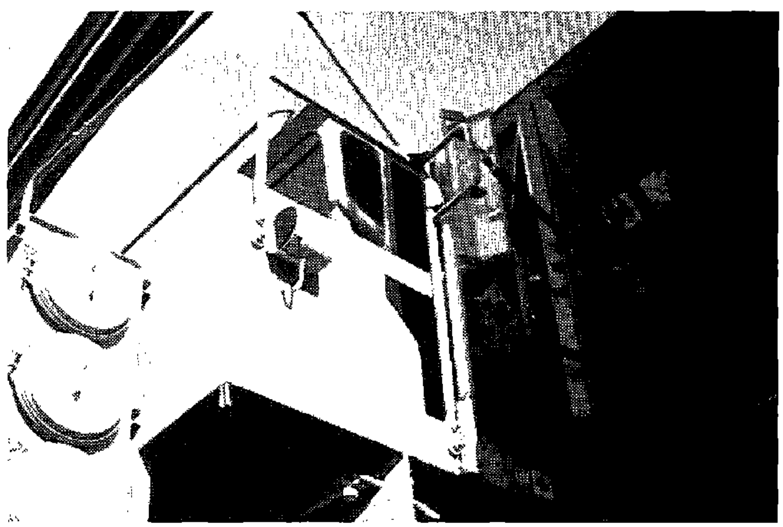


FIGURE 3.2-9
LEFT MIRROR SYSTEM ON HAULAGE TRUCK

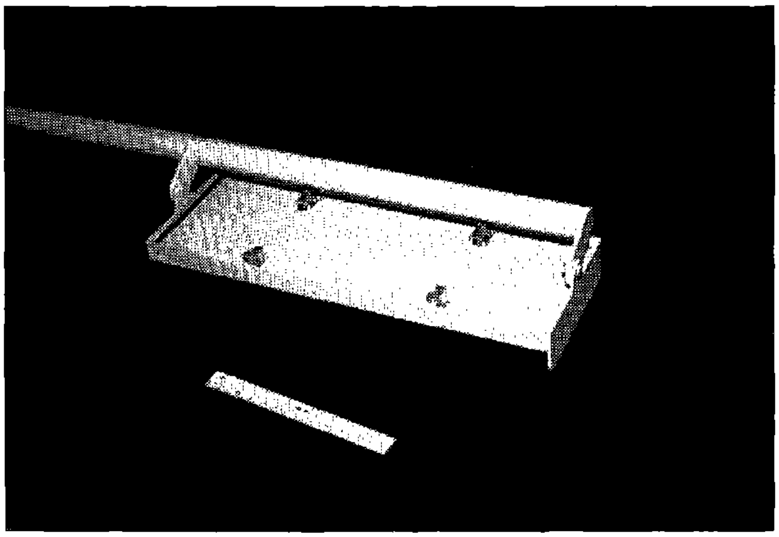


FIGURE 3.2-10
LEFT MIRROR SYSTEM

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- The rear plate of the mirror can be removed by hand by releasing four latches for quick mirror element replacement. The mirror element can be replaced in the field without tools in less than a minute.

The details of the left mirror assembly is shown in Figure 3.2-11. All material and components are common off-the-shelf items.

3.2.6 Improved Right Mirror System. The right mirror system developed is shown in Figure 3.1-12 and Figure 3.2-13. In Figure 3.2-12 it is shown with a 12-inch diameter polished steel convex mirror of greater radius of curvature. Careful observation of this figure shows the advantages of a rectangular shaped convex mirror. This mirror has superior field of view and orientation features and is more than equivalent to a larger diameter circular mirror. Figure 3.1-13 shows the mounting location of the right mirror and illustrates the problem large haulage trucks have when maneuvering in truck maintenance areas past structures such as I beam columns or maintenance bay doors.

The right mirror system as developed and demonstrated has the following specifications and features:

- The field of view contain a view of the right side of the truck including the top edge of the load bed and the rear tire. This image of the side of the truck can be compressed into only 20 percent of the view by mirror alignment. The vertical field of view is approximately 60 percent and the horizontal field of view is greater than 25 degrees from top to bottom. Circular convex mirrors can equal this only across the center.
- The image size is slightly above average for the mirrors in common use. Image recognition is improved by the improved orientation features in the view.
- The mirror element is a 12-in by 16-inch rectangular section of a spherical mirror. The mirror radius of curvature is uniform with a range of 20 to 25 inches.
- The mirror element was constructed of tempered glass, however, plexiglass can be used as an option. The mirror was backed by rigid high density foam containing mounting hardware for attachment by 4 bolts.
- The mirror enclosure is fabricated from 3/16-inch steel plate and is topped with a 1" rubber fender to prevent the common minor rock spills from causing damage.
- The mounting structure with U Bolt attachment was designed for universal application without right handrail modification. Since alignment is permanent after installation, a simplified structure is feasible for specific models of trucks.
- The mirror face is mounted with the left edge in line with the load bed. It is also aligned 60 degrees out from the side of the truck and 15 degrees down from the vertical. The alignment will vary slightly for different trucks, however, no adjustment is needed for individual drivers, so that adjustment after installation is not required.

A drawing in Figure 3.2-14 shows the assembly of the right mirror system.

Evaluation of the right mirror system in the lab and in the field shows that the rectangular convex approach gives considerably more effective field of view with a consistent view orientation which would not vary significantly from truck to truck. The field of view is greater than 100 percent wider than a standard 12-inch polished steel circular convex mirror.

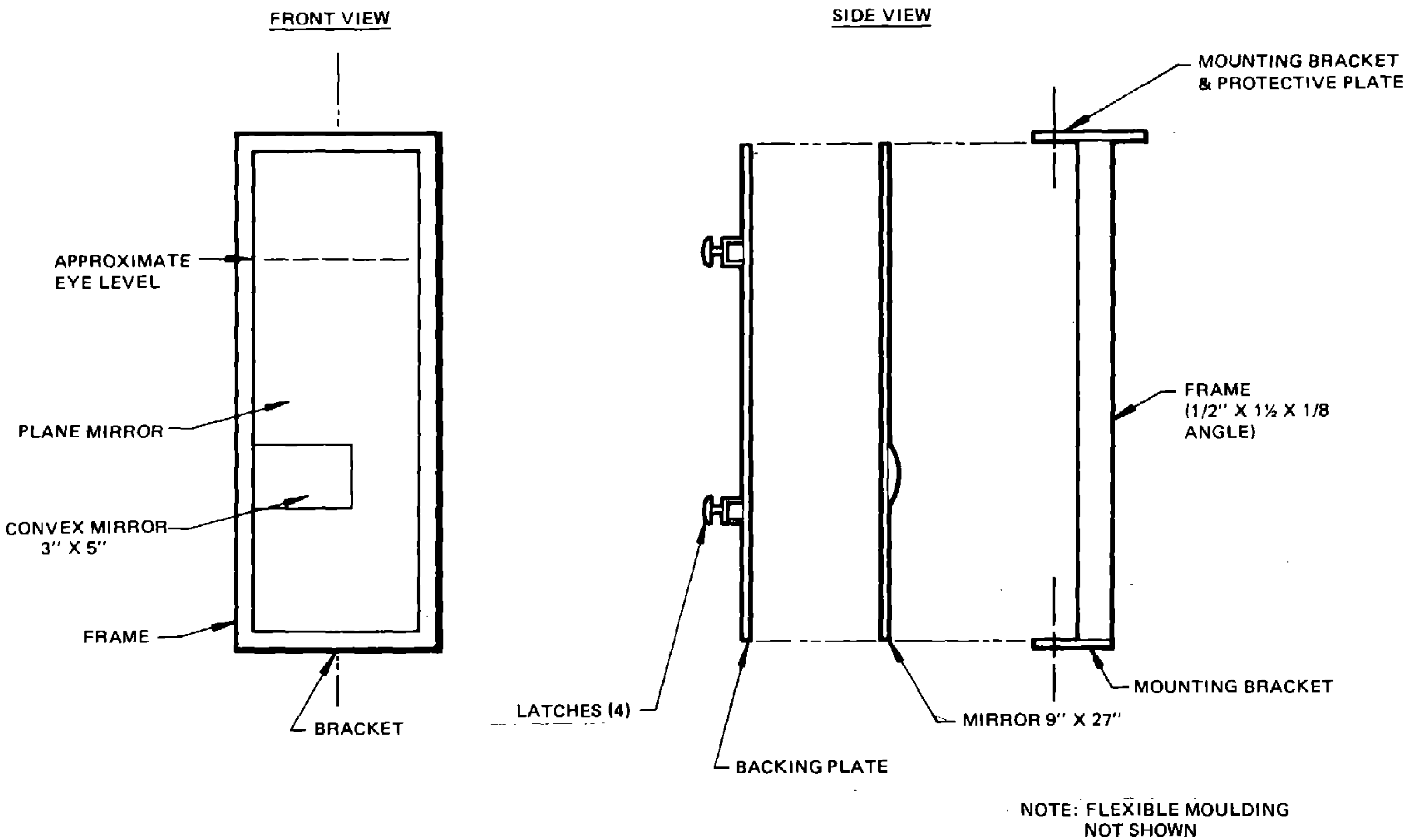


FIGURE 3.2-11
LEFT MIRROR LESS MOUNTING STRUCTURE

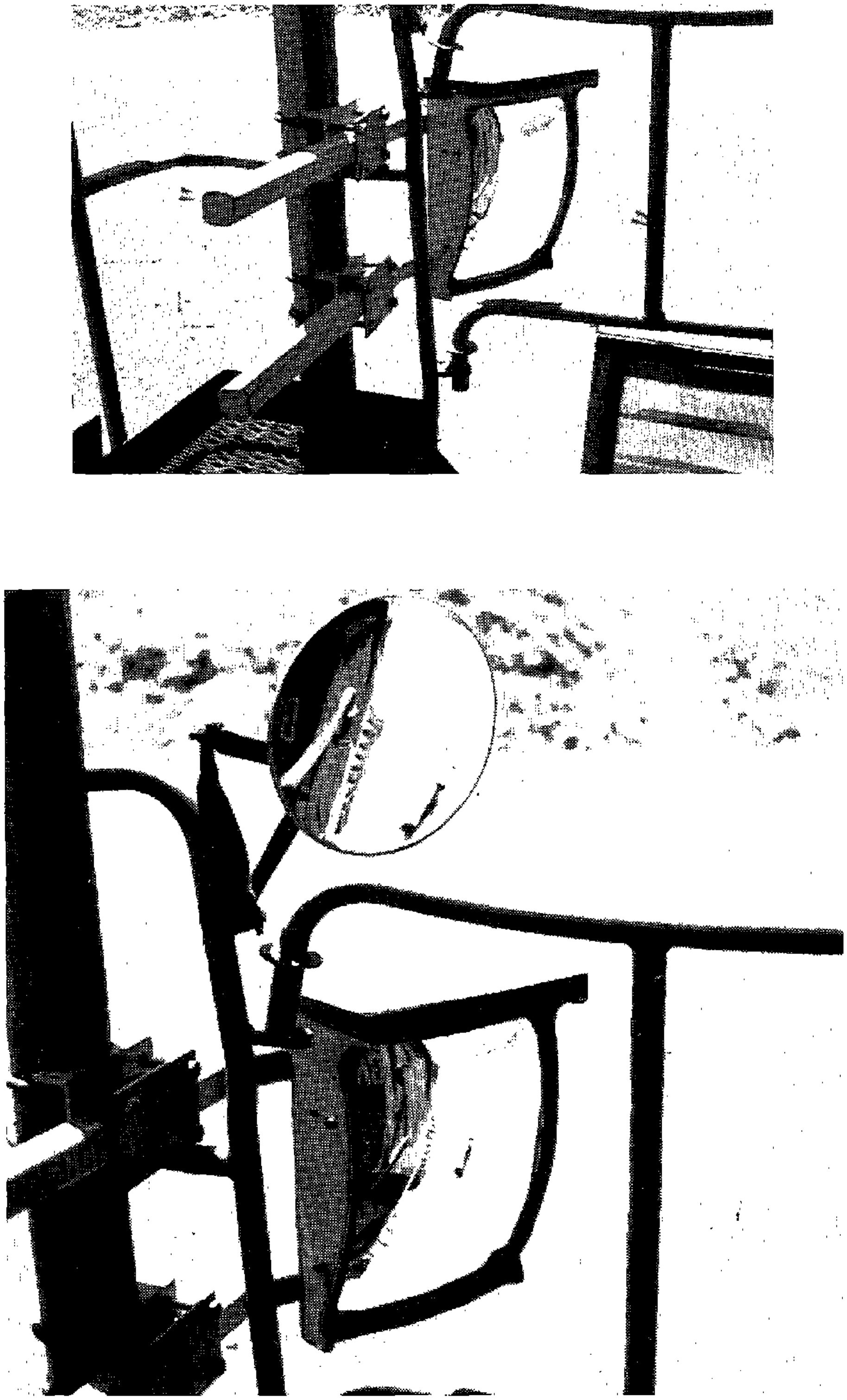


FIGURE 3.2-12
RIGHT MIRROR SYSTEM VIEW

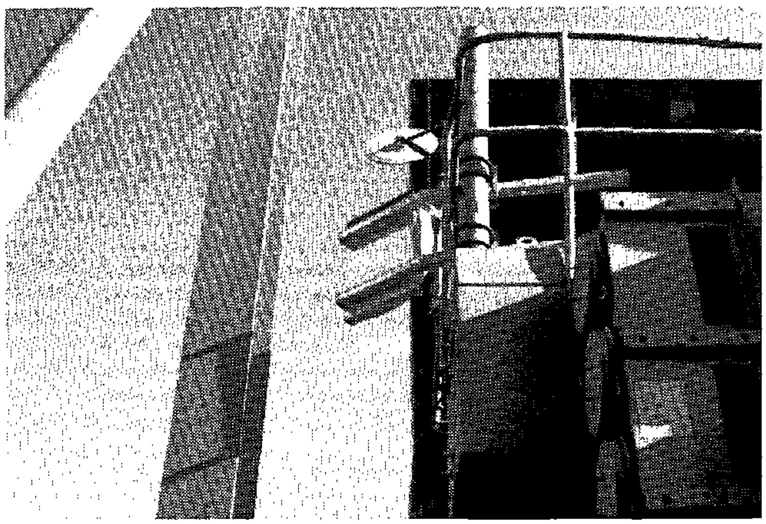


FIGURE 3.2-13
RIGHT MIRROR ALIGNMENT

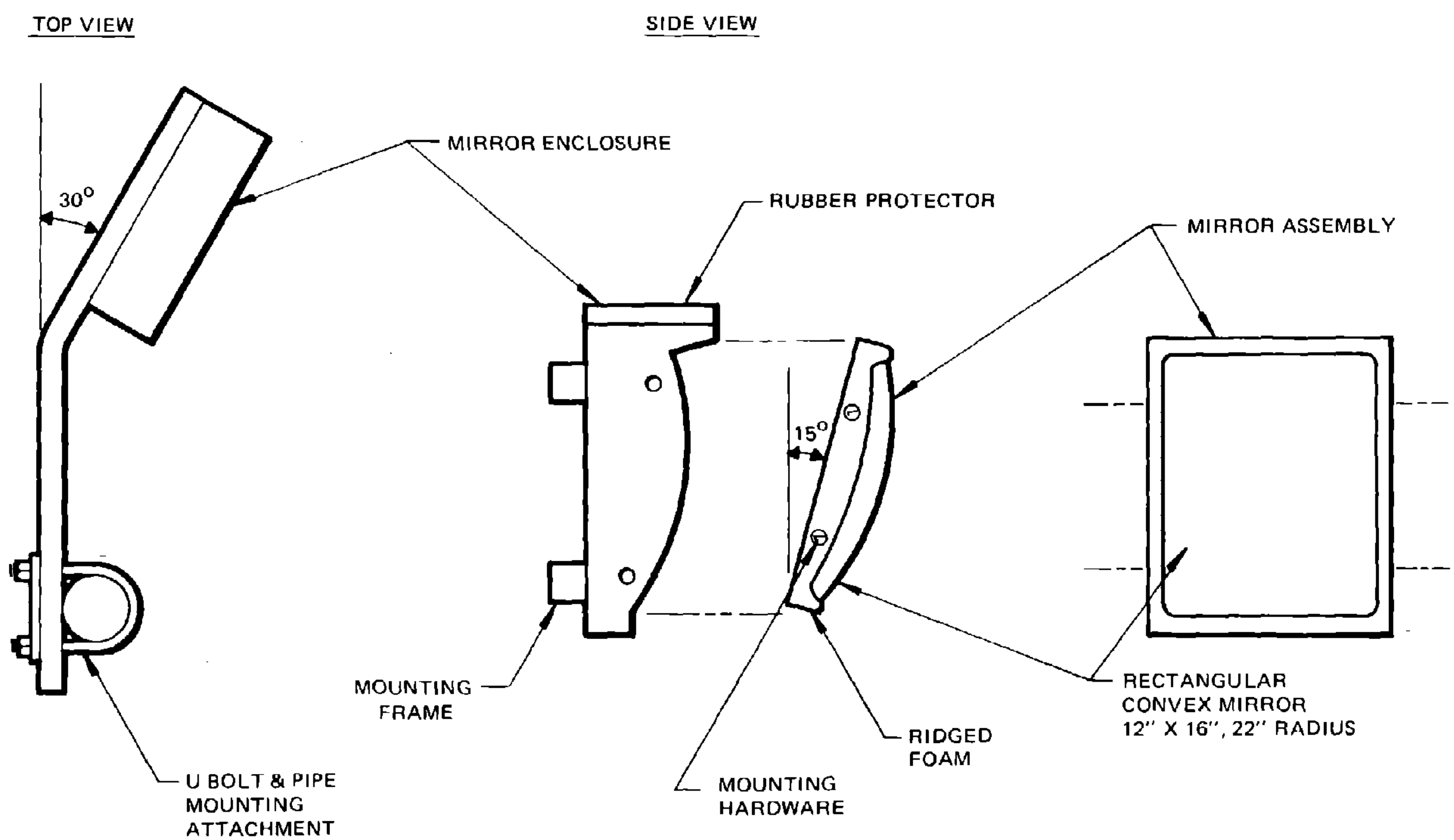


FIGURE 3.2-14
RIGHT MIRROR SYSTEM

3.3 BLIND AREA VIEWER DESCRIPTION. The Blind Area Viewer is an entirely new concept in its application to mine truck haulage. The Blind Area Viewer was developed to help the truck driver see into the blind areas to the front and right of the truck. It is basically a fresnel lens (or flat lens) which has a well oriented, wide angle view emphasizing the scene below the driver's unaided line of sight. A Blind Area Viewer is shown mounted on an engine hood in Figure 3.3-1. The view through the Blind Area Viewer is shown in Figure 3.3-2. The main feature of the Blind Area Viewer is a downward angle of view of 70 degrees combined with a wide horizontal view. This allows objects to be seen to within five feet of the truck. The visibility improvement this creates is shown in Figure 3.3-3.

This particular fresnel optical capability is unique in the fresnel lens industry and the Blind Area Viewer is the first known application of this particular fresnel concept. This fresnel unit consists of two elements and is the equivalent of three lenses.

A commercially available single element fresnel lens for this type of application was evaluated, however, only a 30-degree downward angle of view could be obtained. The two elements of the Blind Area Viewer fresnel lens are one-eighth inch thick and are sandwiched between two panes of glass in a lens assembly. This protects the finely grooved lens from fouling due to dust and moisture. The lens is mounted in a rugged enclosure to protect it from rock spills and to prevent glare (see Figure 3.3-4). The Blind Area Viewer is mounted perpendicular to the driver's line of sight and can be tilted away from the driver to optimize the optical qualities. This tilt of the lens improves the view by reducing light losses and is more effective in a range from 15 to 25 degrees downward tilt.

The fresnel lens system has the following features and specifications:

- The fresnel lenses are pressed into plastic plates composed of cellulose acetate buytyrate and have a design life of five years. Each fresnel lens unit is 12-inch by 14-inch by 1/8-inch.
- The two elements of the fresnel lens contain three linear echelon analogs of a cylinder lenses.
- The field of view is 70 degrees downward and 15 degrees upward. The horizontal field of view is 60 degrees. This is a rectangular wide angle field of view with the downward angle of view emphasized. The downward angle of view of 70 degrees approaches the practical limit of the lens configuration. The lens is designed to emphasize the portion of the view between 20 and 50 degrees downward.
- The lens assembly has an estimated light loss of between 15 and 20 percent. This light loss increases in the view range from 50 to 70 degrees downward. The effect of this light loss is a loss in image contrast and increased-sensitivity to glare. Below a downward angle of 50 degrees high contrast items such as helmets and painted vehicles can be seen and recognized.
- Glare must be controlled for effective utilization of the fresnel lens assembly. The best approach which does not increase light losses is to prevent direct sunlight or direct lighting from contacting the lens assembly. This requires glare control louvers on the front of the lens. On the driver's side of the lens, the load bed and the enclosure provide glare control.

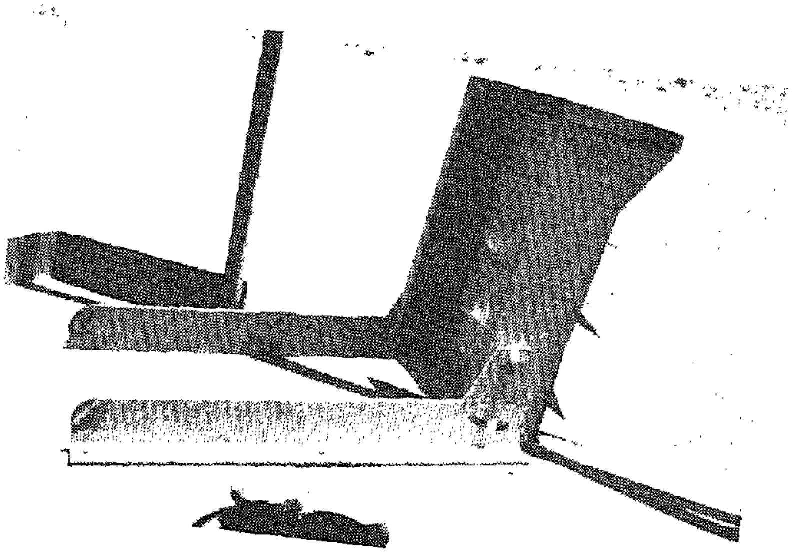
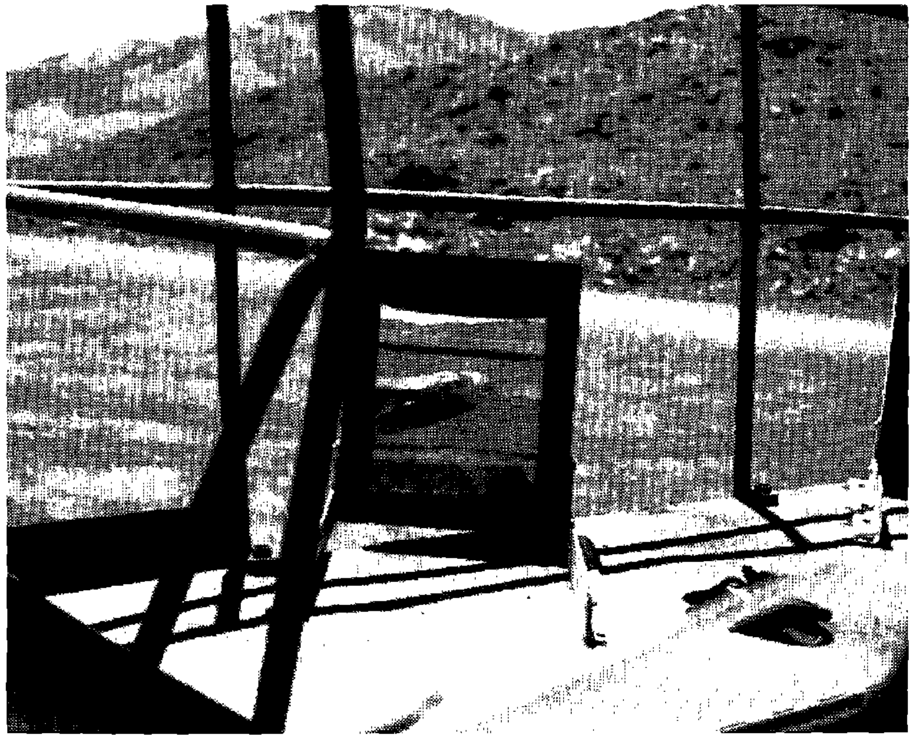


FIGURE 3.3-1
BLIND AREA VIEWER



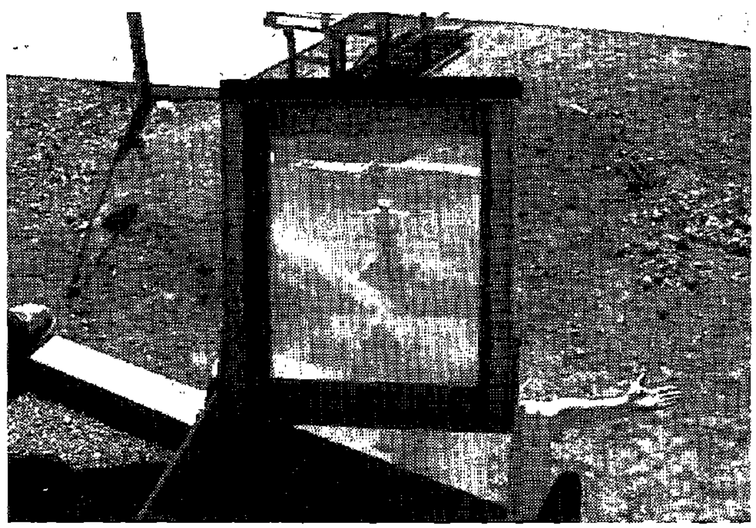


FIGURE 3.3-2
VIEW THROUGH BLIND AREA VIEWER

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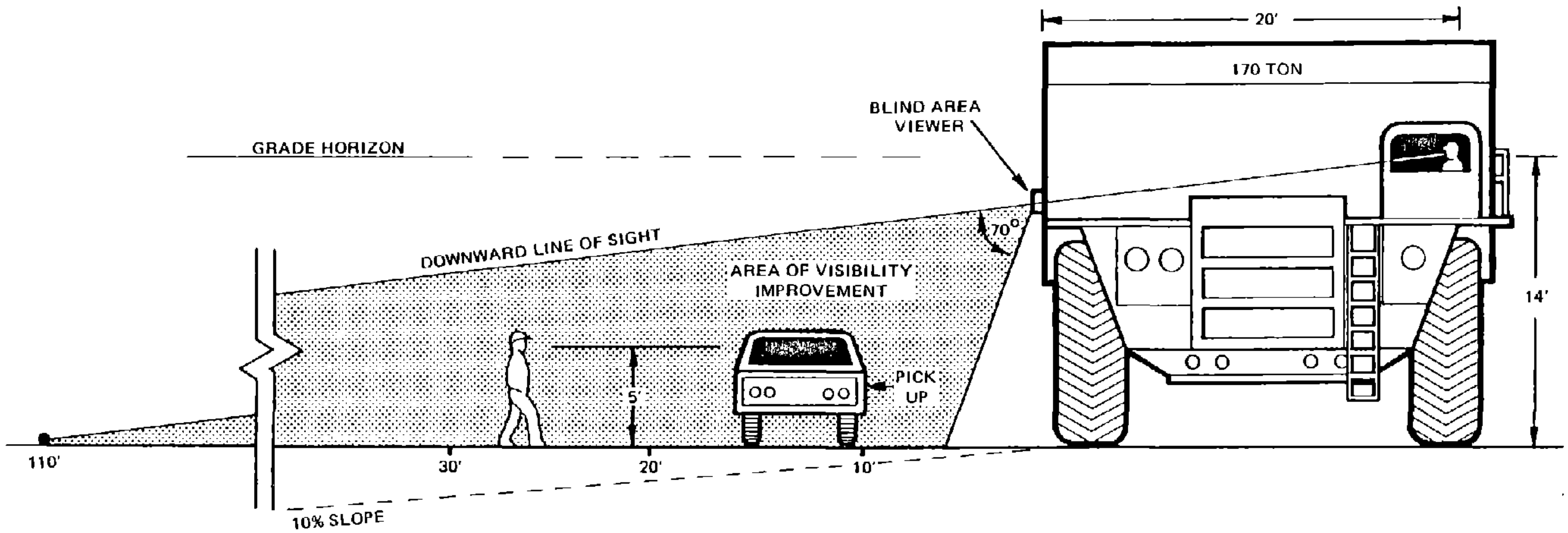

FIGURE 3.3-3
VISIBILITY IMPROVEMENT DUE TO
FRONT BLIND AREA VIEWER

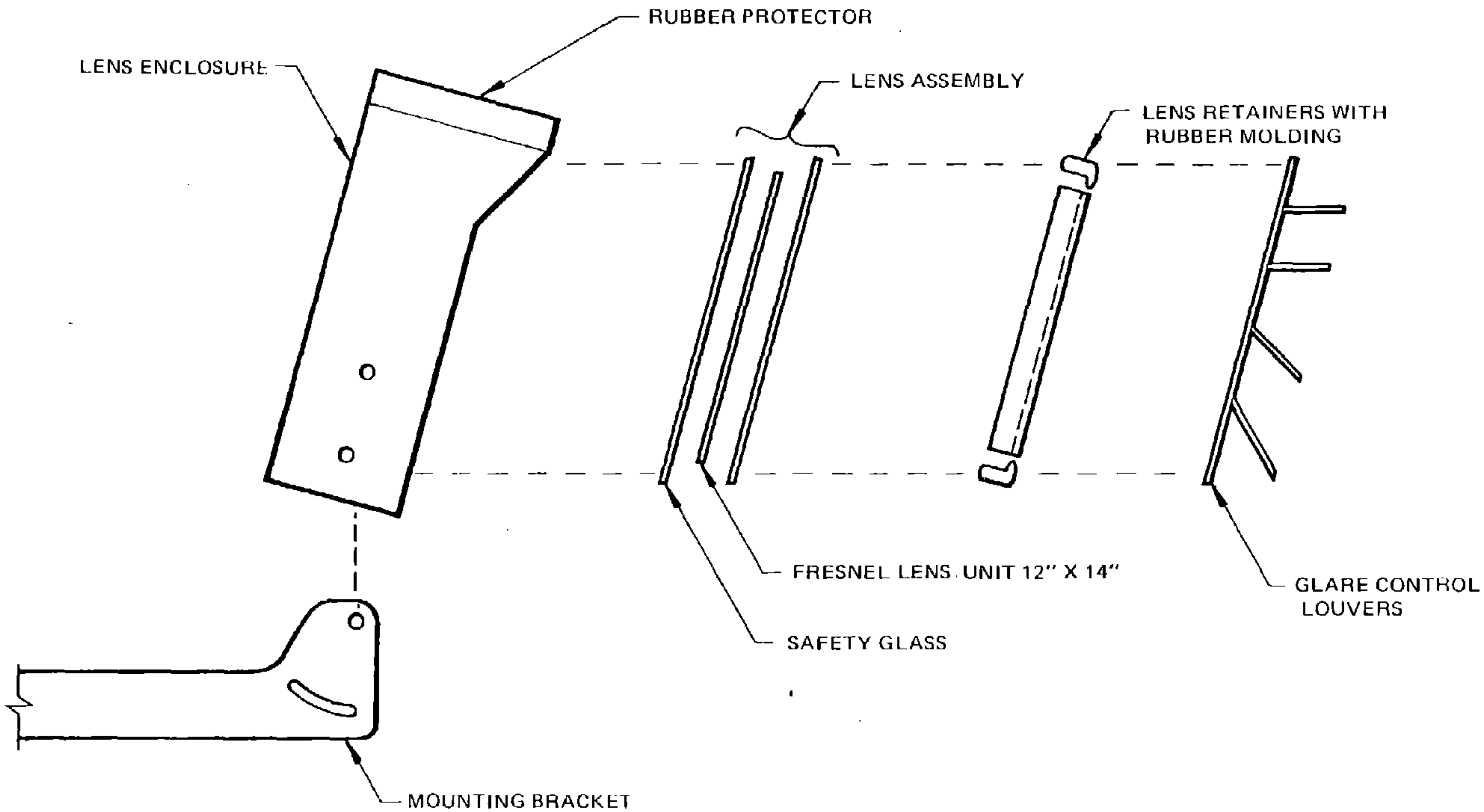

FIGURE 3.3-4
BLIND AREA VIEWER ASSEMBLY

- The two panes of glass protecting the fresnel unit can be standard, tempered, or laminated safety glass. Automotive quality glass is recommended. Two types of glass were tested in the prototypes with no significant differences noted.

Driver's utilization of the Blind Area Viewer was evaluated and the following was concluded:

- The truck driver's response was favorable during the short term 10-day demonstation. Interpretation of the view presented to the driver requires a period of time to become familiar with, for example, distance estimation (from the vehicle) of the objects seen in the viewer.
- The truck drivers expressed that they felt an increase in the degree of safety confidence when beginning to move their trucks. In other words, they were more certain that their start up path was free of hazards.
- At night, object recognition is limited to well illuminated objects (within truck headlight beams, shop lights, etc.) and illumination sources (other headlights, taillights, or flashlights). This is not adequate for all hazardous situations, however, most operating vehicles and mine personnel utilize lights continuously for personal safety at night. Auxiliary lighting on board each truck may be needed.
- Glare in the fresnel lens becomes a problem at low sun and lighting angles. Experience with the blind area viewers at the short term demonstration indicates that the light control louvers and enclosure can be improved for more glare reduction.

3.4 CCTV SYSTEM DESCRIPTION

3.4.1 Previous Use of CCTV Systems on Large Haulage Vehicle. Only one CCTV system was discovered that actually had been in use on a large haulage truck. The truck was an experimental model that since has been dismantled. A CCTV system consisting of a cab mounted monitor and two cameras was used on a Marian V-CON truck prototype to provide visibility to inexperienced drivers. One camera gave a rear view with the left rear tires included; and the other camera gave a view of the right side blind area. The following information about this novel system was obtained:

- The components of the system were standard off-the-shelf components with no special modifications.
- A standard wide angle lens was used on each camera.
- At night, in reduced illumination situations, some view detail could be maintained with the monitor adjusted to maximum brightness.
- The CCTV system was useful to new drivers but as experience was gained, the driver used the system less. To more experienced drivers the system was a novelty.
- At one mine, the CCTV system was removed after a few months because of its lack of use to the drivers.
- There was no provision for preventing mud and dust accumulation. Therefore, the lenses needed frequent manual cleaning.
- No other maintenance problems were encountered during the period of use.
- No electrical interference was encountered. A 75-volt battery power source was used.

3.4.2 Improved CCTV System. An improved CCTV System was developed for application to the rear blind area on largest haulage vehicles. This CCTV System was designed to demonstrate a combination of unique features which will improve the utilization of CCTV Systems in the mine haulage environment. The CCTV System is shown installed on a 150-ton haulage truck in Figure 3.4-1. It consists of an advance CCTV camera with a lens cleaning system and a 6-inch CCTV monitor with the systems controls. Details of the camera enclosure are shown in Figure 3.4-2. This CCTV system has the following features:

- The system is designed to operate under all lighting levels including nighttime conditions with automatic adjustment to light changes.
- The monitor is a standard CCTV model and cannot receive broadcast television channels.
- The camera is a charge coupled solid state silicon imaging device. The camera enclosure is designed to adapt to other vidicon tube type cameras. The camera system is a fixed mount system. A wide angle camera lens with an auto-iris was used.
- On demand the lens cleaning system will wash and wipe the camera lens window. The cleaning cycle is automatically timed and is initiated by a single actuation of push button contractor.
- The camera enclosure can be sealed from the outside environment. Provisions for the use of dry nitrogen purging, or desiccants were included in the design. The lens cleaning system is external to the camera enclosure. Functionally the washer reservior can be removed from the camera location for a lower profile system.
- A four-inch diameter glass window is used to effectively protect the camera lens from damage. The glass is mounted flush with the cover plate for effective use of standard wiper systems. The lens wiper is a compact windshield wiper with an 85 degrees stroke. Both the lens wiper and washer are standard automotive products.
- The system is powered by 12-volt and 24-volt DC sources. Automotive type batteries were used for the demonstration.

The camera and lens selected for use in this CCTV system has the following features:

- The charge coupled camera operates on 12 volts DC and consumes only five watts of power (less auto-iris lens), eliminating heat problems.
- The camera with an auto-iris lens operates at normal and very low light levels without manual adjustments. The silicon imaging device has an anti-bloom feature which prevents lights, reflections and the sun from obscuring the video picture.
- The CCTV camera with its lens is 8 inches long, 4-1/2 inches wide and 3 inches high. Its weight is less than four pounds.
- The CCTV camera is mounted on a rubber pad and is ruggedized internally for protection from shock and vibration. For low temperature operation, a thermostatically-controlled tape heater is attached to the camera. No provisions for cooling are needed.

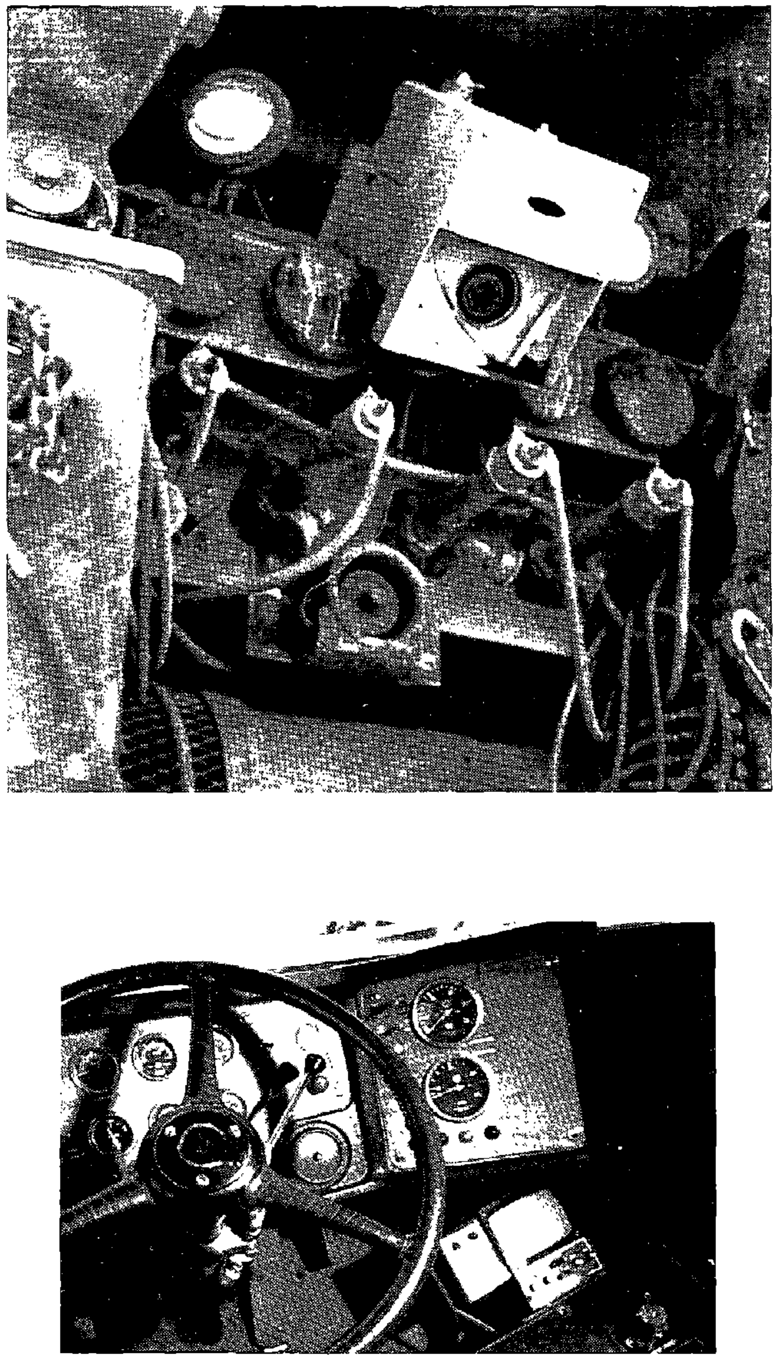

FIGURE 3.4-1
CCTV SYSTEM ON HAULAGE TRUCK

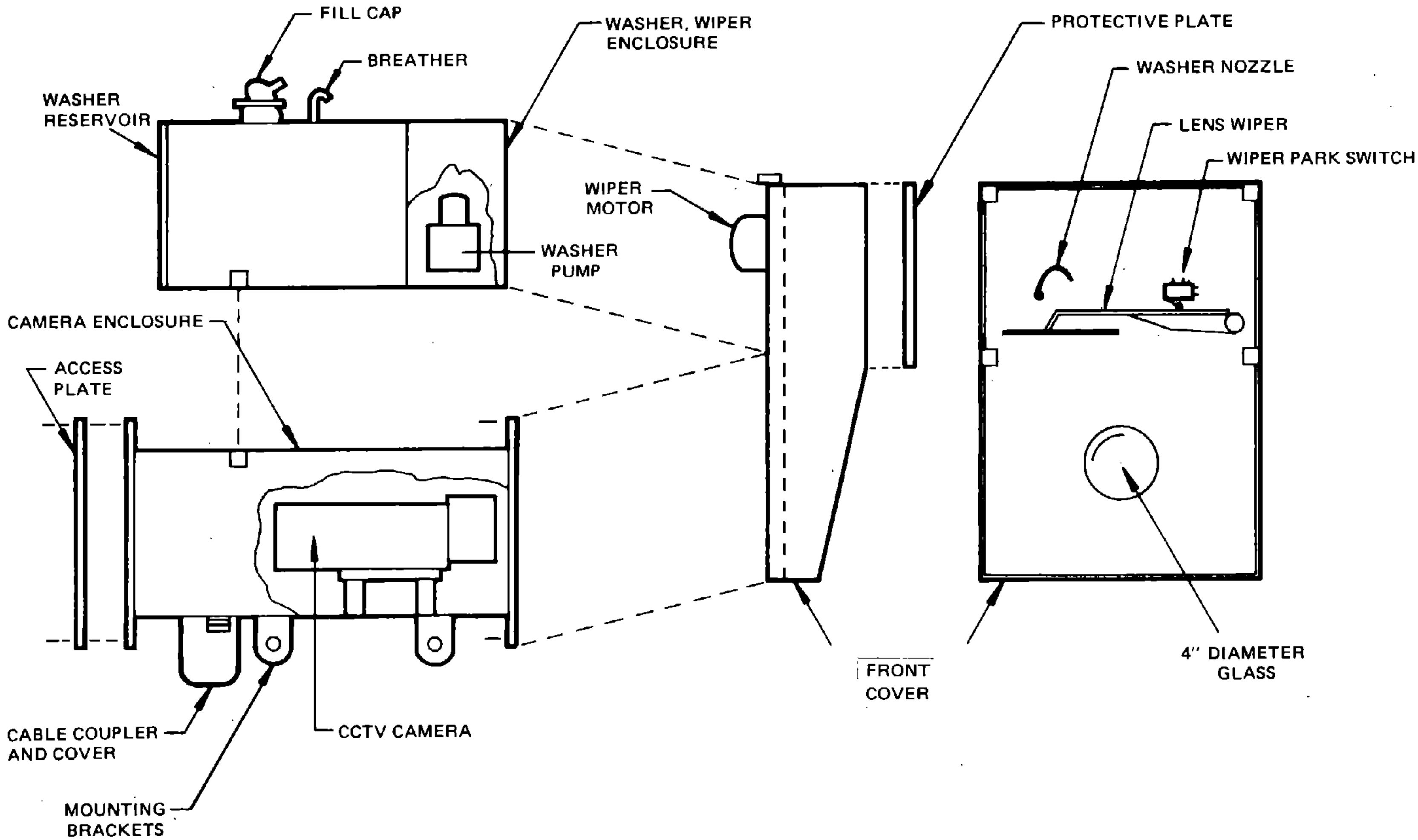

FIGURE 3.4-2
CCTV CAMERA ENCLOSURE ASSEMBLY

- The CCTV camera uses a high cost silicon imaging device. This is an advanced application of integrated circuit technology. This technology has the potential of becoming the low cost standard in the near future.

The CCTV camera is an RCA[1] TC1160 with a grade B silicon imaging device (SID 52501). The 5½" x 5½" x 17" enclosure can be adapted to other vidicon type cameras, however, there is no alternate camera that is a direct replacement. With a significant difference in performance, a RCA 1025/S05 camera could be used. The monitor is a Setchell Carlson Model 6M917 modified to operate on 24 volts DC.

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[1] Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

4.0 DEMONSTRATION OF THE IMPROVED VISIBILITY SYSTEM

The complete visibility system was mock-up-demonstrated twice at MBAssociates' facilities and field demonstrated at Eagle Mountain mine.

The mock-up demonstrations, which occurred both before and after the field demonstration, were conducted on the roof top of a single story building which was used to simulate the placement of the visibility aids on a large truck (see Figure 4.0-1). These mock-up demonstrations were attended by the USBM technical project officer, USBM officials, MESA officials, and Mining Industry representatives. The roof top mock-up was also used to conduct final system tests prior to the field demonstration installation on an actual truck.

The field demonstration occurred in July on an isolated mine waste dump at Eagle Mountain Mine, California. As shown in Figure 4.0-2, the visibility system was mounted on a Terex 150-ton electric wheel drive haulage truck through cooperation of the USBM and the mine safety department. One week prior to this demonstration, the visibility system was installed on truck No. 615 during routine preventive maintenance work down-time. The truck was then returned to active production.

Eight days later the demonstration began with the visibility aid equipped truck being observed during active production. Then the truck was pulled out of production and taken to an inactive dump site. All visibility aids were inspected for damage and cleanliness. Only one problem was detected. An extensively tested relay in the CCTV lens cleaning system had fused closed resulting in a burned out washer pump. This was repaired quickly and a relay with a higher current rating was later substituted. Both static and dynamic demonstrations were conducted.

For the static demonstration the driver's visibility limits were delineated as shown in Figure 4.0-2 using white tiles placed on the ground to show the previously existing blind areas. Flags on fiberglass poles were placed to show the five foot high visibility limits. The visibility improvements were then demonstrated by observations from the truck cab showing the positions where small vehicles and persons could be detected in locations where they had been totally concealed. As part of this demonstration an automobile was made to circle the large truck at various distances. Two photographers were present and documented the visibility improvement on 16mm technical movie footage and in still photos.

For a dynamic demonstration the haulage vehicle was returned to productive service and again observed in operation at the shovel and dump sites. Careful attention was focused on the usage of the visibility aids by the truck drivers who had one week of experience with the visibility system. The dynamic demonstration was concluded at shift change.

At the ready line both the oncoming and offgoing truck drivers were informally interviewed for their opinions and suggestions.

After an afternoon break, a nighttime demonstration similar to the static demonstration was accomplished and the demonstration was concluded by removal of the blind area viewers and CCTV system. At the driver's request, with concurrence of mine management and USBM, it was decided to leave the improved mirrors on the truck. These mirrors, left and right side, will remain on the truck indefinitely and will likely be included in Phase V testing if it is approved.

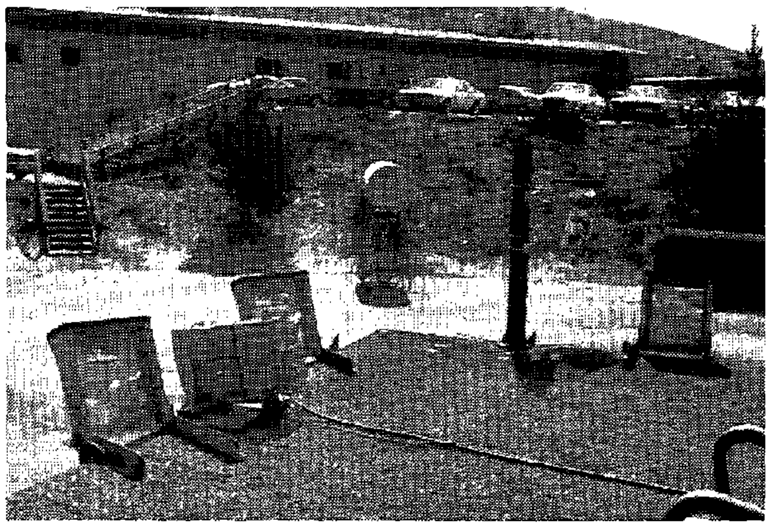

FIGURE 4.0-1
VISIBILITY SYSTEM MOCK-UP DEMONSTRATION

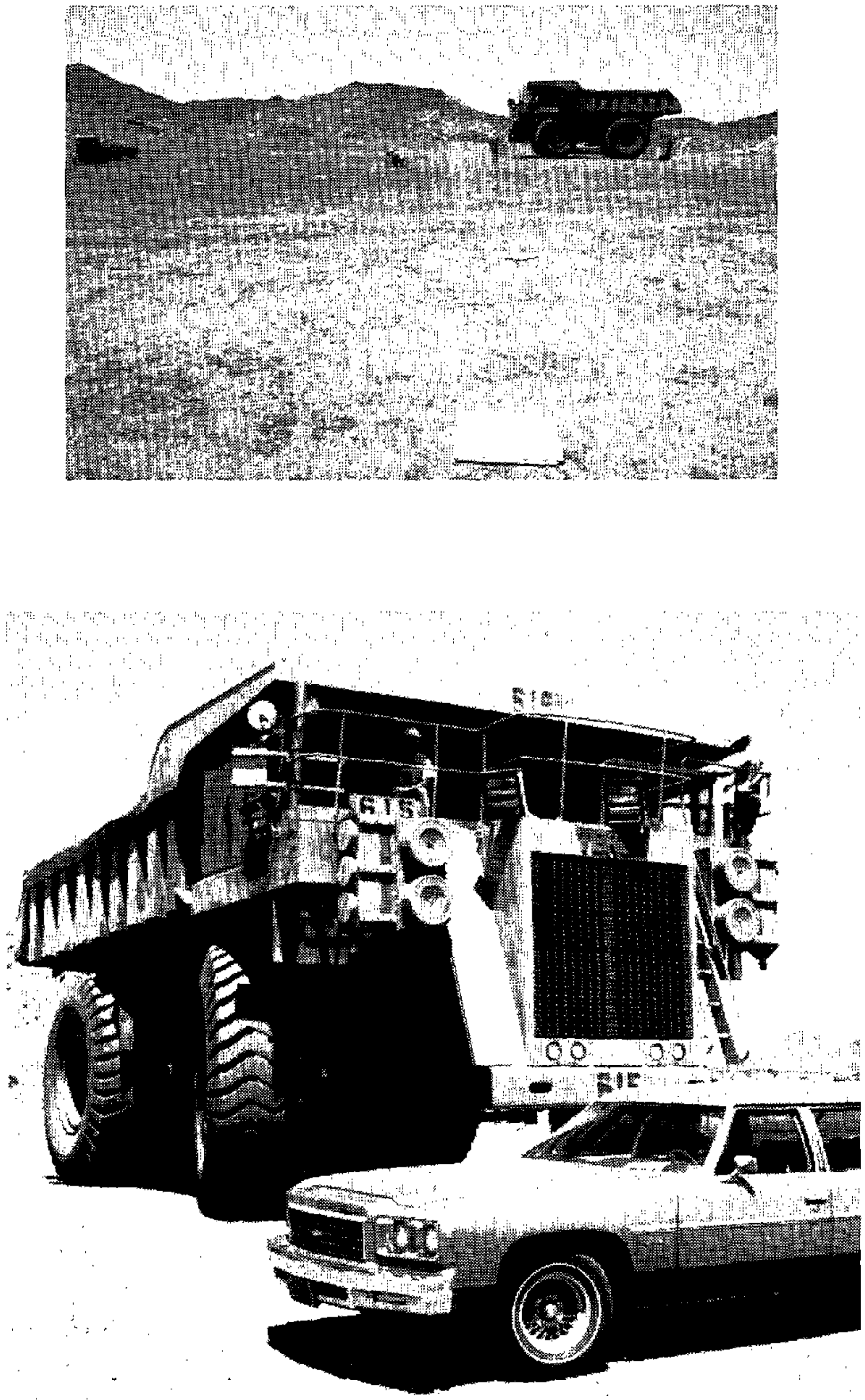

FIGURE 4.0-2
FIELD DEMONSTRATION

5.0 COST SUMMARY

The approach followed in this project was to select and develop concepts which would prove effective and involve utilization costs that would be acceptable to practically oriented mine operators. The cost effectiveness of each visibility aid is based on comparisons of visibility aid costs and the benefits of improved visibility for mining operations. Initial costs, extended utilization costs and potential benefits are discussed in subsequent sections.

5.1 INITIAL COSTS. The component costs, fabrication time, assembly time and installation time for the visibility aids is shown in Figure 5.1-1. These cost estimates are bsased on reproduction of the original prototypes in quantites of 10 to 100 units. Future prototypes will be less costly due to more emphasis on fabrication efficiency. A range of costs was included to account for quantity price discounts, component options and price variations. The initial costs of the mirror systems and the blind area viewer are within the range of costs presently expended by mine operators for existing mirrors (with brackets and mounting structure). At the present time, the CCTV system has a relatively high cost which may be acceptable only for the largest haulage trucks, however, the cost of the CCTV camera will drop considerably as this technology develops. Even at the present cost level and considering 100 ton trucks, the loss of one such truck over the edge of a dump site is 100 times the cost of a CCTV system.

5.2 EXTENDED UTILIZATION COSTS. The maintenance costs of the visibility system should be less than other less effective systems. The mirror systems and the blind area viewers are designed to provide a considerably longer service life than existing mirror systems. Long term testing can prove it will survive two to ten times longer. The initial costs shown in Figure 5.1-1 show the cost of replacing optical elements of the mirrors and blind area viewers. The CCTV system is designed to be maintenance free. Components were selected for dependability and ruggedized where applicable. The service life of the CCTV system should exceed mine operator expectations.

5.3 BENEFITS. The most tangible benefit of the improved visibility system is a considerable increase in the visual fields of view which greatly increases the visual detection capability of the driver. The driver is provided a means of greater visual awareness and the view provided is oriented for best possible interpretation and habitual utilization. This visual awareness will reduce injury accidents, fatalities, and property damage. With improved visibility there would be a considerable reduction in damage to haulage trucks, tires, vehicles, equipment and structures. The benefits of improved visibility would vary at each individual mine and would be difficult to evaluate quantitatively. In long term testing or utilization, the frequency of accidents would be reduced and maintenance and repair costs would be lower but difficult to document. An example of an intangible benefit would be a reduction in driver fatigue due to less stress. With visual certainty and a convenient view orientation, a driver would be more confident and experience fewer near misses. With his first-hand knowledge of the mine's losses and safety problems, each mine operator can best assess the potential value of an improved visibility system. Long term testing of improved visibility aids is needed to provide historical data to help determine the benefits in a quantifiable way.

5.4 MIRROR SYSTEMS. The initial costs of an improved mirror system is most similar to the costs of existing mirror systems, however, the maintenance costs would be lower and the effectiveness is much greater. The cost effectiveness is definitely greater than for existing mirrors.

SUMMARY OF INITIAL COSTS

	Optical Elements Cost	Components Parts Cost	Misc. Materials Cost	Total Material Cost	Fabrication Man Hours	Assembly Man Hours	Installation Man Hours	Total Man Hours
Left Mirror		$20	$20	$55 - 65	7 Hr.	.2 Hr.	2 Hr.	9.2 Hr.
Flat Mirror	$10 - 20							
Convex Mirror	$5							
Right Mirror		$10	$20	$60 - 75	6 Hr.	1 Hr.	3 Hr.	10 Hr.
Convex Mirror	$30 - 45							
Blind Area Viewer		$5	$20	$90 - 115	6 Hr.	1 Hr.	2 Hr.	9 Hr.
Fresnel Element	$45 - 60							
Glass	$20 - 30							
CCTV System			$50	$3160 - 3740	14 Hr.	10 Hr.	16 Hr.	40 Hr.
CCD Camera	$2000							
Lens	$200 - 500							
Monitor	$300							
Lens Cleaning System		100 - 150						
• Electrical Hardware		40 - 60						
Power Supply		50 - 100						

FIGURE 5.1-1
SUMMARY OF ESTIMATED COSTS FOR VISIBILITY AIDS

5.5 BLIND AREA VIEWER. The initial costs of a Blind Area Viewer system are slightly higher than an existing mirror system, however, the view provided has no comparison in existing systems. The cost of a blind area viewer can easily be justified by the visual coverage provided in a blind area that has a history of high accident frequency. The viewer is a non-powered, very low maintenance device. The cost effectiveness of the Blind Area Viewer is definitely sufficient to warrant its use.

5.6 CCTV SYSTEM. The cost of the CCTV system is high compared to non-powered devices. Yet, when compared to the cost of a haulage truck, the relative cost is very low. The CCTV system was developed for haulage trucks larger than 170 tons to prevent direct rear backing collisions and to prevent backing through dump berms with the right wheels. The CCTV system will be cost effective in mines where the truck loss from berm backing accidents is a safety problem. The initial cost of the CCTV system (as demonstrated) is expected to drop considerably in the future; and lower cost component options can reduce the initial cost in certain mine environments. The initial and long term utilization cost of the CCTV system is equivalent or less than the cost of certain drive-train, steering and braking safety devices.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION. The improved visibility system represents a significant improvement over existing visibility aids. It greatly increases visibility of the driver and adds a degree of safety certainty not present with existing systems. The visibility system makes it possible to observe those areas around the truck that were identified as being a significant factor in accidents resulting in fatalities, lost time accidents and property damage. Each visibility aid was developed according to specifications identified by an analysis of the problem. Bench tests and field demonstrations showed that these visibility aids were capable of providing the necessary visual-optical characteristics. The short term demonstrations showed that these visibility aids were capable of providing the necessary visual-optical characteristics. The short term demonstration showed favorable results as to driver usage, maintainability and reliability. To further prove the driver acceptance, reliability/maintainability and safety potential, long term testing is required. The testing and demonstration of the initial prototypes has also identified possible design improvements for improved fabrication, installation and utilization. With long term testing and design improvements, these visibility aids can be proven effective and suitable to the mine environment with a high probability of extensive surface mine utilization and acceptance.

6.2 LEFT MIRROR SYSTEM. The left mirror system provides the driver with both a wide angle view and a plane mirror view that includes all the visual orientation cues that are needed for backing maneuvers. It is optimally sized for its application. In addition it is designed for quick replacement of the mirror. It is recommended that the design be modified only to facilitate manufacturing efficiency and installation adaptability, as required. The optical capabilities and maintenance features should be retained with the exception of further optimization of the convex mirror add-on. For night use of this mirror, illumination of the area behind and to the left of the rear tires is needed for backing situations.

6.3 RIGHT MIRROR SYSTEM. The right mirror system gives a reliable, optimally-shaped view of the right rear side of the truck. Once installed, it does not need to be adjusted. Its field of view is more than a 100 percent improvement over existing mirrors, is less vulnerable to rock spills, and compact enough to avoid tight clearance damage. Therefore, the mirror's size and shape is in an optimum range. Its dimensions and radius can be increased up to 25 percent for larger trucks; however, fabrication capability for these larger sizes was not available and a larger mirror on the demonstration truck would have been more vulnerable to damage. It is recommended that the mirror mounting assembly, enclosure, and mounting structure, be redesigned based on the experience of the demonstration truck for greater installation and fabrication efficiency. Although the present mounting brackets have a tendency to swing away on impact with structures, this feature can be improved by specifically including this "swing away" feature.

6.4 BLIND AREA VIEWER. The blind area viewer provides a normally-oriented view of the blind areas to within five feet of the truck with a 60-degree field of view. This view capability is unique and provides a safety capability to an area of high accident frequency. The blind area viewer is particularly effective in detecting high contrast objects such as helmets, painted vehicles, and lights. For low contrast objects, the blind area viewer is sensitive to lighting conditions. For the blind area viewer to be effective in all lighting conditions, improved shielding from glare and stray light is needed. Added illuminations may be required at night. It is recommended that the enclosure be improved to increase light shielding and to facilitate fabrication, installation, and maintenance efficiency. The fresnel unit with its glass protectors has optical properties considered the most effective available, and further improvements are now known to be possible at this time.

During the short term demonstration, evaluation of driver usage was very favorable, however view interpretation requires an adjustment period. Determining driver acceptance and maintainability would require long term testing.

6.5 CCTV SYSTEM. The CCTV system is a cost effective, dependable method of direct rear vision for haulage trucks larger than 170 tons. In the field demonstration the low light capability, antiblooming and lens washing system were proven effective for providing a clear view in all environmental conditions. The system had no heat problems in 110 degrees ambient temperatures. The CCTV system has been demonstrated to provide an effective view of a blind area that has a history of high accident frequency. The short term demonstration has shown a need for improvements, particularly regarding installation and fabrication efficiency. The system can be simplified and both a warm climate and cold climate model can be developed with a standard enclosure. The size of the camera unit needs to be reduced for more adaptability to locations on the rear of the truck. It is recommended that the CCTV system be improved in a number of features prior to any long term testing. These improvements would include enclosure modifications power supply simplification, a wider field lens, relocation of the wash reservoir, and simplified cable connections. Long term testing is required to prove the effectiveness of this system.

APPENDIX A

DISCUSSION OF COST VS BENEFITS

The concepts of "cost-benefit" and "cost-effectiveness" have come into increasing usage in recent years in an effort to justify (or attack) an existing or proposed safety program. As O'Neill and Kelley(1) point out in their informative paper, both of these concepts are often misunderstood and misused.

There is much room for discussion as to what is the appropriate criterion of statistical significance to apply in interpreting the results of such a program as visibility aids. In attempting to plan for a "before vs after" type of evaluation of accident occurrences, there is no pre-established significance level that automatically can be used. It is most appropriate that a study present the essential raw data as well as the level of statistical significance that was found. Then, arguments can be made in support of the particular acceptance level the authors choose to use. Some authors of scientific papers don't choose any level, but instead merely report the results and let the reader reach his own conclusions regarding the risks and trade-offs associated with accepting or rejecting the null hypothesis.

This is sometimes difficult to do, because one can only attempt to consider all the consequences and then decide whether or not there is enough likelihood for a real difference to have occurred to warrant making a decision. For example, the reader must decide whether a 5% or a 10% or a 20% chance of being wrong is worth the risk. However, there are two ways of being wrong, namely falsely accepting as being real a difference in accident experience that is actually only apparent, but not real. (This type of error is called "Type I"); and the risk of falsely rejecting a real difference ("Type II" error).

This hard fact of life for researchers is rather cumbersome. It is more clearly stated by the following diagram to show the various decision alternatives and possible errors in assessing the effectiveness of a visibility aid.

		True State of Affairs	
		The Aid is Effective	The Aid is Not Effective
Researcher's Decision	The Aid is Effective	Correct	False Alarm Type I error
	The aid is Not Effective	Miss Type II error	Correct

Usually it is not feasible to protect against both kinds of errors simultaneously. The decision-maker must, therefore, decide which kind of error would be the most severe and obtain greater protection against that particular kind of error. As related to the question of visibility aids, a Type I (false alarm) error would be to conclude that the aids are effective when they really are not. A Type II (miss) error would be to decide that the aids are not effective when they really are. Which ever error would hurt the most, that is the error for which one should make the greatest attempt to avoid.

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(1) O'Neill, B. and Kelley, A. B., "Costs, Benefits, Effectiveness and Safety: Setting the Record Straight, "Society of Automotive Engineers Reprint No. 740988, 1974

A related and very important point is that the researcher actually never has the option of saying "There was no difference." He can only state, "I found no evidence of a difference." There is a great and important difference between these two statements. For example, if one chooses to be 95% confident that he is not falsely accepting a "no difference" result (Type I), he might well be taking a very high (80 - 90%) risk of rejecting a real difference that would be of benefit (Type II, due to the small change in accident experience necessary to show a real benefit when an individual accident can cost several hundred thousand dollars.

This again brings us to a consideration of the appropriateness of the cost-benefit approach in evaluating visibility aids. In an excelelnt paper recently published on the topic, O'Neill and Kelley[(1)] agree with several other researchers who state that where the saving of lives and injuries is concerned, there is no adequate way to express "benefits" in dollars. Since comparable unit designation is a prime requirement for conducting a cost-benefit analysis, such analysis may not be valid. Actually, O'Neill and Kelley argue that it is not even necessary to perform a cost-benefit analysis, because it is more appropriate to perform a COST-EFFECTIVENESS evaluation, wherein the criteria do not have to be stated in terms of dollars. This argument is stated by O'Neill and Kelley as follows:

> "Cost-effectiveness analysis compares the cost of alternative means for effectively achieving an agreed upon goal. The means may be programs, technologies, devices, or combinations of approaches. The goals are often expressed in public policy as laws and standards.
>
> Much of the philosophy and methodology of cost-effectiveness analysis was derived from cost-benefit analyses. As a result, there are many similarities in the techniques and many people confuse the two." (pp. 3-4)

The authors go on to point out that in order to perform a valid comparison between two (or more) alternate means for attaining a goal (i.e., accident reduction), the capability of measuring the cost and effectiveness of each alternative must exist. However, while in the cost-benefit approach, both costs and benefits must be measured and compared in monetary units, the cost-effectiveness method requires that the systems being compared have common goals or purposes, which do not have to be expressed in monetary units.

In the case of visibility aids, their costs would be the basis for estimating how many accidents would have to be prevented by other alternative uses of the same amount of money. Apparently this type of evaluation has not yet been attempted for visibility aids and, indeed, O'Neill and Kelley condlue that it is not being used very much in general in high safety.

Since most, if not all, of the alternative methods for expending mine safety funds also cannot show "proof" of the number of accidents they would prevent, a cost-effectiveness evaluation of visibility aids cannot properly be accomplished, and it is possible that a decision to use them could therefore be based solely on the of the amount of increased visibility and consequent human factors advantages.

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(1) op cit

In any event, writers on the topic of cost-benefit analysis are in agreement that this analysis must take into account all of the costs, all of the benefits and all of the alternatives. For example, Pagano and Sauerlender,[2] in their most thorough discourse state:

> "Probably the most conceptually difficult aspect of benefit-cost analysis is the measure of the benefits of each alternative project or system. When the terminology "cost-effectiveness" is used, the measure is referred to as a measure of effectiveness. The analyst would have a comparatively easy task if all the benefits were known and could be quantified. This is not the usual case. Most benefits are subject to a great deal of uncertainty, and the analyst may not be able to estimate even the likelihood that a benefit may be at any given level. Some benefits and costs are not even subject to quantification. How does the analyst measure the increased security and well-being of society? He cannot even measure, let alone place a value on these benefits." (p. 160)

Even assuming that it were possible to list all of the benefits to be derived from the use of visibility aids, it would still be very difficult to perform a comprehensive cost-benefit analysis. We could never be sure that our information on the benefits was as accurate and complete as that on the costs, and it is highly unlikely that we would be able to apply a uniform quantification system to all the factors involved.

Pagano and Sauerlender cite opinions by many other authors, and the consensus seems to be that because of its limitations, benefit-cost analysis should be only one of the tools used by the decision-maker in determining the best course of action. If it is properly done, it can be the best tool the decision-maker has at his disposal; but it should seldom, if ever, be the sole basis for a decision.

When the listing of benefits is incomplete, as in the analyses performed in this study where we have concentrated largely on accident reduction, the results of the analysis are even less to be trusted. The analyses that have been conducted in this fashion are victims of the "sole criterion fallacy," described by Pagano and Sauerlender, which states that it is a fallacy to assume that a single criterion, such as accident reduction, can be used to evaluate all alternative safety programs. This is because of differences in complexity and other aspects among the various programs.

An additional problem that arises when using accident reduction in benefit-cost analysis is that it is very difficult to determine dollar costs for fatalities. O'Neill and Kelley[1] say it can't be done and recommend a cost-effectiveness approach to get away from the need to quantify benefits in monetary terms. The present authors agree, for it would make possible inclusion in the analysis such factors as driver comfort or stress, increased alertness, more efficient maneuvering, etc.

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(2) Pagano, A. M. andSauerlender, O. H., "Benefit-Cost Analysis", Appendix E in Roadway Delineation Systems, Washington, D.C.: Highway Research Board, National Cooperative Highway Research Program Report 130, 1972

(1) op cit

It is likely that one benefit of visibility aids would be a reduction in driver stress (increase in driver comfort) due to the increased visibility and resultant decrease in uncertainty. Pagano and Sauerlender[2] also discuss this under the heading of "Strain and Discomfort of Nonuniform Driving," and go on to say that such strain and discomfort is a road user cost that can be reduced through highway improvement. The present authors feel this cost could also be reduced by vehicle improvement, such as improved headlights, taillights and passive aids to vehicle visibility such as reflectorization and improved reflex reflectors (larger and less directional). Pagano and Sauerlender quote the following from an AASHO report:

> "There is value in the convenience of being able to go to one's destination without interference. There is a comfort value, over and above the saving in vehicle operating cost, in being able to drive without frequent brake applications, stops and starts, or unexpected interferences to travel. There is value in the conservation of health through driving in a relaxed manner without the tension necessary where roadside interference is imminent."

and they go on to say that:

> "There are two problems involved in the evaluation of the strain and discomfort factor. One is the enumeration of the factors that affect strain and discomfort; the second, the placing of some dollar value on this cost." (p. 184)

Again, however, it should be stressed that inability to quantify certain benefits and/or costs should not automatically be used by the decision-maker as an excuse for excluding them from consideration. There is too much at stake.

One further point bears discussion before leaving the general topic of cost-benefit or cost-effectiveness analysis, and this has to do with the use of accident records to derive accident reduction estimates.

As the reports by Arthur D. Little, Inc.[3] and T. W. Forbes[4] point out, there are a number of methodological difficulties involved in any attempt to use accident records to prove or disprove a traffic safety benefit. Particularly is this true when one is dealing with the prevention of crashes, rather than the reduction of injuries or fatalities. Any accident records approach is fraught with problems that arise in the accident reporting process, in which a relatively small amount of information normally is reported about the accident circumstances. Particularly meager is information describing the driver's capabilities and the nature of the roadway and environment leading up to and surrounding the crash location.

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(2) op cit

(3) "The State of the Art of Traffic Safety," Cambridge, Mass.: Arthur D. Little, Inc., June 1966.

(4) Forbes, T. W., "General Approach and Methods," Chapter 2 in Human Factors in Highway Traffic Safety Research (T. W. Forbes, Ed.), New York, N.Y.: Wiley-Interscience, 1972.

There are many combinations of accident-producing circumstances. Any attempt to prove a safety benefit must take account of these many circumstances in the research plan, and the researcher can deal with this in two ways:

1) Select for study only those accidents that are matched on all variables except for the one(s) under study, or

2) Study a random selection of accidents from among two or more groups of drivers that differ only in the experimental variables.

Neither of these methods is easy to accomplish, since they require large sample sizes plus detailed information on accidents and/or drivers. It is for these reasons that studies often employ the "before-after" approach. As pointed out earlier, however, the difficulty with this approach is that one must be preapred to deal with any and all of the many other changes that may occur during the periods under study.

Selection of the two populations of drivers to be studied is critical when the simultaneous approach is used, and selection of the type of accidents to be studied is also critical. As stated earlier, there are so many factors known to relate to accident causation that a matched sample approach will require study of hundreds of accidents to produce meaningful results to be able to study daytime collisions with parked vehicles. This is the type of accident in which visibility aids would be expected to be of most value to an approaching driver in detecting a vehicle. However, a large number of total accidents is necessary in order to provide a sufficient number of this type of accident for adequate statistical analysis, and while this approach would isolate a single, accident-related circumstance, there are many more.

Regardlless of this issue, however, when it is not possible to isolate satisfactorily a particular set of accident circumstances and the study must compare groups of drivers or vehicles, it is definitely not appropriate to concentrate on a few types or accidents solely for drawing conclusions. All accidents incurred by both groups must be looked at collectively, as well as in their separate categories, in an effort to ascertain whether the two groups of drivers (or vehicles) are truly comparable in all aspects except visibility aids.

The following list presents some of the factors that should be considered in any study of the effectiveness of visibility aids in terms of accident occurrences:

1. Exposure to risk - -

The groups of drivers to be studied should be matched, to the extent possible, as to the mine layout and type of driving rules that are in force.

2. Driver age and driving experience - -

The groups should be matched at least in coarse groupings that differentiate on these variables.

3. The "novelty effect" - -

It is desirable to allow at least one year to elapse after introduction of visibility aids to allow for the novelty effect to wear off before collecting "after" data, and also to permit any "learning effect" that might occur to take place. That is, "after" measurements should be made only when the new relationship has stabilized.

4. Driver vision - -

Because of the wide range of visual abilities found in the driving population, and the demonstrated relationship between vision and accidents, as much information on visual performance (particularly night vision) of the drivers as possible should be obtained.

APPENDIX B

PHASE IV REPORT

The prototype visibility system was installed and demonstrated on a 150-ton haulage truck at Eagle Mountain Mine. The visibility system was demonstrated in actual production use and at an isolated static demonstration site. The demonstration was attended by the USBM technical project officer and was documented with still photography, 35mm color slides and 16mm color motion photography. The visibility system was shown to conform to the specification detailed in the Phase II report and the Final Report except for the CCTV camera lens. This lens was a standard low cost type and will be replaced with a wide angle lens on future prototypes. The details of the field demonstration and mock-up demonstrations is included in Chapter 4. The visibility systems are described and evaluated in Chapters 3, 5 and 6.

The field demonstration was accomplished on 26 July 1977 and mock-up demonstrations occurred on 6 July 1977 and 25 August 1977. As a result of these demonstrations, design improvement needs were identified and long term testing in actual mine use was proposed for the evaluation of long term utilization factors.