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VISUAL ATTENTION LOCATIONS FOR OPERATING CONTINUOUS MINERS, SHUTTLE CARS, AND SCOOPS

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Canyon Research Group, Inc.

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The primary purpose of this investigation was to determine the visibility requirements for shuttle car and continuous miner operators. Scoops were considered, insofar as they fulfill functions in the mine similar to those carried out by shuttle cars (that is, loading, transporting, and unloading of coal). A second objective was to evaluate the actual field of visibility for a sample machine to develop a simple procedure for visibility evaluation of mobile equipment. A procedure was developed for assessing whether operators in existing machines could be expected to see the visual attention locations. The procedure makes use of a human eye reference measurement instrument (HERMI) designed for this project and an outside-in photographic procedure for documenting compliance with the recommendations. Samples of continuous miners, shuttle cars, and scoops were used to test the procedure and the results are presented.

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FOREWORD

This report was prepared by Canyon Research Group, Inc., Westlake Village, California under USBM Contract number J0387213. The contract was initiated under the Coal Health and Safety Industrial Type Hazards Program. It was administered under the technical direction of Pittsburgh Research Center with Thomas Bobick acting as Technical Project Officer. Alan G. Bolton, Jr. 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 May 1980 to January 1981. This report was submitted by the authors on 31 January 1981.

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1.0 INTRODUCTION

1.1 Purpose

This research was carried out under Contract J0387213 awarded to Canyon Research Group by the Bureau of Mines, Pittsburgh Research Center, Bruceton, PA. The primary purpose of this effort was to determine the visibility requirements for shuttle car and continuous miner operators. Scoops were considered, in so far as they fulfill functions in the mine similar to those carried out by shuttle cars (i.e., loading, transporting, and unloading of coal). A secondary objective was to evaluate the actual field of visibility for a sample of machines. The purpose of this latter evaluation was to develop a simple procedure for visibility evaluation of mobile equipment.

1.2 Background

The operator station on underground mobile face equipment is required to be protected by an overhead canopy. Machines operated in very low seams, however, have been exempted from this requirement. One reason for this exemption was that canopies, in low seams, restrict the field of vision of the operator. In the future, it is likely that the exempted seam height will be lowered as new equipment and canopy configurations are developed for such restrictive environments.

A major concern in low seam, as well as high seam, canopy applications is to maximize the visual field of the operator. Visibility is important in terms of both safety and productivity. Each year people are killed, equipment is damaged, cables are cut, and roof supports are knocked down because the operators of mobile equipment cannot see due to large "blind areas" created by the design of the equipment and canopies.

The Mine Safety and Health Administration (MSHA) Approval and Certification Center (Triadelphia, WV) has begun preliminary activities aimed at ultimately publishing human factors guidelines or requirements for the design of various pieces of mobile face equipment. One area which will be addressed in the final product is visibility from the operator's station. It was with this in mind that the Bureau undertook the current investigation. The information collected during this project is a first step toward describing minimum visibility recommendations or requirements for shuttle cars and continuous miners.

1.3 Equipment Configurations

Continuous miners, shuttle cars, and especially scoops come in a variety of sizes and configurations. These parameters have a direct bearing on the establishment of visibility requirements which will be discussed further in Section 2.5 ("Visibility

Requirements"). The following pages summarize the diversity of equipment configurations being marketed today for use in underground coal mines.

Continuous Miners (CMs). CMs can be categorized according to operational seam height or extraction method. The most widely used classification scheme is based on extraction method. Various sources and manufacturers use different names for types of extraction methods, thus, the designation used here is not universal, but is comprehensive. CMs are of one of four general types (see Figure 1-1):

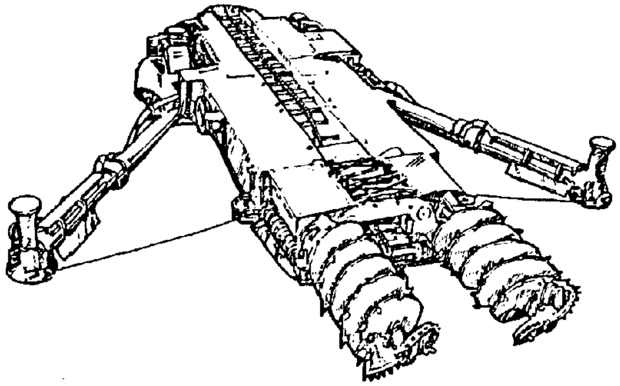
1. Auger. These are generally used in low seam operations. Examples include the Fairchild Mark 21 and 22 models. The machines are track mounted or cable drawn. Typically they are equipped with dual rotating augers with cutter bits located around the periphery of a helix on each auger.

2. Boom head. Boom head miners are more common in Europe than in the United States. European examples include: Dosco Roadheader 2400, MK2A, LH100 and the twin boom TB600; and the Anderson Strathclyde Boom Miner. In the United States, only AEC, Inc. manufactures boom miners including their Models 125, 200, 250, and 330. Typically a boom miner consists of a long arm with a "ball" of cutting bits mounted on the end. The cutting head either spins perpendicular to the boom arm, or parallel with it.

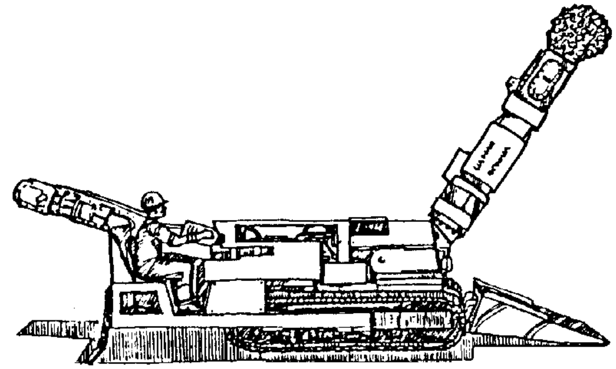
3. Cutting chain head. This is not a popular type of continuous miner in the United States. An example is the Dosco NCB Dinthreading machine. Typically, this type of machine consists of a frame, around which is a series of chains with cutting bits positioned along them.

4. Drum-head. This is, far and away, the most popular type of continuous miner in the United States today. Examples include: Jeffrey 1028, 120H, 120L, 122M, 101MC; Joy 12CM, 14CM, 15CM; Lee Norse LN800, CM245, HH546, 386, and265, HH106LP; and Marietta 2460, 3080, 5012. Typically, these machines consist of a roller (or drum) the width of the machine, mounted on a vertically adjustable boom. The cutter bits are usually arranged in a helix pattern around the drum. In some cases (e.g., Jeffrey 122M), the drum may also include several sets of cutter chains, but typically this only accounts for approximately 25 percent of the total cutting width.

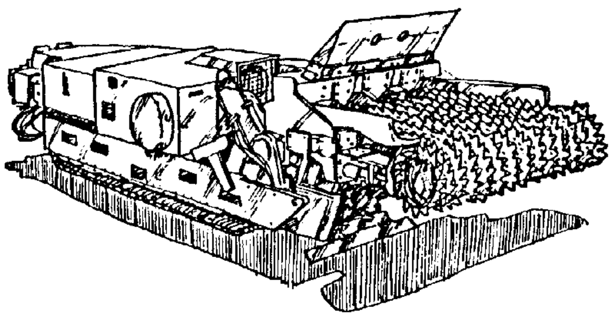
All four types of continuous miners have a gathering head (disc or mechanical arm and conveyor) under the cutting member of the machine. This provides for continuous loading of coal. Most of the CMs, especially the drum-head type, have a conveyor tail



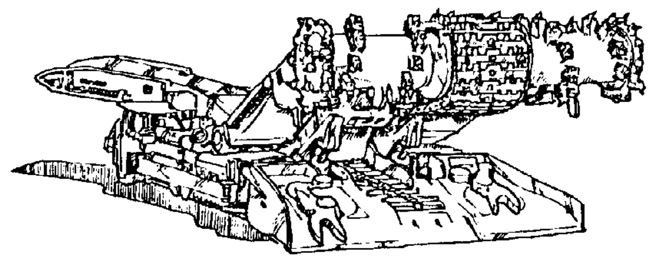
Auger



Boom Head



Cutting Chain



Drum Head

Figure 1-1. Sketches of generic types of continuous miners.

boom that is adjustable up and down, and side to side. In virtually all cases, the operator station is located on the right side of the machine at the rear. Some machines are equipped with remote controls which allow the operator to control the machine from a distance (in some cases up to 100 feet line-of-sight). This report does not address remote control operation of CMs. Generally speaking, visibility is greatly enhanced through the use of remote controls and thus usually is not a problem.

Various optional design features impact on the establishment of visibility requirements by changing the distance or location of critical visual features relative to the operator, or by changing the position of the operator. Some of these features include:

1. Rear boom swing arc: 45° to 60°.

2. Overall height of the machine: from approximately 2 feet to over 6 feet (.61 to 1.83 meters).

3. Width of the machine: from 8 feet to over 12 feet (2.4 to 3.6 meters).

4. Width of cutting head: from about 8 feet to over 15 feet for drum-head types (2.4 to 4.6 meters).

5. Length of machine: generally from 31 to 35 feet for drum-head types (9.4 to 10.7 meters).

6. "Floating cabs": which can raise or lower the operator cab, and hence the operator.

7. Built-in roof bolter and dust control systems.

8. Operator seat configuration: from sitting upright to near reclining postures.

9. Canopy design: height, position of supporting members.

10. Lights and meters: position can obstruct vision.

Shuttle Cars (SCs). Shuttle cars are used to transport coal from the face to a dump site from which it is carried out of the mine via belt or track haulage. Shuttle cars are distinguished from other haulage vehicles by (1) the presence of a conveyor which runs the length of the machine and (2) being open on both ends. The conveyor moves the load to the end of the machine when loading and off the machine when unloading. Shuttle cars are typically powered from cables and are mounted on rubber tires. Manufacturers of shuttle cars include Joy, Jeffrey, FMC, and National Mine Service.

The operator position can be located on either side of the machine. In fact, on a typical working section, two shuttle cars service one continuous miner. One SC of the pair has the operator's compartment on the same side as the continuous miner operator's compartment (the "standard" configuration). The other SC of the pair has the compartment on the opposite side (the "non-standard" configuration). SC operator compartments are always on the side of the machine; however, two distinct locations are used. The first, positions the operator in the middle, between the wheels of the car (i.e., center driven). The second, positions the operator at one end of the car, behind the wheels (i.e., end driven). Figure 1-2 illustrates these two types.

Shuttle cars are not driven backwards. The operator changes position inside the compartment so as always to face the direction of movement. SCs go back and forth, but effectively never turn around. In the case of the center driven machine, the distance from the operator to the front of the machine stays approximately the same no matter which direction the SC is moving. On the other hand, in the case of the end driven machine, the operator is at the front of the machine traveling in one direction, but at the rear of the machine traveling in the opposite direction. This tends to complicate the specification of adequate visibility requirements.

In addition to operator position, there are other design options which impact on visibility, including:

1. Overall height of the machine: from approximately 24 inches to over 50 inches (71.1 to 127cm).

2. Width of the machine: from approximately 8 feet to over 10 feet (2.4 to 3.0 meters).

3. Length of the machine: from approximately 24 feet to 27 feet (7.3 to 8.2 meters).

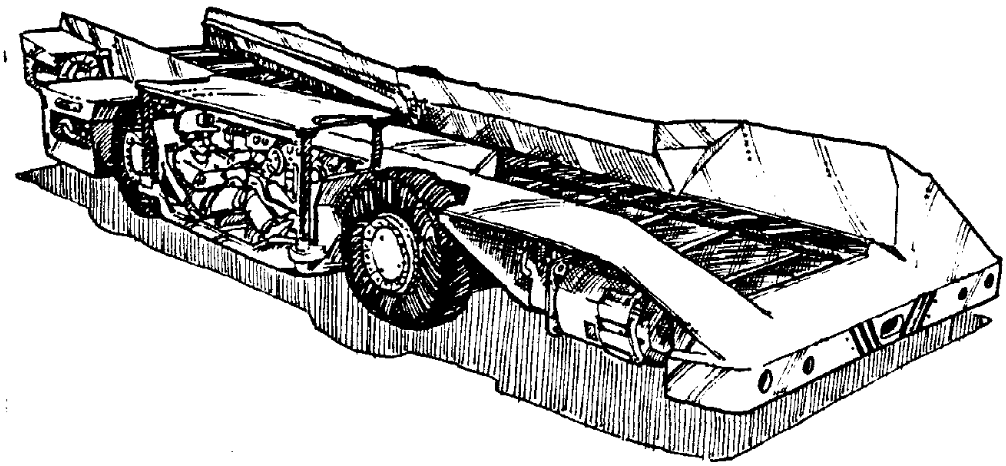
4. Canopy design: height, position of supporting members.

5. Side boards: present and absent.

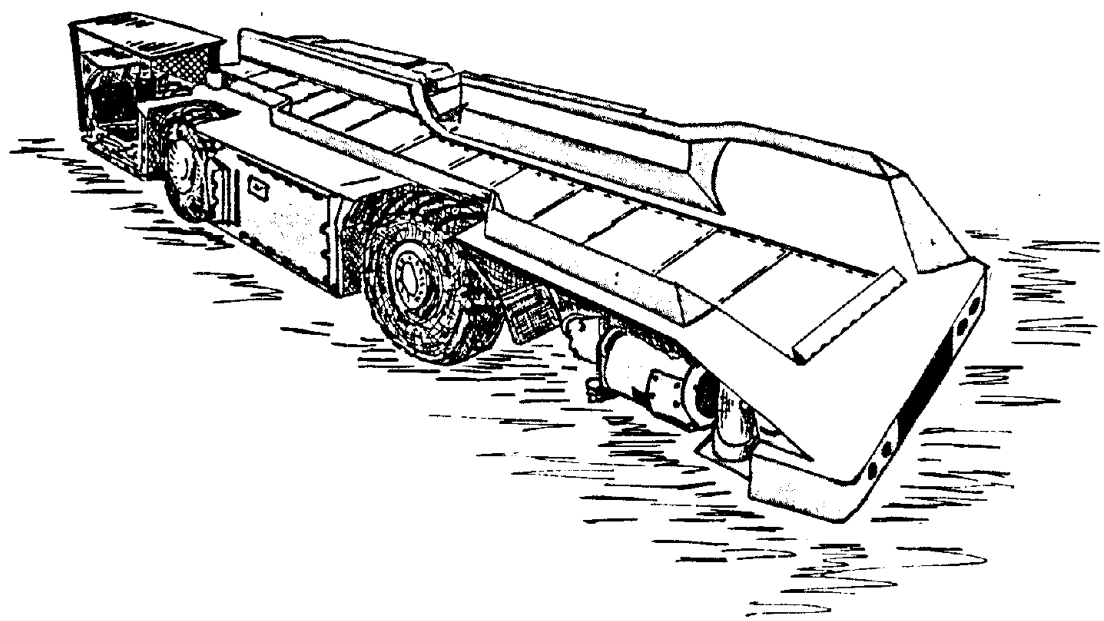
6. Lights and meters: position can obstruct vision.

Scoops. Whereas shuttle cars are a readily distinguishable equipment type, scoops are not. They are more variable in design and blend readily into other haulage equipment types, such as L-H-D equipment and tractor-trailer haulage vehicles. This project focused on scoops, as coal haulage vehicles, distinct from L-H-D and tractor-trailer vehicles. To be considered a scoop for the purposes of this report, the vehicle must possess the following characteristics:

1. Loading of the bucket is accomplished by charging the coal pile and "scooping-up" the coal. This eliminates most tractor-trailer haulage vehicles because they are passively loaded.



Center Driven



End Driven

Figure 1-2. Two common types of shuttle cars in which the operator is positioned in the middle between the wheels or at the end.

2. The bucket is unloaded by activating a ram device to push the coal out of the bucket. This eliminates most L-H-D devices because they unload by lifting the load high into the air and "dumping" it.

3. The entire bucket can not be raised above the frame of the machine. The front end can be tipped but the back end of the bucket can not be significantly raised.

A typical scoop is pictured in Figure 1-3. Most scoops are battery operated, with rubber tires, and articulated frames. Manufacturers of scoops include: Eimco-Elkhorn, FMC, Kersey, S&H Manufacturing, S&S Corporation, and West Virginia Armature. Scoops are typically used in low seam operations.

The position of the operator on scoops is more variable across both manufacturers and models than is found with continuous miners or shuttle cars. Figure 1-4 illustrates, schematically, four operator positions commonly found on scoops today. The arrow in the operator's compartment indicates the orientation of the operator's body. Depending on the seam height, the operator may be sitting upright or lying flat on the floor looking along the side of the machine.

1.4 Organization of Report

This report is divided into two main chapters: "Determining Visibility Requirements," and "Assessment of Visibility." Section 2.0 describes the methodology used to determine visibility requirements and presents the results at each step of the process. Various approaches to specifying visibility requirements are discussed. One approach is selected and recommended requirements specified.

Section 3.0 describes the methodology and apparatus used to record the fields of visibility from a sample of machines. These fields are then compared to the visibility requirements set forth in Section 2.0 and evaluated.

Section 4.0 discusses future research and applications for the recommended requirements and visibility assessment methodology.

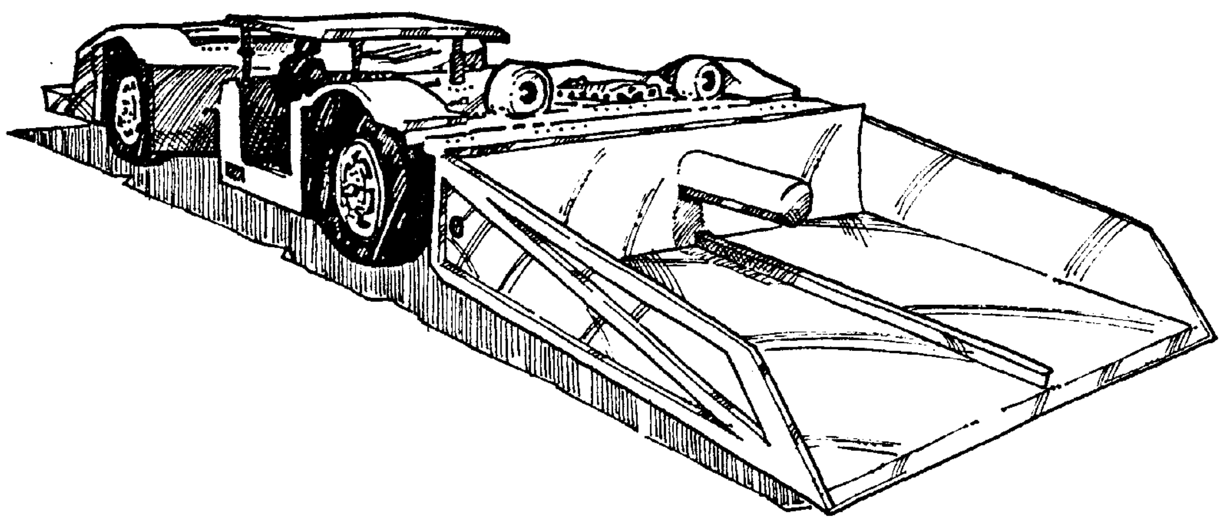


Figure 1-3. Sketch of a typical scoop, as defined for this project.

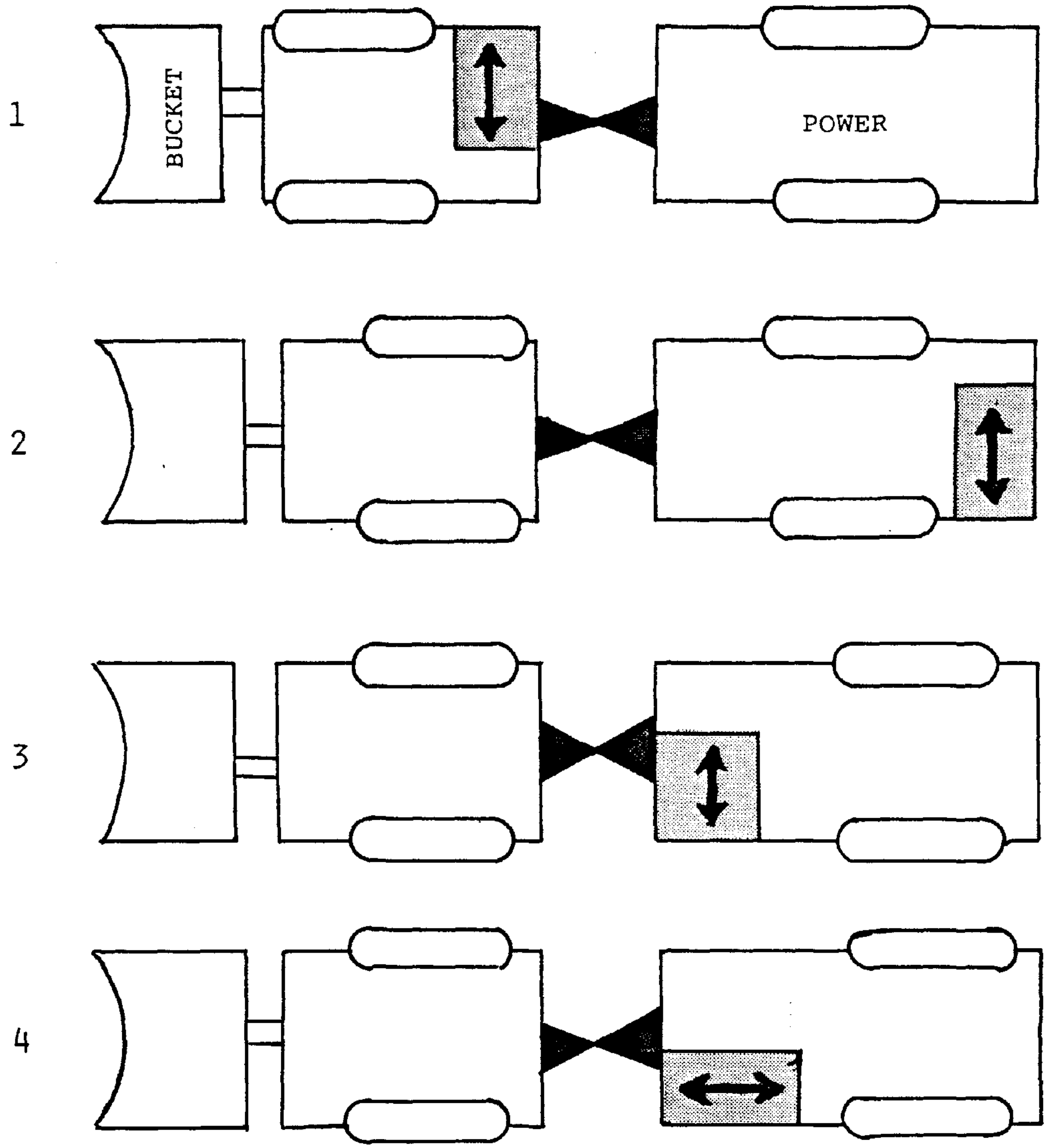


Figure 1-4. Four common operator positions found on various scoops. Arrow indicates orientation of operator inside compartment.

2.0 DETERMINING VISIBILITY REQUIREMENTS

2.1 Approach and Methodology

It is important to distinguish visibility requirements, i.e., what needs to be seen, from fields of visibility, i.e., what can be seen. Determining what operators need to see in order to perform their job efficiently and safely can only be determined by observing operators performing the task and by interviewing them. Fields of visibility, on the other hand, can be assessed objectively and independent of the operator by recording what actually can be seen from the operator's position.

The observation and interview approach was used in this project to determine visibility requirements. A total of twelve (12) mines, seven (7) low seam (under 48 inches seam height) and five (5) high seam (over 48 inches) were visited. More low seam than high seam mines were included because of the greater visibility problems encountered in low seams. At each mine, at least two working sections (each with one continuous miner, two shuttle cars and one scoop) were observed and the operators interviewed. Thus a total of 28 working sections were observed and approximately 100 operators interviewed. Operators were observed operating eight (8) different models of continuous miners, five (5) models of shuttle cars, and six (6) models of scoops. The following manufacturers' equipment were observed:

Continuous Miners:

Lee Norse (26H, 45, 265HH)
National Mine Service (Marietta)
Joy (12CM, 14CM)
Jeffrey (101, 120L)

Shuttle Cars:

Joy (10SC, 12SC, 18SC, 21SC)
Jeffrey (402)

Scoops:

S&S (CX1, CX2, 74, 86, 110)
Eimco-Elkhorn (AR4)
Kelsey (BJD)

Operators with varied degrees of experience were interviewed. No systematic differences in visual requirements were noted between novice and experienced operators.

A problem typically encountered in determining visibility requirements was evident in the operators' responses. When asked what they needed to see, most operators responded in terms of what they could see. The logic being that they do their job effectively and safely and if they can not see a particular feature, therefore, it is not necessary to see it. This problem was somewhat overcome by using a task analytic approach in the interviews.

The task analytic approach is diagrammed in Figure 2-1. The job is divided into tasks, e.g., loading, tramming, unloading. For each task, the operator was asked what information is required to do the job, e.g., position of shuttle car under the tail boom of the continuous miner, location of obstacles in the roadway, position of shuttle car in roadway; information requirements being global in nature. For each information requirement, specific visual features which serve as sources of that information were then identified.

Approaching the identification of visual features through information requirements tends to break the "what-I-can-see-is-required-and-what-I-can't-isn't" set among equipment operators. Observations of operators performing the task were used to verify the information obtained from the interviews. The position of the cap lamp beam permitted the observer to see what the operator was looking at during the performance of the task. Occasionally, visual features not elicited in the interview were discovered through observation. The operator was then questioned about them and their relevance to the task.

The importance of each visual feature was determined by rating the importance of each information requirement in terms of safety and productivity. The location of each visual feature in the visual field was identified. From this information, visibility requirements were specified. Each of these steps will be discussed in the following pages.

2.2 Major Tasks for Shuttle Cars, Scoops and Continuous Miners

The major tasks for shuttle car (SC) and continuous miner (CM) operators, for which visibility from the cab is required, derive from the basic mining cycle and the purpose of each type of machine. The primary purposes of shuttle cars and scoops are to load coal at the face, transport it to a dump site, and unload the coal. The primary purposes of a continuous miner are to extract coal from the working face and load haulage vehicle or continuous conveyor belts. In addition, a continuous miner must tram from location to location within the mine.

For purposes of establishing visibility requirements, it is best to maintain a broad perspective in identifying tasks. The job of specifying visibility requirements increases geometrically with the number of tasks identified, therefore, it is unwise to divide tasks too finely. Further, finely divided tasks make it more difficult to see the whole picture and the interrelationship of the parts. With a small number of major tasks, this perspective can be maintained.

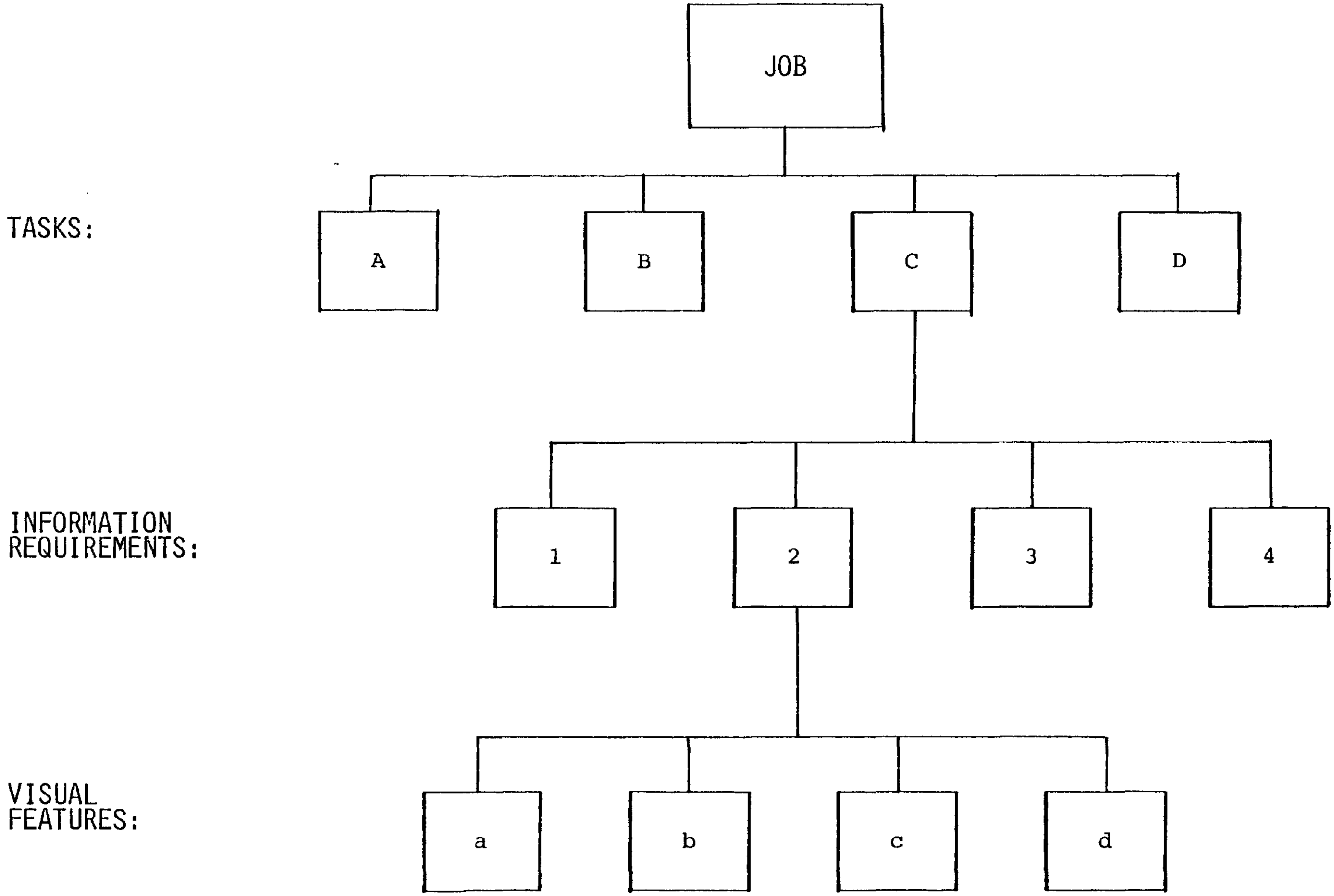


Figure 2-1. Task analytic approach to determining visibility requirements.

The following is a brief description of the major tasks of each class of equipment.

Continuous miners. The job of the continuous miner, at the face, can be conceptualized into three broad tasks: (1) tramming, (2) extracting coal, and (3) loading. Typically, the extraction and loading tasks are done concurrently, but are divided here to facilitate later analysis.

Tramming a continuous miner requires at least one person in addition to the operator. The machine is typically large and difficult to maneuver around corners. Often, the machine must be backed up and moved forward. Restriction is especially severe where brattice curtains have been hung to direct air to the working face. The continuous miner helper assists the operator by serving as an extra pair of eyes guiding the operator's movements. In addition, the helper is responsible for keeping the machine's cables clear of the machine. Tramming can be along a straight section of roadway or around corners.

Extracting coal involves positioning the continuous miner in the section and aligning it to the face. The cutting head or drum is activated and the machine moved forward into the face. With drum-head and chain-head miners, the head is raised and lowered to shear the coal from the face. The operator must limit the up and down excursion of the head depending on the thickness of cut desired.

Loading of coal is usually done simultaneously with extraction. The coal is automatically gathered under the cutting head and delivered by conveyor to a haulage vehicle or continuous conveyor at the rear of the continuous miner. Typically, continuous miners have a "tail boom" which extends from the rear of the machine and delivers coal to the haulage vehicle or conveyor. The continuous miner operator can usually control the lateral swing of the conveyor as well as the vertical height. The operator must position the tail boom over the dump point and control the flow of material (start or stop) to prevent excessive build-up of material at the dump point. Typically, the helper signals the operator to stop the flow when the haulage vehicle is full, or a pile has developed on the conveyor.

Shuttle cars and scoops. Shuttle cars and scoops, performing their job in the working face section, engage in three major tasks: loading, tramming, and dumping. Essentially the tasks are performed the same by shuttle cars and scoops. The major exceptions are in loading (i.e., shuttle cars are "passively" loaded; scoops "actively" loaded) and tramming (i.e., the operator always faces in the direction of travel in a shuttle car; scoops can be effectively operated "backward").

In loading a shuttle car, the driver positions the car under the tail boom to receive the coal. The driver moves the coal pile to the opposite end of the shuttle car by activating the conveyor which runs the length of the car. The purpose is to maximize the load being carried. In loading a scoop, on the other hand, the operator must align the scoop with the coal pile and charge it, digging the scoop blade into the coal pile and "scooping it up."

Tramming involves negotiating both straight concourses and turns. With a cable powered shuttle car, the driver must be careful not to run over his own cable if it fails to be reeled up fast enough. In very low seams, a scoop operator may adjust the height of the scoop blade to avoid contact with the roof.

Unloading of either a shuttle car or scoop involves positioning the machine over the dump site (often a ramp is provided) and discharging the load. In a shuttle car, this is done by activating the conveyor in the car. In a scoop, the material is unloaded by activating a ram-type device in the scoop blade.

2.3 Information Requirements

Information requirements are broad categories of information that the equipment operator needs in order to operate the equipment safely and efficiently. The types of information that are relevant to our purposes are those that relate to the interface between the machine and the mine environment. We are not concerned with the stored knowledge required to operate the equipment such as, the function of the various controls on the machine, the proper hydraulic pressures, or the correct operating procedures. We are concerned with information that changes as a function of time or location within the mine and for which the visual sense is a significant source. This includes such things as the position of the machine, location of obstacles, and the speed of travel.

Table 2-1 lists the information requirements for the major tasks performed by continuous miners, shuttle cars and scoops. Many of the requirements are common to all three classes of equipment, others are unique. A brief discussion of these requirements for each class of equipment follows.

Continuous miners. During tramming, the operator must guide the machine along the roadway and around corners in a safe efficient manner. To do this, the operator first must know the position of the machine relative to the ribs, roof and pillar corners so as not to hit them. The roof can be hit by the cutting head, tail boom, or canopy (especially if the machine is equipped with an hydraulic lift canopy). The extended tail boom makes it necessary for the operator to be aware of ribs and corners after the cab has passed them. Second,the operator must be aware of the location of obstacles orhazards in his path (on the roadway, roof, and ribs). A list of such hazards and obstacles will be presented in the next section of this report. The operator must learn of these obstructions and hazards in sufficient time to take evasive action. Third, in tramming,

TABLE 2-1

Information Requirements for Continuous Miner, Shuttle Car and Scoop Operators

Information Requirements	Continuous Miner	Shuttle Car	Scoop
TRAMMING	0	0	0
1. Position of the machine relative to ribs, roof and corners	X	X	X
2. Location of obstacles and hazards	X	X	X
3. Speed of movement	X	X	X
4. Location of machine within the mine	X	X	X
LOADING	0	0	0
1. Position of tail-boom relative to haulage conveyance	X		
2. Available load space remaining on haulage vehicle	X		X
3. Relative rate of material off the tail-boom	X	X	
4. Position of vehicle relative to continuous miner		X	
5. Position of blade relative to coal pile			X
6. Location of obstacles and hazards	X	X	X
7. Position and height of load on vehicle		X	X
8. Position of vehicle relative to roof supports	X		X

TABLE 2-1 (Continued)

Information Requirements for Continuous Miner, Shuttle Car and Scoop Operators

Information Requirements	Continuous Miner	Shuttle Car	Scoop
DUMPING		0	0
1. Position of vehicle relative to dump site		X	X
2. Position of load on the vehicle		X	X
3. Location of obstacles and hazards		X	X
4. Status of dump site		X	X
EXTRACTION	0		
1. Position of cutting head	X		
2. Alignment of cutting head to working face	X		
3. Location of machine relative to roof supports	X		
4. Location of obstacles and hazards	X		
5. Rate of cutting coal from face	X		
6. Condition of working face	X		

the operator must be aware of the machine's speed of motion. This can be sensed through auditory, tactual (vibration), and/or the visual sense. The exact speed is not important, but rather only the perception of "too fast," or "safe." Of secondary importance is the requirement that the operator know his position in the mine. The operator must know how to go from one place to another in the mine by a safe, efficient route. The operator must recognize (or be told) where to turn and how far to go to get to the desired destination.

The task of extraction requires that the operator know the vertical and lateral position of the cutting head. If the head is raised or lowered further than desired, the integrity of the roof may be impaired, or the bottom may be left uneven. In addition to the position of the cutting head, the operator must know the alignment of the head to the working face. This can be judged from the relationship of the machine to the rib or brattice, but is usually done with the aid of surveyor's marks (or hanging string) on the roof. As extraction progresses, and the machine is moved forward, the operator must know the location of the last row of roof supports so that the cab remains out-by the last row. Roof bolts may be seen directly by the operator, or the helper can signal the operator when he is approaching the last row. Since the machine is against the face during extraction, obstacles and hazards of which the operator must be aware are located principally along side the machine. It is important to know the relative location of the brattice or ribs, the cable and hoses and the helper. Often the helper serves as another set of eyes to alert the operator of impending hazards.

Of somewhat less importance during extraction is knowledge of the condition of the work face. The presence of impurities or an undulating seam can not be seen during the actual extraction. The face may be inspected after the machine is withdrawn from the cut. The operator then would not be on the machine. Impurities can sometimes be sensed by a change in the sound of the cutting head or a change in odor caused by cutting into a layer of waste rock. The rate of cutting coal from the face is similarly indicated by vibratory cues, the rate of flow of materials off the tail conveyor, and auditory cues of the cutting head. Due to the dust and water spray characteristic of continuous miners, it is impossible to actually see the coal being ripped from the face.

Loading requires the operator to direct attention to the tail boom to know its position and the amount and flow of material off it. The operator controls the tail boom to position it over the center of the haulage vehicle. He may move the conveyor laterally to distribute the load inside the haulage vehicle. He needs to know the available load space remaining on the haulage vehicle so as not to over fill it. Often the helper, or shuttle car driver will signal the continuous miner operator when the vehicle is full. Knowing the rate of flow of material off the tail boom helps the operator gauge the cutting efficiency of his machine. During loading, the amount of movement of the machine is minimal, nonetheless, the operator must be aware of the location of obstacles and hazards. These may include the helper, cables, and roof bolts (to avoid contact with tail boom).

Shuttle cars. The information requirements for tramming a shuttle car are essentially the same as those for tramming a continuous miner. In the case of a shuttle car, however, the operator always faces in the direction of travel and thus effectively does not "back up."

In loading, the shuttle car operator must know his position relative to that of the continuous miner, and especially in reference to the continuous miner tail boom. The continuous miner will move forward and back during extraction and loading, thus bumping the shuttle car. This is one source of information which helps the operator maintain his position relative to that of the continuous miner. During loading, the shuttle car operator must be aware of the height and position of the load on his vehicle. By activating the conveyor, the operator moves the load to the rear of the vehicle. If the load is moved too far, it will dump on the ground. If the load is allowed to fill too high, coal can roll off the pile and enter the cab, or be knocked off during tramming by low hanging roof obstructions. One way the operator gauges the filling of his vehicle is by observing the relative rate at which material is coming off the tail boom of the continuous miner. During the actual loading operation, there are relatively few hazards or obstacles that the shuttle car operator will encounter. One potential hazard is the presence of a large coal chunk which could roll off the pile and enter the cab.

During dumping, the operator must know his position relative to the dump site so that he can align his vehicle properly for dumping. Once the vehicle has been aligned, the load is moved off the vehicle. At this point, the operator must be aware of the position of the load on the vehicle so that it can be properly fed into the dump site. The operator, upon approaching the dump site, must be aware of its status. Is the conveyor activated? If not, the load can not be dumped without overflowing the site. In similar fashion, if a conveyor is not part of the dump site, the operator must know if the site is empty so that the load can be accepted. In some mines, a light is lit when the dump site conveyor is activated. In some mines, the operator activates the dump site by pulling a switch. At many dump sites, a tender operator is positioned to do clean-up work and tend the equipment. The shuttle car operator must know the location of such personnel if the shuttle car constitutes a hazard to the person.

Scoops. The information requirements while tramming and dumping a scoop are essentially the same as those for shuttle cars. In loading, however, scoops have additional information requirements associated with their "active" loading process. In scooping a load of coal, the operator must know the position of the blade relative to the coal pile. This helps maximize the load. When the scoop is dug into the pile, the operator should be aware of the available load space remaining on the blade. If space is available, the operator may continue forward to fill the blade, or take a second pass at the pile to maximize the load. In many situation, the scoop must work close to the last row of roof supports. The operator must, therefore, be aware of their location so as not to progress in-by them.

2.4 Visual Features

There are usually multiple sources of information available to satisfy any given information requirement. In some cases, redundant sources exist, in other cases, several individual sources must be combined in order to satisfy the requirement. Not all sources of information are visual; some are auditory and others are tactual. Our concern, of course, is with the visual features that serve as sources of information.

Specification of the information requirements is relatively easy, given a thorough knowledge of the individual tasks. On the other hand, specifying the visual features that provide the information is very difficult. The principle reason is that there are multiple sources of information. Usually, operators are not aware of how they get the information, only that they become aware of it. The operators, in essence, build a cognitive structure or pattern of phenomena which is so integrated that it constitutes a functional unit whose properties are more than the sum of the parts (i.e., a cognitive gestalt). When we attempt to dissect this gestalt into its parts, we lose some of its essential character. Nevertheless, in order to develop visual requirements, specific visual features must be identified which serve as the sources of the information required to safely and efficiently operate the equipment. Table 2-2 lists the principal visual features which serve as sources for the information requirements of continuous miner, shuttle car, and scoop operators. The location of each visual feature is addressed in the next section of this report.

Importance of visual features. There are several inherent difficulties in rating the relative importance of specific visual features. The importance of visual features depends on their likelihood of occurrence which varies from mine to mine. An example would be roof hazards. In mines with an undulating roof and low hanging roof bolts, roof hazards can be important sources of information to avoid mishaps. With a good flat high roof, on the other hand, it is less important that the operator be able to see it.

Usually there are redundant visual sources associated with a given information requirement. An example would be the same-side leading corner of a machine and the opposite-side leading corner. Generally being able to see one gives enough information to the

TABLE 2-2

Visual Features Associated with Information Requirements

I. TRAMMING	CM	SC	S
A. Position of Machine in Roadway			
1. Rib same[1] side	X	X	X
2. Rib opposite[1] side	X	X	X
3. Cross cut corners	X	X	X
4. Roof	X	X	X
5. Center line roof marks	X	X	X
6. Leading corner of machine, same side	X	X	X
7. Leading corner of machine, opposite side	X	X	X
8. Trailing corner of machine, same side	X		X
9. Trailing corner of machine, opposite side	X		X
10. Helper's cap lamp	X		
B. Location of Obstacles and Hazards			
1. Roof obstructions: e.g.	X	X	X
a. roof bolts			
b. cross beams and straps			
c. hanging cables and pipes			
d. flexible and rigid ventilation tubing			
e. low areas and kettle bottoms			
f. overhead conveyor belts			
g. spalling			
2. Roadway obstruction: e.g.	X	X	X
a. tools and supplies			
b. other mobile equipment			
c. personnel			
d. standing water			
e. ditches and holes			
f. rails			
g. brattice			
h. trailing cables			
i. rubble			
3. Rib obstructions: e.g.	X	X	X
a. brattice			
b. rubble along rib			
c. irregularities in rib			
d. rib roll-bulges or spalling			
e. flexible and rigid ventilation tubing			
f. cables			

TABLE 2-2 (Continued)

Visual Features Associated with Information Requirements

I. TRAMMING (Continued)	CM	SC	S
C. Speed of Movement			
1. Rib same side	X	X	X
2. Roof	X	X	X
3. Roadway ahead of machine	X	X	X
D. Location of Machine within the Mine			
1. Signs	X	X	X
2. General surroundings	X	X	X
II. LOADING			
A. Position of Tail Boom			
1. End of tail boom	X		
2. Center line of haulage conveyance	X		
B. Available Load Space			
1. Top of pile in vehicle		X	X
2. Front end of haulage vehicle	X		
3. Back edge of scoop bucket			X
4. Helper	X		
5. Haulage vehicle operator	X		
C. Relative Rate of Material Off Tail Boom			
1. Material coming off boom	X	X	
D. Position of Vehicle Relative to CM			
1. Tail boom		X	
2. Rear corner of CM		X	

TABLE 2-2 (Continued)

Visual Features Associated with Information Requirements

II. LOADING (Continued)	CM	SC	S
E. Position of Blade Relative to Coal Pile			
1. Coal pile			X
2. Back corner, same side, of blade			X
3. Side of blade, same side			X
F. Location of Obstructions and Hazards			
1. Roof obstructions: e.g	X	X	X
a. roof bolts			
b. cross beams and straps			
c. flexible and rigid ventilation tubing			
d. low areas and kettle bottoms			
e. spalling			
2. Roadway obstructions: e.g.	X	X	X
a. tools and supplies			
b. personnel			
c. ditches and holes			
d. trailing cables			
3. Rib obstructions: e.g.	X	X	X
a. brattice			
b. irregularities in rib			
c. rib roll bulges or spalling			
d. flexible and rigid ventilation tubing			
e. cables			
G. Position and Height of Load			
1. Top of load		X	X
2. Slope of load		X	X
H. Position of Vehicle Relative to Roof Bolts			
1. Roof bolts or supports	X		X
2. Helpers cap lamp	X		
3. Rib spot markers	X		

TABLE 2-2 (Continued)

Visual Features Associated with Information Requirements

III. DUMPING	CM	SC	S
A. Position of Vehicle Relative to Dump Site			
1. Front end of dump site		X	X
2. Same side leading corner of vehicle		X	X
3. Dump site activation pull cord or lever		X	X
4. Ramp		X	X
B. Position of Load on Vehicle			
1. Top of load		X	X
2. Back slope of load		X	X
3. Back corner, same side of scoop blade			X
C. Location of Obstacles and Hazards			
1. Edge of loading ramp		X	X
2. Personnel		X	X
3. Tools, supplies		X	X
4. Low roof		X	X
D. Status of Dump Site			
1. Center of dump site		X	X
2. Status lights or signal		X	X
3. Tender's cap lamp		X	X
IV. EXTRACTION			
A. Position of Cutting Head			
1. Same side outer edge of cutting head	X		
2. Opposite side outer edge of cutting head	X		
3. Intersection of roof and face	X		
4. Floor at same side front edge	X		
5. Top edge of cutting head	X		

TABLE 2-2 (Continued)

Visual Features Associated with Information Requirements

IV. EXTRACTION (Continued)	CM	SC	S
B. Alignment of Cutting Head to Face			
1. Same side outer edge of cutting head	X		
2. Opposite side outer edge of cutting head	X		
3. Intersection of roof and face	X		
4. Same side, side of machine	X		
5. Same side rib or brattice	X		
6. Opposite side rib or brattice	X		
7. Surveyor marks on roof	X		
8. Helper's cap lamp	X		
C. Location of Machine Relative to Roof Supports			
1. Roof supports (last row in-by the face)	X		
2. Helper's cap lamp	X		
3. Spot marker on same side rib	X		
D. Location of Obstacles and Hazards			
1. Rib obstructions/hazards:	X		
a. brattice cloth			
b. rubble along rib			
c. irregularities in rib			
d. rib roll bulges or spalling			
2. Roadway obstructions/hazards:	X		
a. temporary roof supports			
b. trailing cable			
c. other personnel (including helper)			
3. Roof obstructions/hazards:	X		
a. impending roof fall conditions			
E. Rate of Cutting Coal from Face			
1. End of tail conveyor	X		

TABLE 2-2 (Continued)

Visual Features Associated with Information Requirements

IV. EXTRACTION (Continued)	CM	SC	S
F.Condition of Working Face			
1. Intersection of roof and face	X		
2. Intersection of rib and face, same side	X		

[1]Same side refers to same side of machine as operator; opposite side refers to opposite of machine from operator.

operator to locate the other, cognitively. How does one rate each corner? If each is rated without regard to the other, they might both get high ratings, implying that both must be seen. If each is rated, assuming the other can be seen, they both might get low ratings, implying that neither must be seen.

There are multiple criteria which can be used to rate individual visual features including:

1. How good is the cue for supplying the needed information?

2. How often will it actually occur in a mine?

3. How likely is it to be visible, given the current configurations of underground equipment?

4. If the visual feature is not seen, what effect will it have on accidents and productivity?

Given the complexity of rating visual features, it was decided that a more appropriate approach would be to first rate the importance of the information requirements and classify them into importance categories.

Two, three-point scales were developed to rate each information requirement. One scale deals with safety and the other with productivity. The scales are as follows:

SAFETY: If the information is not received:

2 - Major injury or property damage is likely to occur
1 - Minor injury or damage may result
0 - Unlikely that injury or property damage will result

PRODUCTIVITY: If the information is not received:

2 - Quantity and quality of production will be greatly affected
1 - Quantity and quality of production will be only somewhat affected
0 - Unlikely that production will be affected

Each information requirement was rated by four team members who participated in the field observations and interviews. A Delphi technique was used to resolve discrepancies. The ratings on each of the two scales were then averaged and the averages added together for a total importance rating. Table 2-3 lists the information requirements for each class of equipment indicating the average scale ratings and total importance rating of each.

Figure 2-2 shows the frequency distribution of importance ratings across the three classes of equipment. The ratings were divided into four priority categories for specifying visual requirements. The categories are as follows:

Importance Rating	Priority	Definition
3.50 - 4.00	1	No head or torso flexion should be required to obtain information
2.50 - 3.49	2	Reasonable head flexion permitted to obtain information
1.00 - 2.49	3	Reasonable head flexion and torso flexion permitted to obtain information
0.0 - 0.99	4	Major body repositioning permitted to obtain information

The specification of reasonable head and torso flexion will be discussed in Section 3.0.

The priority categories are indicated in Table 2-3 for each information requirement. The visual features take on the importance rating of the information requirement of which they are a part. Where two or more visual features serve as redundant sources of information, those features ahead and/or on the same side of the machine as the operator are given preference over features behind and/or on the opposite side of the machine. This preference takes into account the general configurations of equipment wherein it will be easier to design equipment for same-side viewing than for opposite-side viewing.

Location of visual features. The location of a visual feature can be specified by its position in three planes: fore-aft, lateral or side-to-side, and vertical or up-down. To do this, however, requires that reference points in each plane be identified. Ideally, the reference points, and hence the location of the visual feature should be so determined that they can be generalized across specific equipment configurations. For example, a continuous mining operator needs to see the cutting head of his machine. If the fore-aft location were specified with reference to the operator's head position, the location of the cutting head would vary depending on the length of the machine and the location of the operator's compartment. However, if the fore-aft position is specified with reference to a machine point, in this case the front edge, it does not matter what the length of the machine is or where the operator is positioned.

TABLE 2-3

Importance Ratings for Each Information Requirement for Each Class of Equipment

Information Requirement	Mean Ratings Safety	Productivity	Total	Priority
CONTINUOUS MINER				
Tramming:				
1. Position of machine in roadway	1.75	2.00	3.75	1
2. Location of obstacles and hazards	2.00	2.00	4.00	1
3. Speed of movement	2.00	1.00	3.00	2
4. Location of machine within the mine	0.00	0.75	0.75	4
Extraction:				
1. Vertical position of cutting head	0.25	2.00	2.25	3
2. Alignment of cutting head to face	2.00	2.00	4.00	1
3. Location of machine relative to roof supports	2.00	2.00	4.00	1
4. Location of obstacles and hazards	1.75	2.00	3.75	1
5. Rate of cutting coal from face	0.00	1.25	1.25	3
6. Condition of working face	0.50	1.00	1.50	3
Loading:				
1. Position of tail boom	0.75	1.25	2.00	3
2. Available load space	0.00	0.75	0.75	4
3. Relative rate of material off tail boom	0.00	0.75	0.75	4
4. Position of vehicle relative to roof bolts	2.00	1.75	3.75	1
5. Location of obstructions and hazards	2.00	1.75	3.75	1

TABLE 2-3 (Continued)

Importance Ratings for Each Information Requirement for Each Class of Equipment

Information Requirement	Mean Ratings Safety	Productivity	Total	Priority
SHUTTLE CARS				
Tramming:				
1. Position of machine in roadway	1.75	2.00	3.75	1
2. Location of obstacles and hazards	2.00	2.00	4.00	1
3. Speed of movement	2.00	1.00	3.00	2
4. Location of machine within the mine	0.00	0.75	0.75	4
Loading:				
1. Relative rate of material off tail boom	0.25	0.75	1.00	3
2. Position of vehicle relative to continuous miner	0.00	2.00	2.00	3
3. Location of obstructions and hazards	1.75	1.00	2.75	2
4. Position and height of load	1.00	2.00	3.00	2
Dumping:				
1. Position of vehicle relative to dump site	0.00	1.75	1.75	3
2. Position of load on vehicle	0.25	0.00	0.25	4
3. Location of obstacles and hazards	1.75	2.00	3.75	1
4. Status of dump site	0.00	2.00	2.00	3

TABLE 2-3 (Continued)

Importance Ratings for Each Information Requirement for Each Class of Equipment

Information Requirement	Mean Ratings Safety	Mean Ratings Productivity	Mean Ratings Total	Priority
SCOOPS				
Tramming:				
1. Position of machine in roadway	1.75	2.00	3.75	1
2. Location of obstacles and hazards	2.00	2.00	4.00	1
3. Speed of movement	2.00	1.00	3.00	2
4. Location of machine within the mine	0.00	0.75	0.75	4
Loading:				
1. Available load space	0.00	1.75	1.75	3
2. Position of blade relative to coal pile	0.25	1.25	1.50	3
3. Location of obstructions and hazards	2.00	2.00	4.00	1
4. Position and height of load	0.00	1.75	1.75	3
5. Position of vehicle relative to roof bolts	2.00	2.00	4.00	1
Dumping:				
1. Position of vehicle relative to dump site	0.00	1.75	1.75	3
2. Position of load on vehicle	0.25	0.00	0.25	4
3. Location of obstacles and hazards	1.75	2.00	3.75	1
4. Status of dump site	0.00	2.00	2.00	3

Total Rating	Continous Miner	Shuttle Car	Scoop	Combined	
4.00	///	/	///	~~////~~ //	1
3.75	////	//	//	~~////~~ ///	
3.50					
3.25					2
3.00	/	//	/	////	
2.75		/			
2.50					
2.25	/			/	3
2.00	/	//	/	////	
1.75		/	///	////	
1.50	/		/	//	
1.25	/			/	
1.00		/		/	
.75	///	/	/	~~////~~	4
.50					
.25		/	/	//	
.00					

Figure 2-2. Frequency distribution of total importance ratings.

Specifying the location of visual features, even with the use of generalizable reference points, requires that specific assumptions be made about the size of the equipment, how the equipment will be used, where it will be used, and most importantly, when or where the visual feature should be seen. We will address this last point first, since it is central to our approach.

The philosophy underlying the specification of visual feature locations is that the location specified should represent the last point at which the information, if received, can be used by the operator. An example will clarify this. Consider a road obstruction such as a pile of timber, and its location in the fore-aft plane. How far in front of the vehicle must the operator be able to see the obstruction? If he can see the pile 200 feet ahead, that would be nice, but it is not really necessary. The location where he <u>must</u> be able to see it is a necessary stopping distance ahead of the machine. This necessary stopping distance is a function of the speed of the machine, the reaction time of the operator, and the inherent stopping capability of the machine. A more detailed discussion of necessary stopping distance is presented later in this report.

Specifying the location of in-mine visual features requires assumptions to be made regarding how the equipment is being used and the geometry of the mine roadways. For example, several visual features involve the ribs on the same-side and opposite-side of the operator's compartment. Using the widest machine point as the lateral plane reference point, the distance to the rib must be determined. This involves three elements: the width of the machine, the width of the roadway, and the position of the vehicle in the roadway. Unless some simplifying assumptions are made, visibility requirements will be different for each mine, or area within a mine. It would be ludicrous to demand manufacturers to design their equipment to match the specific size and use characteristics of a mine. It would not be cost effective.

To overcome this, the following simplifying assumptions are made concerning the equipment, its use, and mine conditions:

1. Overall width of equipment:

Continuous Miner:	10.5 ft.
Shuttle Car:	9.5 ft.
Scoop:	8.0 ft.

2. Width of roadways: 16.0 to 20.0 ft.

3. Distance while tramming from widest machine point to rib on same-side as operator's compartment:

Continuous Miner:	5 ft. (2 ft. during extraction)
Shuttle Car:	3 ft.
Scoop:	4 ft.

These assumed distances are based on underground observations of equipment, interviews with operators, and review of equipment dimensions. They are representative of the vast majority of mining situations.

An important visual feature for the continuous miner operator is his helper. The operator must be able to see the helper so as to avoid an accident, and to receive important cap lamp signals from him. Technically, the helper's location can be anywhere, but to formulate a visibility requiremnt on this state of affairs would lead to a requirement that the operator be able to see everywhere. From underground observations and interviews, we found that helpers rarely get closer than 5 feet to the side of a continuous miner while it is operating. Thus, we assumed that the helper would remain at least 5 feet away from the widest machine point at all times when the machine is operating.

Appendix A contains the complete list and diagrams of visual features, organized by machine class and information requirement, and their location in the three planes. A word of explanation is required, however, insofar as roadway obstacles are concerned.

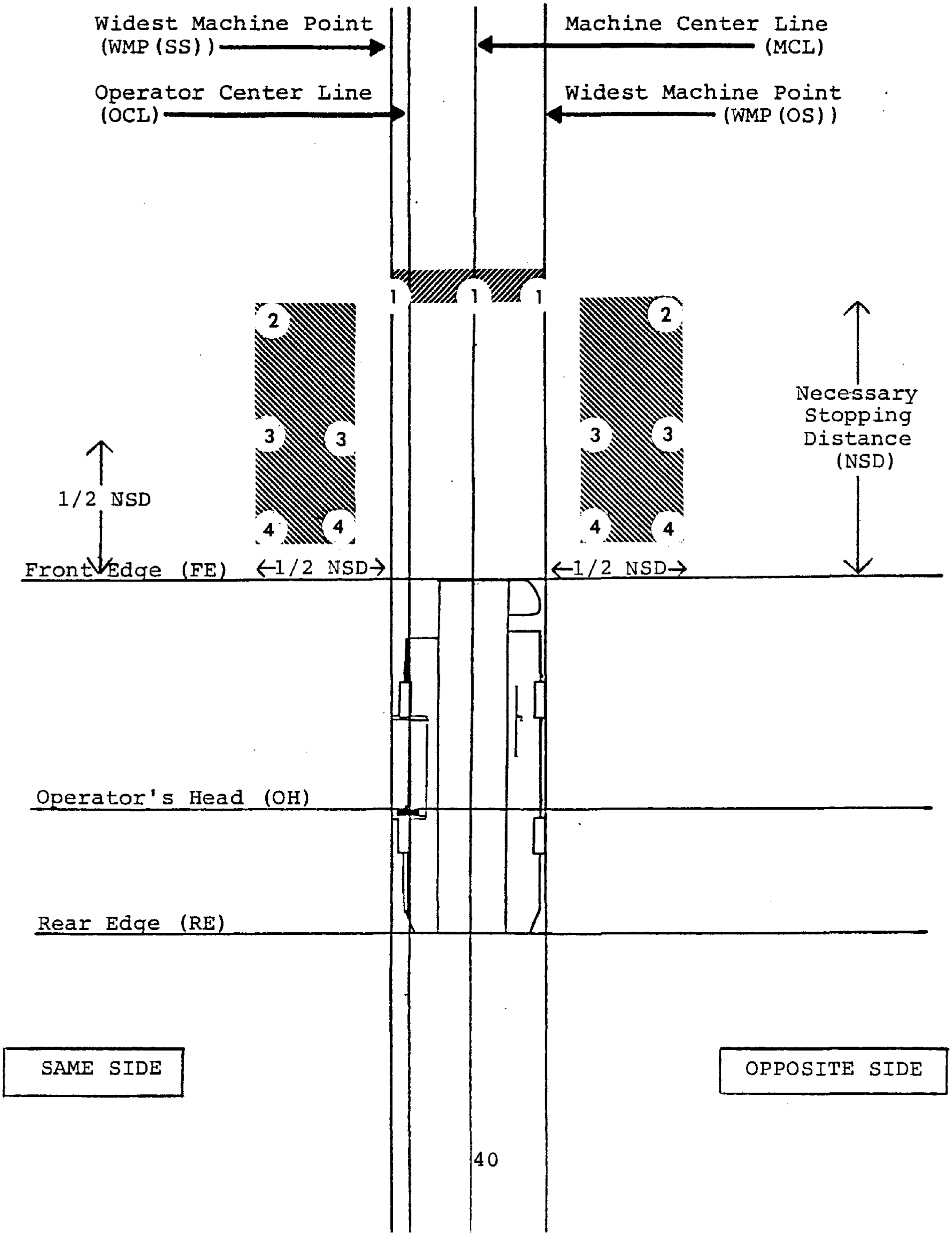
Figure 2-3 depicts the roadway hazard zone for moving equipment. It is important that the operator be able to see obstacles in the shaded zone of Figure 2-3. Obstacles not in the shaded zone are either not a threat, or even if the operator saw them, there is little that can be done to avoid them. The shaded areas outside the widest machine points represent locations where if obstacles are seen, the operator will not attempt a change in direction, i.e., he will not turn his machine, for if he did there would be no chance of stopping the machine in time to avoid hitting them. The reader is reminded that as the machine moves or turns, these shaded areas also move and turn with the machine.

Rather than specify an area, specific points in the area which define the perimeter and midlines are specified. These are marked as numbered circles in Figure 2-3. The rationale being that if these points can be seen, effectively the area can be seen. This approach will later facilitate the specification of visibility requirements.

2.5 Visibility Requirements

Approaches to specifying requirements. There are two generic approaches for specifying visibility requirements. The first is to specify "visual windows" of given size and location. The second approach is to specify specific points in space which must be visible. Note, neither of these approaches deals directly with methods for assessing whether a particular piece of equipment meets the requirements. Approaches to assessment will be discussed in Section 3.0 of this report. Obviously, however, the approach taken to specify requirements will impact on the approach taken to assess existing equipment for compliance.

Figure 2-3. Roadway obstacle hazard zone (shaded).



Visual windows are defined as areas of unobstructed vision. Visual windows must be specified in terms of visual angle, rather than in absolute size (unless the distance from the operator to the window is also specified). For example, it is meaningless to specify a window 20 inches by 8 inches in the forward direction. A 20 x 8 window 10 inches from the operator's face will provide much more visual access than if the same window were placed 10 feet in front of the operator. This is illustrated in Figure 2-4. If the distance is specified, the visual angle can be computed. The further away from the observer the window is placed, the larger in size it must be to maintain the same visual angle.

The logic behind specifying requirements in terms of windows is that by defining a window, one can see some specific visual feature through it. Reflecting on this for a moment, it becomes apparent that visual windows are, in essence, second order approximations to the primary requirement of seeing a particular visual feature.

A major problem is encountered in translating the primary requirement of seeing a particular visual feature into a visual window specification. The problem is that different sized and positioned visual windows would be required to see the same visual feature from differently configured equipment. For example, Figure 2-5 shows the horizontal visual angles required to see the same visual feature from the two major configurations of shuttle cars (i.e., a point 5 ft. in front of the machine, and 3 ft. from the widest machine point on the same side as the operator). In this particular case, the larger angle (Shuttle Car B) is over 50 percent greater than the smaller angle (Shuttle Car A). If the 9° angle were used as a standard, the visual feature would not be visible from Shuttle Car B. Thus, if visual windows were used to specify requirements, a different set of windows would have to be specified for each configuration of equipment. If any of the following parameters change, the visual angles (horizontal and vertical) to a fixed point outside the cab will change:

1. Machine height

2. Machine length

3. Machine width

4. Operator cab position

5. Seat back angle

Given the locations of the visual features and the relative position of the operator's head (resulting from a particular equipment configuration), it is, of course, possible to compute the various visual angles involved, but the process is laborious and would only apply to the specific equipment configuration upon which it was based.

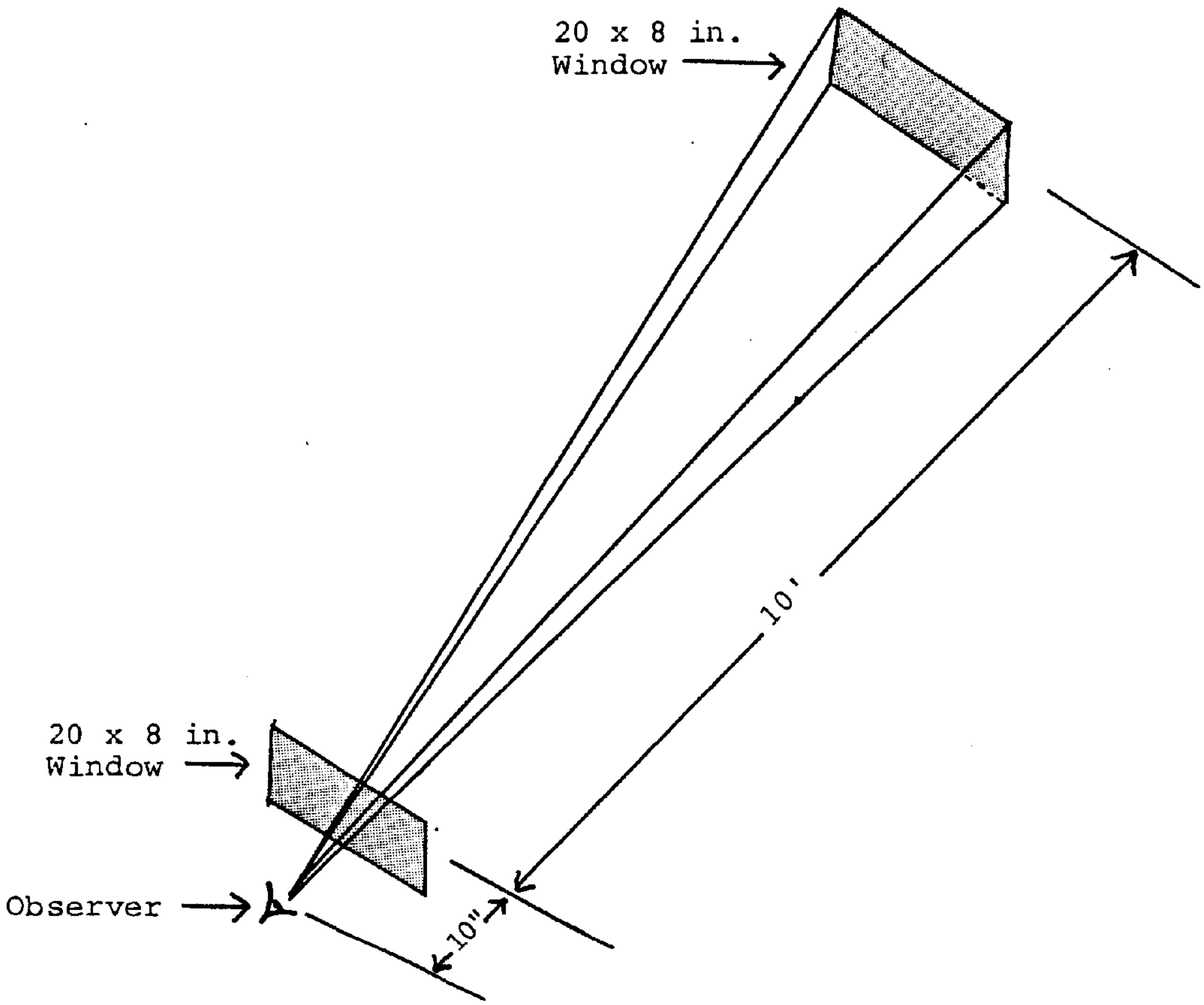


Figure 2-4. Illustration of effect of placing a fixed size visual window at different distances from the operator.

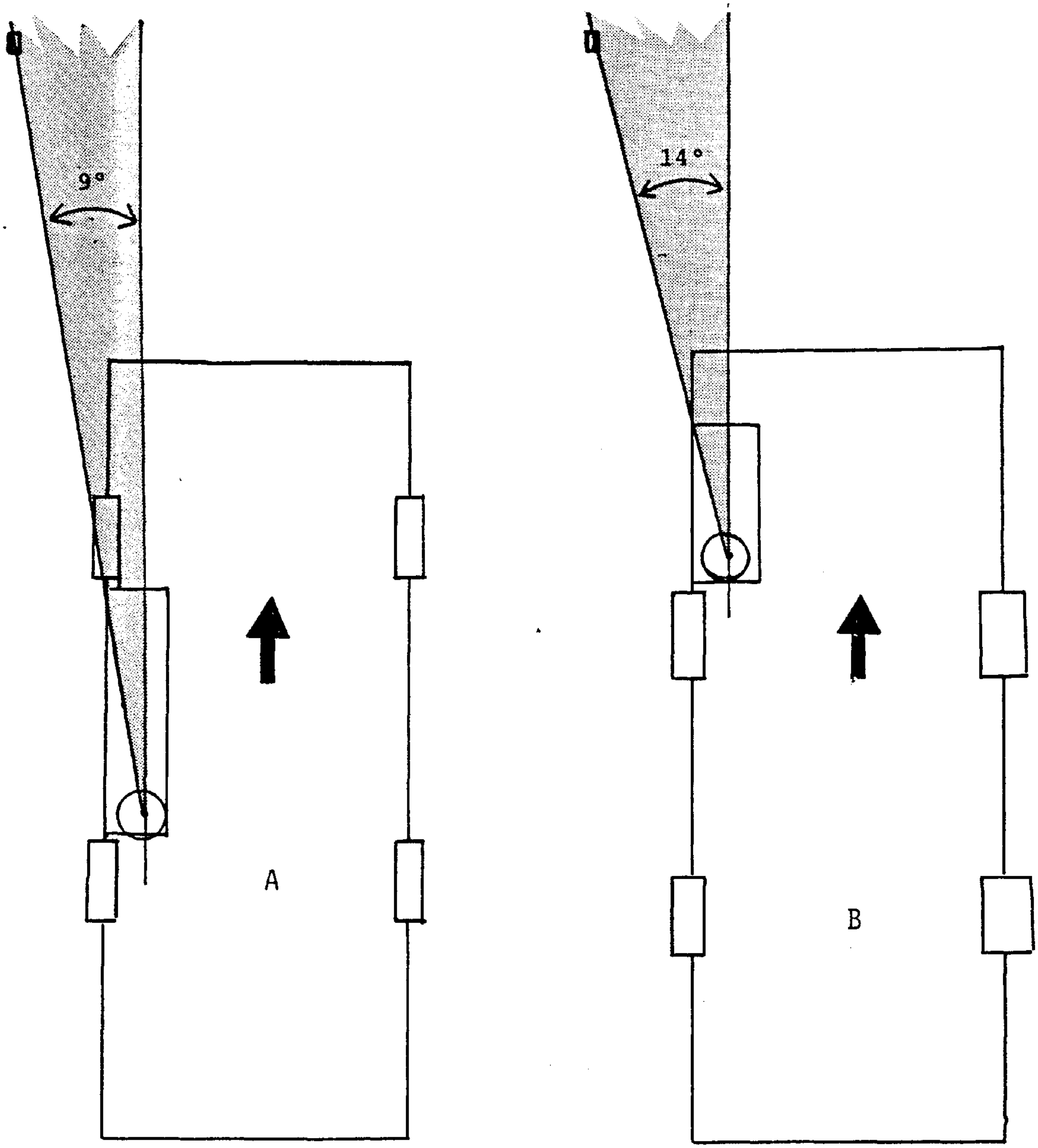


Figure 2-5. Horizontal visual angle to a visual feature from two different shuttle car configurations.

The second approach to specifying visual requirements eliminates this problem by eliminating the need to translate visual features into visual angles. The approach specifies the requirements in terms of specific locations or visual attention locations which must be visible from the operator's position. The key to the approach is to specify the locations with reference to machine points. In this way, the requirement will apply to all configurations of the equipment class. For example, operators may be required to see an object on the ground a necessary stopping distance ahead of the machine. This point can be located in space as follows:

Fore-Aft: Front edge of machine + necessary stopping distance

Lateral: Machine center line

Vertical: Floor

Determining the necessary stopping distance will be addressed shortly; suffice to say that it depends, in part, on the speed and braking capacity of the particular model of machine. The point is, however, once that distance is determined (or estimated), the above requirement remains the same. In similar manner, the requirement, as written, does not change if the length of the equipment changes, the operator's posture or position changes, or if the width or height of the machine changes. Thus, the requirements are generalizable to all equipment with a given class, i.e., all continuous miners, all shuttle cars, etc.

It was the above considerations that lead to the adoption of the second method for specifying visual requirements in this report. For each class of equipment (continuous miners, shuttle cars, and scoops) a separate list of requirements was generated. In all cases the requirements identify a visual attention location in space (fore-aft, lateral, and vertical) in which one or more important visual features were located. One goal was to maximize the number of visual features accounted for by using a minimum number of visual attention locations.

The operator should be able to see the specified location:

1. Without head or torso flexion

2. With head flexion, but no torso flexion

3. With head and torso flexion.

The alternative selected depends on the importance priority assigned to the visual features located at the specific location. The highest priority prevails where several features are located at the same place. For example, if at one location there are four features with priority ratings 1, 2, 2, and 3, the overall priority rating of that location would be 1.

To determine the minimum number of visual attention locations which would account for the maximum number of features, all the visual features for a particular class of equipment were combined into a composite graph. (Appendix A contains separate graphs for each vertical height for each class of equipment.) This composite was used to identify points of commonality among the visual features. Consideration was also given to redundancy among visual features associated with the same information requirement. Following a discussion of necessary stopping distance, the recommended visual requirements for continuous miners, shuttle cars, and scoops are presented.

Determining necessary stopping distance. Many of the visual attention locations are specified with reference to the necessary stopping distance (NSD) of the vehicle. There are two components which comprise NSD: (1) the reaction time of the operator from detection of hazard to initiation of brake controls; and (2) the distance required to stop the machine once the braking controls have been activated. The philosophy in specifying NSD was to assume reasonable worst case situations.

Operator reaction time was assumed to be 2 seconds. This corresponds well with reaction times reported for automobile braking. For example, Johansson and Rumar (1971) found that 90 percent of the reaction times they measured under actual driving conditions were less than 1.5 seconds. The 2 second value adopted here takes into account the adverse environment encountered underground, as well as, larger movement times which might occur due to less than optimum control positions found on many mining machines.

The distance required for the vehicle to stop once the brakes are applied can be determined empirically as outlined in SAE Subcommittee 29, Working Group 8, Recommended Brake Standards for Underground Machines (1979). Maximum tram speed is to be used in the determination. Until adequate data exists on braking distances for specific models of machines, an alternative procedure is suggested. The SAE Subcommittee 29 Brake Standard contains minimum performance criteria for brake systems for rubber tired, self propelled underground mining machines. It is suggested that this criteria be used as the worst case braking distances.

Table 2-4 presents the necessary stopping distances for various maximum tram speeds using the assumptions discussed above. For very slow moving equipment (such as continuous miners), the computed necessary stopping distance is less than 10 feet. Interviews with continuous miner operators revealed a desire to see at least 10 feet ahead of the machine during tramming. It was, therefore, decided to assign as a minimum 10 feet as a necessary stopping distance. Thus, any vehicle with a maximum tram speed of 2.5 mph or less is automatically assigned a 10 ft. NSD.

TABLE 2-4

Necessary Stopping Distance as a Function of Maximum Tram Speed

Maximum Tram Speed (mph)	Reaction Time Distance (ft)*	+	Braking Distance (ft)**	=	Necessary Stopping Distance (ft)***
1	3.0		0.7		10.0
2	6.0		1.4		10.0
2.5	7.0		1.8		10.0
3	9.0		2.3		11.0
4	12.0		3.4		15.0
5	15.0		4.7		20.0
6	18.0		6.1		24.0
7	21.0		7.7		29.0
8	23.0		9.5		33.0
9	26.0		11.4		37.0
10	29.0		13.5		43.0

*Assumes 2 second reaction time.

**From SAE Subcommittee 29, Working Group 8: Brake Standards for Underground Machines.

***Values rounded off to nearest whole number. Values less than 10 ft. are assigned a value of 10 ft.

One point of confirmation for this procedure is that during the interviews, shuttle car operators consistently said that they needed to see at least 20 feet ahead of them. Almost all shuttle cars have a maximum tram speed of approximately 5 mph. From Table 2-4, this translates to a necessary stopping distance of 20 ft.

Visual attention locations for operation of continuous miners. Table 2-5 contains the coordinates (fore-aft, lateral, and vertical) for each of the 71 visual attention locations associated with continuous miner operation. Table 2-5 also lists the priorities of the visual features located at each of the positions. The table is grouped into 30 fore-aft/lateral positions, at which from one to seven vertical heights are indicated. Figure 2-6 presents a schematic illustrating these 30 positions. At each position are numbers which correspond to those in Column 1 of Table 2-4. Appendix A contains a list of abbreviations used in Table 2-5.

From the task analysis and visual feature identification portion of this report, a total of 156 visual features were identified as of some importance to continuous miner operators. The same visual feature, if needed while performing more than one task, was counted each time. The 71 recommended visual attention locations account for 130 (83 percent) of all the visual features identified. A more detailed breakdown by visual feature importance priority is as follows:

Visual Feature Priority	Total Number	Accounted for by Requirements	% Accounted for
1	106	91	86%
2	3	1	33%
3	27	24	89%
4	20	14	70%

Considering only the visual features with priorities 1, 2, and 3, the 71 requirements account for 85 percent of them. Eighty-five percent is quite good considering that many of the features not included are redundant sources of information to those included. Further, some of the features not included are located in the line of sight from the operator to a position that is included. This effectively means that additional features are being included, although they do not occur at the specific location indicated in Table 2.5.

TABLE 2-5

Recommended Visual Attention Locations for Continuous Miner Operation

No.	Fore-Aft	Side-to-Side	Up-Down	Priority
1	FE + 20'	WMP(OS) + 5'	OEH	1
2	FE + 20'	WMP(SS) + 5'	OEH	1
3	FE + NSD	WMP(SS) + 1/2 NSD	Floor	1,1
4	FE + NSD	WMP(SS) + 1/2 NSD	OEH	1,4
5	FE + NSD	WMP(SS) + 1/2 NSD	HMP	1,1
6	FE + NSD	WMP(SS)	Floor	1
7	FE + NSD	WMP(SS)	HMP	1
8	FE + NSD	MCL	Floor	1
9	FE + NSD	MCL	HMP	1
10	FE + NSD	WMP(OS)	Floor	1
11	FE + NSD	WMP(OS)	HMP	1
12	FE + NSD	WMP(OS) + 1/2 NSD	Floor	1
13	FE + NSD	WMP(OS) + 1/2 NSD	OEH	1,4
14	FE + NSD	WMP(OS) + 1/2 NSD	HMP	1
15	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	Floor	1
16	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	OEH	1
17	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	HMP	1
18	FE + 1/2 NSD	WMP(OS) + 1'	Floor	1
19	FE + 1/2 NSD	WMP(OS) + 1'	HMP	1
20	FE + 1/2 NSD	WMP(SS) + 1'	Floor	1
21	FE + 1/2 NSD	WMP(SS) + 1'	HMP	1
22	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	Floor	1,1
23	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	HMP	1,1
24	FE + 2'	WMP(SS) + 1/2 NSD	Floor	1,1
25	FE + 2'	WMP(SS) + 1/2 NSD	OEH	1,1
26	FE + 2'	WMP(SS) + 1/2 NSD	HMP	1,1
27	FE - 3'	WMP(SS) + 2'	Floor	1
28	FE - 3'	WMP(SS) + 2'	OEH	1
29	FE - 3'	WMP(SS) + 2'	HMP	1

TABLE 2-5 (Continued)

Recommended Visual Attention Locations for Continuous Miner Operation

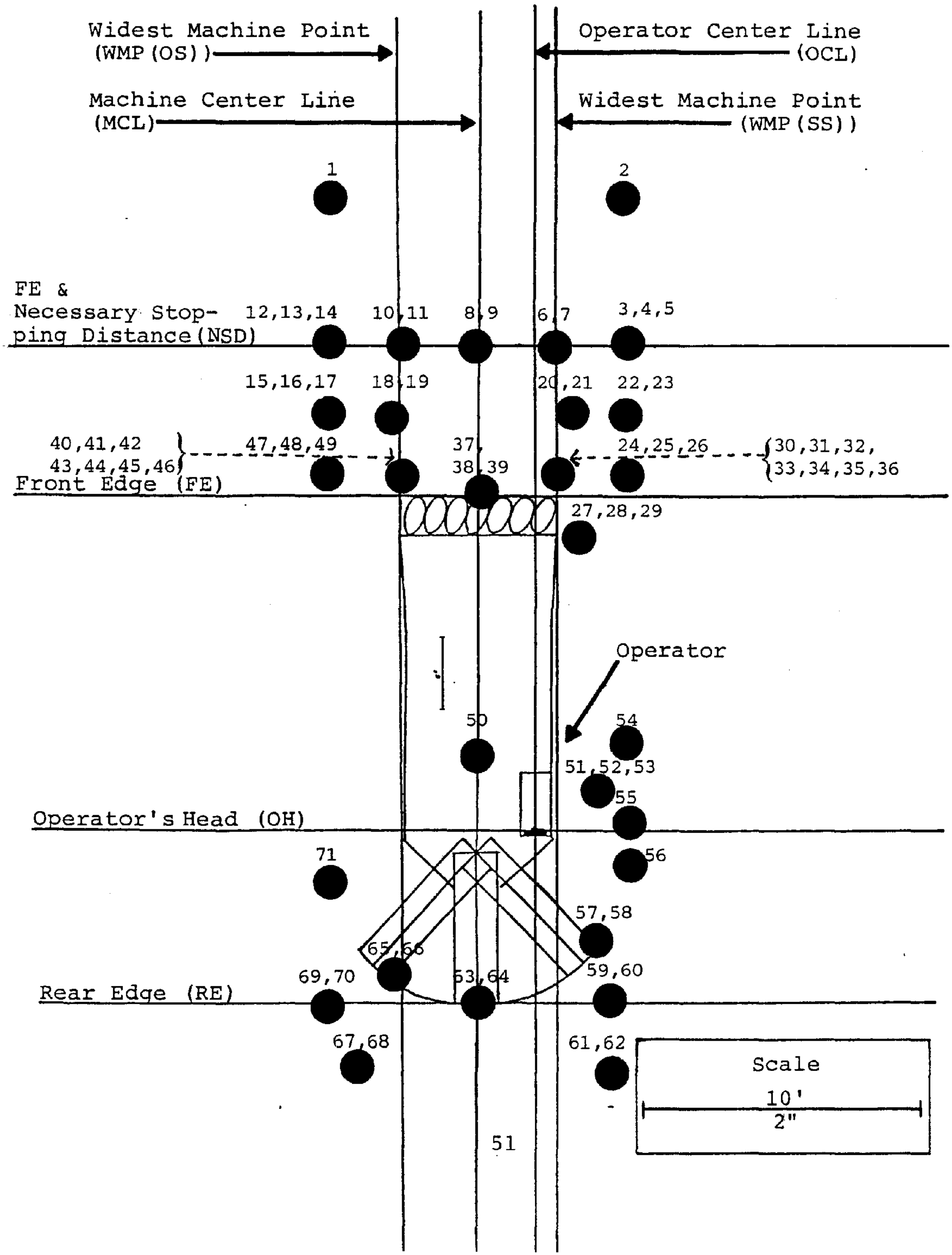
No.	Fore-Aft	Side-to-Side	Up-Down	Priority
30	FE + 1'	WMP(SS)	Floor	3,3,1
31	FE + 1'	WMP(SS)	MMH	1
32	FE + 1'	WMP(SS)	OEH	1
33	FE + 1'	WMP(SS)	HMP	1
34	FE + 1'	WMP(SS)	SH	3,3,1
35	FE + 1'	WMP(SS)	MBH	1
36	FE + 1'	WMP(SS)	MCH	3
37	FE	MCL	SH	1,1,3,3
38	FE	MCL	MBH	1
39	FE	MCL	MCH	3
40	FE + 1'	WMP(OS)	Floor	3,1
41	FE + 1'	WMP(OS)	MMH	1
42	FE + 1'	WMP(OS)	OEH	1
43	FE + 1'	WMP(OS)	HMP	1
44	FE + 1'	WMP(OS)	SH	1,3,3
45	FE + 1'	WMP(OS)	MBH	1
46	FE + 1'	WMP(OS)	MCH	3
47	FE + 1'	WMP(OS) + 1/2 NSD	Floor	1
48	FE + 1'	WMP(OS) + 1/2 NSD	OEH	1
49	FE + 1'	WMP(OS) + 1/2 NSD	HMP	1
50	OH + 5'	MCL	SH	1,1
51	OH + 3'	WMP(SS) + 3'	Floor	1
52	OH + 3'	WMP(SS) + 3'	OEH	1,1,1
53	OH + 3'	WMP(SS) + 3'	HMP	1
54	OH + 1/2 NSD	WMP(SS) + 1/2 NSD	OEH	1,2
55	OH	WMP(SS) + 5'	OEH	1,1,1,1,1
56	OH - 3'	WMP(SS) + 5'	OEH	1,1,1,1
57	RE (w/MBS(SS))	MBS(SS)	MMH	1,1,1,3,3, 4,4,4
58	RE (w/MBS(SS))	MBS(SS)	MBH	1,3,3,4
59	RE (Midline)	WMP(SS) + 4'	MMH	1
60	RE (Midline)	WMP(SS) + 4'	OEH	1
61	RE - 1/2 NSD	WMP(SS) + 4'	OEH	1
62	RE - 1/2 NSD	WMP(SS) + 4'	MBH	1

TABLE 2-5 (Continued)

Recommended Visual Attention Locations for Continuous Miner Operation

No.	Fore-Aft	Side-to-Side	Up-Down	Priority
63	RE (Midline)	MCL	MMH	1,1,3,3,4,4,4
64	RE (Midline)	MCL	MBH	1,3,3,4
65	RE (w/MBS(OS))	MBS(OS)	MMH	1,1,3,3,4,4,4
66	RE (w/MBS(OS))	MBS(OS)	MBH	1,3,3,4
67	RE - 1/2 NSD	WMP(OS) + 4'	OEH	1
68	RE - 1/2 NSD	WMP(OS) + 4'	MBH	1
69	RE (Midline)	WMP(OS) + 5'	MMH	1
70	RE (Midline)	WMP(OS) + 5'	OEH	1
71	OH - 4'	WMP(OS) + 5'	OEH	1,1

Figure 2-6. Visual attention locations (fore-aft and lateral) for continuous miner operation. Numbers refer to Table 2-5.



Visual attention locations for operation of shuttle cars. Table 2-6 contains the coordinates (fore-aft, lateral and vertical) for each of 54 recommended visual attention locations associated with operation of shuttle cars. The table is grouped into 20 fore-aft/lateral positions, at which from one to four vertical heights are indicated. Figure 2-7 presents a schematic illustrating these 20 positions. At each position are numbers which correspond to those in column 1 of Table 2-6. In the case of shuttle cars, these 54 requirements apply to both directions of travel. Appendix A contains a list of abbreviations used in Table 2-6.

A total of 86 visual features were identified in shuttle car operations. The 54 recommended visual attention locations account for 80 (93 percent) of all the visual features identified. A more detailed breakdown by visual feature importance priority is as follows:

Visual Feature Priority	Total Number	Accounted for by Requirements	% Accounted for
1	52	51	98%
2	15	15	100%
3	13	10	77%
4	6	4	67%

Considering only the visual features with priorities 1, 2, and 3, the 54 requirements account for 95 percent of them.

TABLE 2-6

Recommended Visual Attention Locations for Shuttle Car Operation

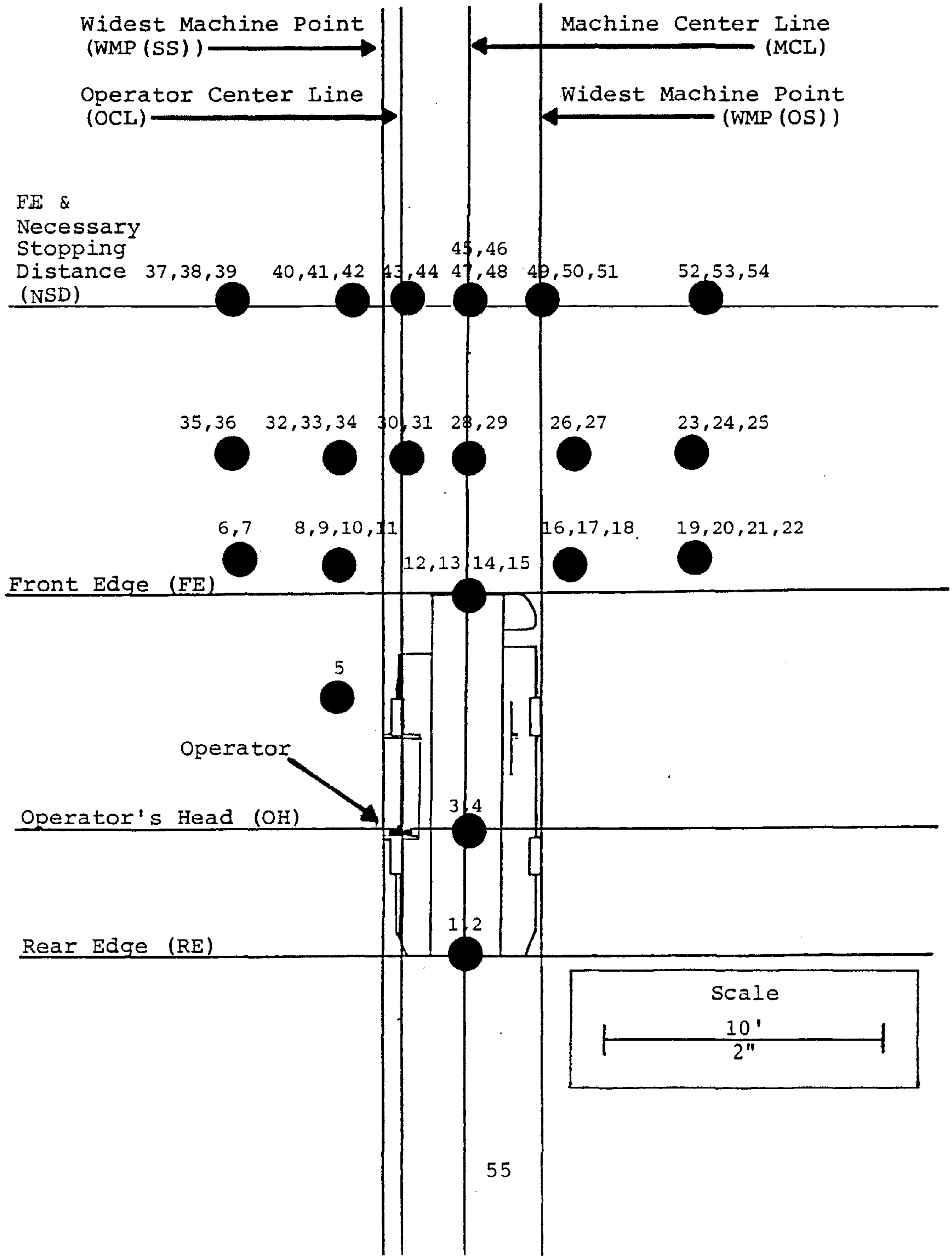
No.	Fore-Aft	Side-to-Side	Up-Down	Priority
1	RE	MCL	OEH	2
2	RE	MCL	HMP	2
3	OH	MCL	OEH	2
4	OH	MCL	HMP	2
5	OH + 10'	WMP(SS) + 3'	OEH	1,2
6	FE + 2'	WMP(SS) + 1/2 NSD	Floor	1
7	FE + 2'	WMP(SS) + 1/2 NSD	HMP	1
8	FE + 2'	WMP(SS) + 3'	Floor	1,1
9	FE + 2'	WMP(SS) + 3'	MMH	1,2,3
10	FE + 2'	WMP(SS) + 3'	OEH	1,2
11	FE + 2'	WMP(SS) + 3'	HMP	1,1,2
12	FE	MCL	MMH	3
13	FE	MCL	OEH	2
14	FE	MCL	HMP	2,4
15	FE	MCL	SH or MBH	3
16	FE + 2'	WMP(OS) + 2'	Floor	1
17	FE + 2'	WMP(OS) + 2'	MMH	1
18	FE + 2'	WMP(OS) + 2'	HMP	1,2
19	FE + 2'	WMP(OS) + 1/2 NSD	Floor	1
20	FE + 2'	WMP(OS) + 1/2 NSD	MMH	2
21	FE + 2'	WMP(OS) + 1/2 NSD	OEH	2
22	FE + 2'	WMP(OS) + 1/2 NSD	HMP	1
23	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	Floor	1
24	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	OEH	1
25	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	HMP	1
26	FE + 1/2 NSD	WMP(OS) + 2'	Floor	1
27	FE + 1/2 NSD	WMP(OS) + 2'	HMP	1
28	FE + 1/2 NSD	MCL	MMH	3
29	FE + 1/2 NSD	MCL	SH	1,3
30	FE + 1/2 NSD	OCL	Floor	2
31	FE + 1/2 NSD	OCL	SH	1,2
32	FE + 1/2 NSD	WMP(SS) + 3'	Floor	1,1
33	FE + 1/2 NSD	WMP(SS) + 3'	MMH	3
34	FE + 1/2 NSD	WMP(SS) + 3'	HMP	1,1

TABLE 2-6 (Continued)

Recommended Visual Attention Locations for Shuttle Car Operation

No.	Fore-Aft	Side-to-Side	Up-Down	Priority
35	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	Floor	1
36	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	HMP	1
37	FE + NSD	WMP(SS) + 1/2 NSD	Floor	1
38	FE + NSD	WMP(SS) + 1/2 NSD	OEH	1
39	FE + NSD	WMP(SS) + 1/2 NSD	HMP	1
40	FE + NSD	WMP(SS) + 2'	Floor	1,1,1,1,3
41	FE + NSD	WMP(SS) + 2'	OEH	1,1,3,4
42	FE + NSD	WMP(SS) + 2'	HMP	1,1
43	FE + NSD	OCL	MMH	3
44	FE + NSD	OCL	HMP	1
45	FE + NSD	MCL	Floor	1,1
46	FE + NSD	MCL	MMH	3
47	FE + NSD	MCL	OEH	1,4
48	FE + NSD	MCL	HMP	1
49	FE + NSD	WMP(OS)	Floor	1,1
50	FE + NSD	WMP(OS)	OEH	1
51	FE + NSD	WMP(OS)	HMP	1
52	FE + NSD	WMP(OS) + 1/2 NSD	Floor	1
53	FE + NSD	WMP(OS) + 1/2 NSD	OEH	1,1,4
54	FE + NSD	WMP(OS) + 1/2 NSD	HMP	1

Figure 2-7. Visual attention locations (fore-aft and lateral) for shuttle car operation. Numbers refer to Table 2-6.



Visual attention locations for operation of scoops. Table 2-7 contains the coordinates (fore-aft, lateral and vertical) for each of 54 recommended visual attention locations associated with operation of scoops. The table is grouped into 26 fore-aft lateral positions, at which from one to four vertical heights are indicated. Figure 2-8 presents a schematic illustrating these 26 positions. At each position are numbers which correspond to those in column 1 of Table 2-7. Appendix A contains a list of abbreviations used in Table 2-7.

A total of 94 visual features were identified in scoop operations. The 54 recommended visual attention locations account for 75 (80 percent) of the visual features identified. A more detailed breakdown by visual feature importance priority is as follows:

Visual Feature Priority	Total Number	Accounted for by Requirements	% Accounted for
1	70	62	89%
2	3	3	100%
3	14	8	57%
4	7	2	29%

Considering only the visual features with priorities 1, 2, and 3, the 54 requirements account for 84 percent of them.

TABLE 2-7

Recommended Visual Attention Locations for Scoop Operation

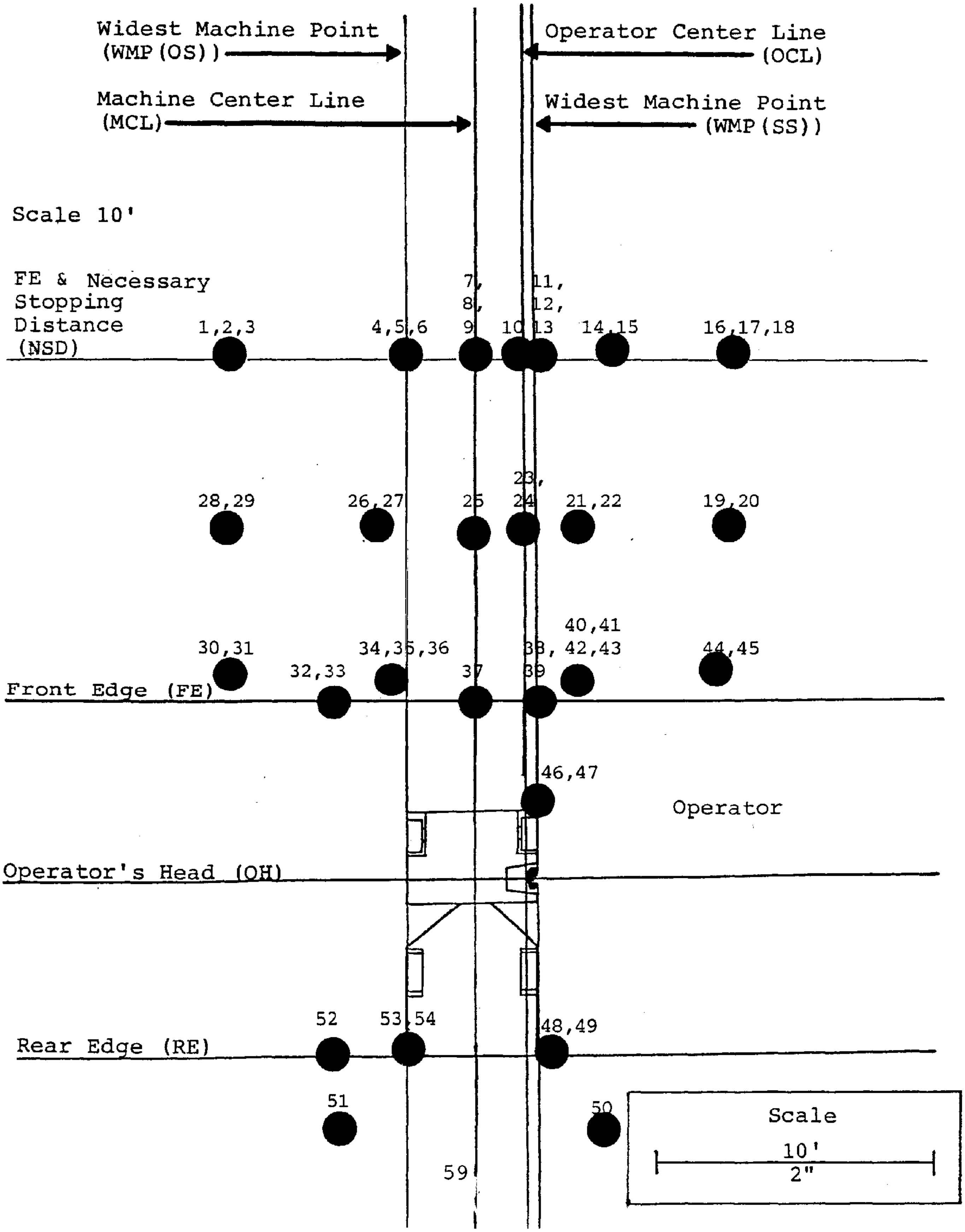
No.	Fore-Aft	Side-to-Side	Up-Down	Priority
1	FE + NSD	WMP(OS) + 1/2 NSD	Floor	1
2	FE + NSD	WMP(OS) + 1/2 NSD	OEH	1
3	FE + NSD	WMP(OS) + 1/2 NSD	HMP	1
4	FE + NSD	WMP(OS)	Floor	1,1
5	FE + NSD	WMP(OS)	OEH	1
6	FE + NSD	WMP(OS)	HMP	1
7	FE + NSD	MCL	Floor	1,1
8	FE + NSD	MCL	OEH	1,4
9	FE + NSD	MCL	HMP	1
10	FE + NSD	OCL	HMP	1
11	FE + NSD	WMP(SS)	Floor	1,1,1,3
12	FE + NSD	WMP(SS)	OEH	1,3
13	FE + NSD	WMP(SS)	HMP	1
14	FE + NSD	WMP(SS) + 5'	Floor	1
15	FE + NSD	WMP(SS) + 5'	HMP	1,3
16	FE + NSD	WMP(SS) + 1/2 NSD	Floor	1
17	FE + NSD	WMP(SS) + 1/2 NSD	OEH	1
18	FE + NSD	WMP(SS) + 1/2 NSD	HMP	1
19	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	Floor	1
20	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	HMP	1
21	FE + 1/2 NSD	WMP(SS) + 3'	Floor	1,1
22	FE + 1/2 NSD	WMP(SS) + 3'	HMP	1,1
23	FE + 1/2 NSD	OCL	Floor	2
24	FE + 1/2 NSD	OCL	SH	1,2
25	FE + 1/2 NSD	MCL	SH	1
26	FE + 1/2 NSD	WMP(OS) + 2'	Floor	1
27	FE + 1/2 NSD	WMP(OS) + 2'	HMP	1
28	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	Floor	1
29	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	HMP	1
30	FE + 2'	WMP(OS) + 1/2 NSD	Floor	1
31	FE + 2'	WMP(OS) + 1/2 NSD	HMP	1

TABLE 2-7 (Continued)

Recommended Visual Attention Locations for Scoop Operation

No.	Fore-Aft	Side-to-Side	Up-Down	Priority
32	FE	WMP(OS) + 5'	Floor	1
33	FE	WMP(OS) + 5'	HMP	1
34	FE + 1'	WMP(OS) + 1'	Floor	1
35	FE + 1'	WMP(OS) + 1'	MMH	1
36	FE + 1'	WMP(OS) + 1'	HMP	1,1
37	FE	MCL	MMH	3
38	FE	WMP(SS)	MMH	1,3,3,4
39	FE	WMP(SS)	HMP	1
40	FE + 1'	WMP(SS) + 3'	Floor	1,1
41	FE + 1'	WMP(SS) + 3'	MMH	1
42	FE + 1'	WMP(SS) + 3'	OEH	1,1,2
43	FE + 1'	WMP(SS) + 3'	HMP	1,1
44	FE + 2'	WMP(SS) + 1/2 NSD	Floor	1
45	FE + 2'	WMP(SS) + 1/2 NSD	HMP	1
46	OH + 5'	WMP(SS)	MMH	3,3
47	OH + 5'	WMP(SS)	SH	1
48	RE	WMP(SS) + 1'	MMH	1,1
49	RE	WMP(SS) + 1'	HMP	1
50	RE - 5'	WMP(SS) + 5'	Floor	1
51	RE - 5'	WMP(OS) + 5'	Floor	1
52	RE	WMP(OS) + 5'	HMP	1
53	RE	WMP(OS)	MMH	1
54	RE	WMP(OS)	HMP	1

Figure 2-8. Visual attention locations (fore-aft and lateral) for scoop operation. Numbers refer to Table 2-7.



3.0 ASSESSING FIELDS OF VISIBILITY

Section 2.0 of this report documented the development of visibility requirements for continuous miner, shuttle car, and scoop operations. The final product consisted of a list of visual attention locations which contain visual features important for the safe and efficient operation of the equipment. Section 2.0, in essence, described what needed to be seen; it did not address whether those locations could be seen or how to determine whether the locations could be seen from a particular piece of equipment. This section, Section 3.0, discusses the development and testing of a methodology for determining whether a particular equipment and operator compartment configuration permits the operator to see the visual attention locations enumerated in Section 2.0. The first part of this section briefly reviews various approaches for assessing the field of visibility on mobile equipment. The second part of this section describes the methodology developed and recommended by the project team. Each of the next three parts presents an evaluation of specific examples of continuous miners, shuttle cars, and scoops. The last part of this section addresses the difficult question of how good visibility must be in order to be acceptable.

3.1 Approaches for Assessing Fields of Visibility

There have been numerous approaches suggested in the literature for assessing fields of visibility of mobile equipment (e.g., SAE XJ1091 - Measurement and evaluation of visibility; Mason, Rhodes, and Best - Summary of sight line techniques for use with mining machinery, National Coal Board ON79/58). These approaches differ in terms of complexity, type of information generated, and utility for the intended application. The approach to be developed here would be used by two principal parties. First, MSHA would use the procedure to evaluate equipment configurations, or canopy designs in terms of visibility afforded. Second, equipment manufacturers would use the procedure to test alternative designs and to suggest equipment modifications to enhance visibility.

With these purposes in mind, the following criteria were generated for evaluating alternative approaches for assessing fields of visibility.

1. Measurement apparatus should be simple to construct and be portable.

2. Set-up should be simple and quick and require little or no special training.

3. Data recording and analysis should be simple, quick, and yield data that is readily interpretable without special training.

4. A permanent visual record should be produced.

5. Data must be compatible with the visual attention location approach for recommending visual requirements, but be easily adaptable to changes in the requirements.

6. The technique should identify obstructions to visibility and be useful for suggesting equipment modifications to enhance visibility.

Most of the various approaches can be classified into three categories: panorama photographic techniques, shadow graph techniques, and line-of-sight techniques. A fourth category, miscellaneous, includes computer-aided procedures and graphic techniques. Each of these four categories will be discussed in turn. Table 3-1 summarizes the various approaches according to the six criteria set out above.

Panorama photograph technique. This technique consists of positioning a camera at the operator's eye position inside the cab and taking a series of overlapping pictures as the camera is rotated 360°. The pictures are then pasted together to produce a panoramic composite. Two variations of this technique are used, differing only in how reference angles are established. One technique requires that concentric rings be painted on the ground at fixed distances from the camera. The other technique places a ranging pole (a vertical pole marked off in fixed vertical increments) a fixed distance from the camera. Either technique permits the resulting pictures to be calibrated in terms of visual angles. Panoramic photography is deceptively simple in principle, yet becomes complex and often unwieldy in practice. First, the camera must be positioned perfectly level and the point of rotation must be at the node point of the camera-lens combination. If either of these conditions are violated, the resulting composite picture is distorted. Second, the viewing angle of the lens usually does not match that of the human eye so that obstructions which would be visible to the operator (in the extremes of the vertical dimension) are often not recorded in the picture. Third, the panorama composite is at only one eye position, so that additional panoramas must be photographed to represent the 5th percentile operator, the 95th percentile operator, the operator with torso flexed left, with torso flexed right, etc. The fourth, and perhaps most significant problem with panoramic photography is analyzing the resulting composite photographs. Visual angles must be determined for the unobstructed spaces. This is time consuming and requires very precise measurement of the photographs. The resulting data are also not readily compatible with the visual attention location approach for specifying visibility requirements. Due to differences in machine configuration, each visual attention location must be converted to visual angle coordinates, and then located on the composite panorama photograph. As discussed in Section 2.0, the visual angles of the attention locations will differ for every

TABLE 3-1

Evaluation of Various Approaches to Assessing Fields of Visibility

	Techniques			
Criteria	Panorama Photograph	Shadow Graphs	Line-of-Sight	Miscellaneous
1. Apparatus: simple, portable	Yes	No	Yes	No
2. Set-Up: simple, quick	No	No	Yes	No
3. Data Recording: simple, quick, interpretable data	No	No	Yes	No
4. Permanent Record	Yes	Yes	Yes	Yes
5. Compatible with Recommended visual requirements	No	No	Yes	Yes
6. Obstructions identified	Yes	?	Yes	Yes

configuration of equipment. For the reasons outlined above, the panorama photograph technique was deemed impractical for this project; although, examples of the technique will be presented in Sections 3.3, 3.4, and 3.5.

Shadow graph techniques. This technique consists of positioning a point source of light at the operator's eye position in the cab. A fixed distance from the machine around all sides, large screens covered with paper or cloth are erected. The technique is performed in a darkened room. The shadow pattern produced by machine obstructions is cast on the paper screens. These shadows are then traced, or photographed (in which case the screen is grided). There are several problems with this technique, some of which are similar to those encountered with the panorama technique. First, the apparatus is bulky and difficult to transport. The screens are difficult to erect, and data reduction is laborous and time consuming. The same problem of translating the shadow graphs to visual attention locations remains. Separate graphs must be produced for 5th and 95th percentile operators. Although it is possible to identify the machine part that is creating the obstruction, this is not easy to do when only the graphs are available. It is often difficult to visualize the effect of altering the machine design on the resulting shadow pattern. Although the shadow graph technique is recommended by SAE for assessing visibility from mobile equipment (SAE XJ1091), no attempts have been made to define visual attention locations for each class of equipment. Thus, the technique gives an overview of the field of visibility without assessing whether what can be seen is important to be seen in terms of the safe, efficient operation of the equipment. Since this project has identified visual attention locations, it was judged that the shadow technique was too time consuming and difficult a procedure for our use.

Line-of-sight techniques. This technique is predicated on a knowledge of what the operator needs to see to operate the equipment. Thus, it is particularly well suited to the present application. There are two variations on the technique. The first is an inside-out technique wherein a camera (or observer) is positioned in the operator's compartment. A target is positioned at the visual attention location and a picture is taken from the cab, or the observer in the cab indicates if he can see the target. The main disadvantage of the inside-out procedure is that separate sets of photographs must be made for the 5th and 95th percentile operators. Other than that, however, the procedure is simple to perform, requires a minimum of equipment, produces a permanent record of the obstructions and requires no data reduction - either the target can or can not be seen.

The second variation of the line-of-sight technique is the outside-in technique. Here a manikin-like device is positioned in the operator's compartment. The device is configured to show both the 5th and 95th percentile eye positions and also can be configured to show eye positions associated with neck and torso flexion. The camera is then positioned at each visual attention location and a picture is taken looking back to the cab. If the "eyes" of the device can be seen, then an operator could see the visual attention location. The set up is simple, the photographs are readily interpretable, machine obstructions are easily identified, and the consequences of changing the machine's configuration are readily predictable. The added advantage of this system is that a single set of photographs are all that is needed to evaluate visibility with a 5th or 95th percentile operator, with or without neck and torso flexion. It is for these reasons that the outside-in line-of-sight technique was chosen as the technique of choice for this project. The next part of this section will describe the procedure and construction of the eye reference device.

Miscellaneous techniques. Included here are graphic techniques in which precise detailed drawings of the equipment are used to determine fields of visibility. The technique is laborous and depends on the availability of detailed drawings. Another variant of this is to use a computer to generate the fields of visibility. This requires a computer program and the same sort of detailed drawing data as the graphic method. Neither of these techniques are practical for the current application.

In summary, therefore, the outside-in line-of-sight technique appears to be the best suited for the current application. Section 3.2 describes in detail this approach as modified for use in underground mobile equipment.

3.2 HERMI and the Outside-In Technique

Overview. The procedure is centered around a human eye reference measurement instrument (HERMI) which represents the eye positions of the 5th percentile female and 95th percentile male performing reasonable neck and trunk flexion. HERMI is placed in the operator's cab simulating the position of the operator. At each visual attention location, the evaluator takes a picture of HERMI in the operator's cab. Examination of the photograph allows direct determination of whether the 5th and/or 95th percentile operator could see that location, and whether to see it the operator would have had to flex his neck and/or trunk. An alternative to photography is to position a sight glass at the visual attention location and have an observer look back and report what parts of HERMI are visible. The disadvantage of this, of course, is that no permanent photographic record is made.

Construction of HERMI. Appendix B contains detailed drawings of HERMI. Figure 3-1 shows pictures of HERMI. The two arcs on HERMI represent the eye positions for the 5th percentile female (lower arc) and 95th percentile male (upper arc) in a relaxed (slumped) sitting posture. The anthropometric data used to

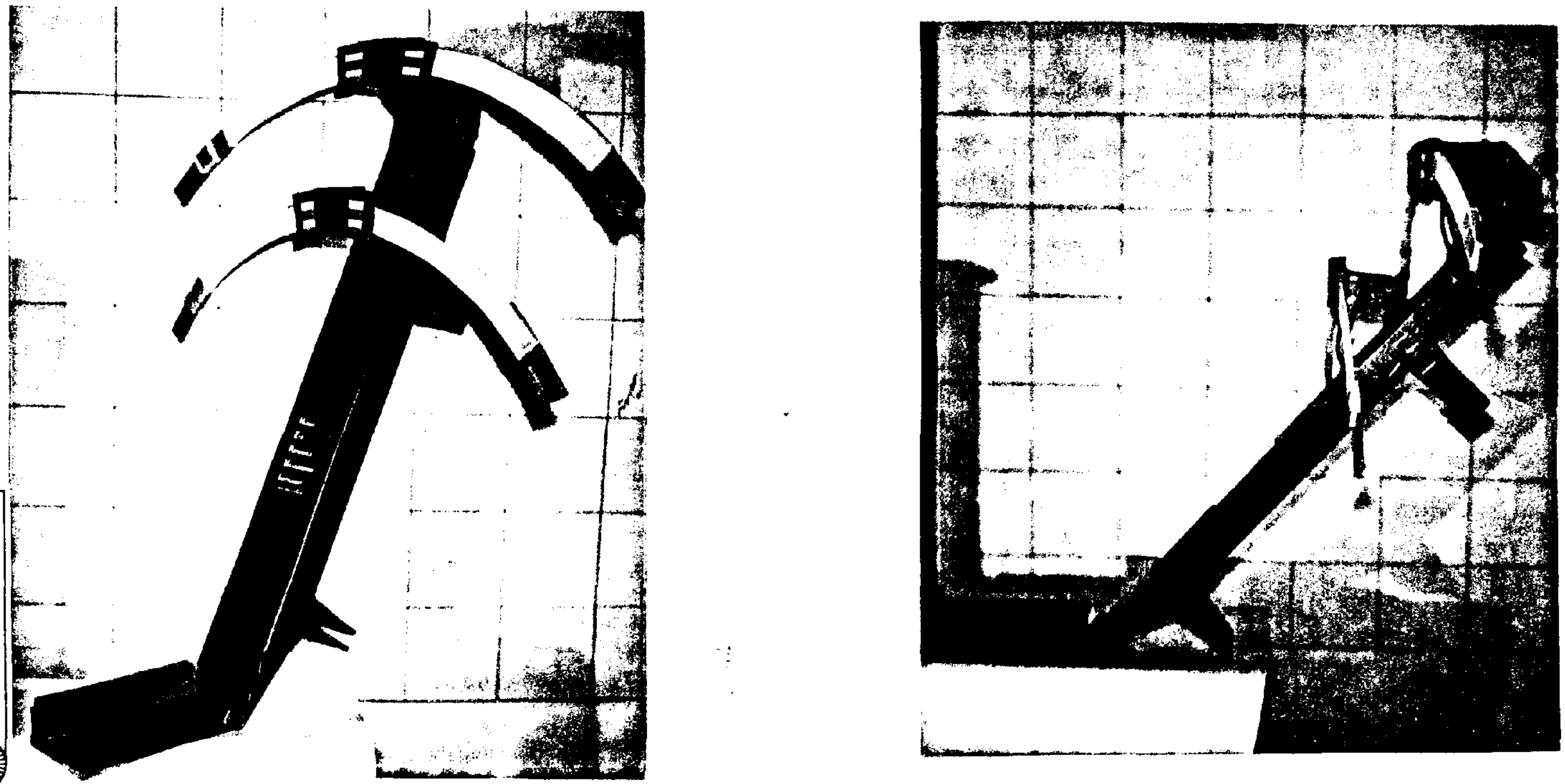
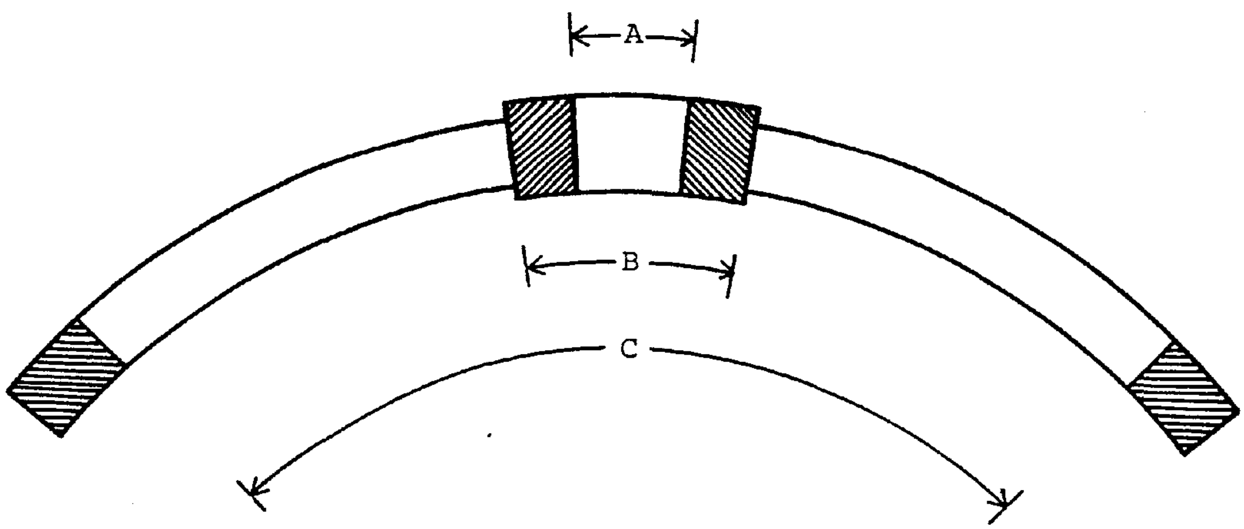


Figure 3-1. Pictures of HERMI.

construct Hermi represent military personnel as taken from Human Engineering Design Data Digest (HEL, 1978) and Anthropometric Data Application Mannikin (Rogers, 1976). Neck and torso flexion was taken as $\pm 35^{\circ}$ as shown in Figure 3-2. The $\pm 35^{\circ}$ value represents mean flexion from military populations. A Bureau of Mines project (Contract H0387022, Biomechanics in Low Coal) concluded that coal miners are not significantly different than military populations in terms of linear body dimensions, hence HERMI can be used in the coal mine equipment context.

Several features of HERMI make it unique for underground mining equipment application. First, the eye arcs are hinged so that they can be oriented perpendicular to the ground from any seat back angle, from upright to full reclining. Further, the base and "spine" are also hinged to allow accomodation to any seat back angle. People in a partially reclined position will rotate their neck forward until their eyes are facing forward. HERMI can imitate this maneuver. Second, the eye arcs can be retracted toward the center line of HERMI. In the event an obstruction exists in a cab which would prevent torso flexion to the full 35° to one side or the other, the eye arc can be shortened to represent the restricted space. At each end of each eye arc is a shaded space which represents the distance from the side of the head to the eye. Thus, when the arc is extended against an obstruction, HERMI is simulating the side of the head against the obstruction and, hence, the eye arc is accurate. Third, HERMI is constructed with stand-offs to maintain the proper fore-aft placement of the eye arcs when the operator leans back against the seat. Fourth, the eye arc is marked as follows:



Area A represents the position of the eyes with the neck and torso in a straight ahead orientation. Area B represents the eye positions if only the neck is flexed $\pm 35^{\circ}$. The entire arc represents neck <u>and</u> torso flexion of $\pm 35^{\circ}$.

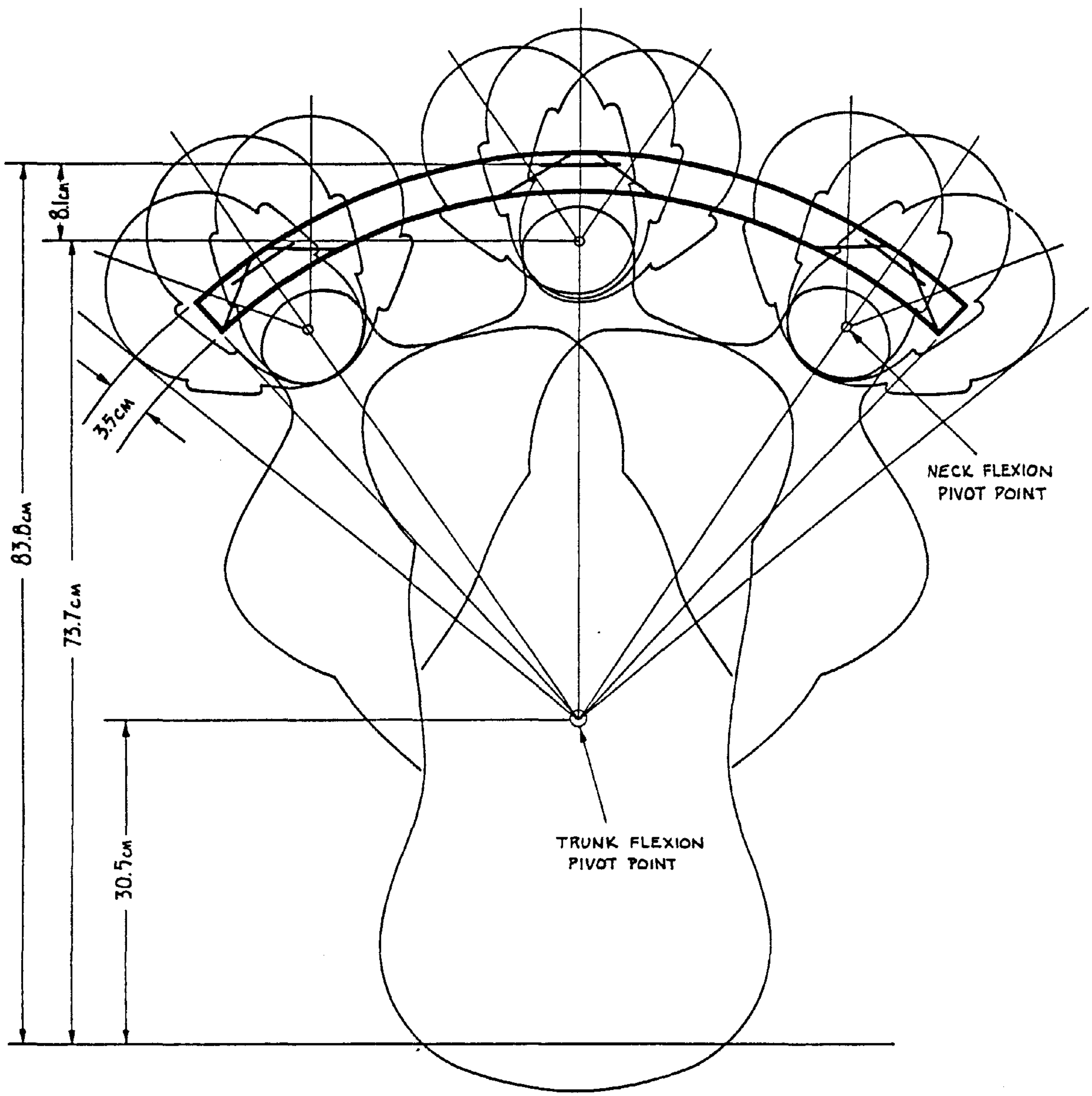


Figure 3-2. Representation of neck and trunk flexion and resulting eye arc used to construct HERMI.

HERMI is constructed for use on non-compressible seats such as is typically found in underground mobile equipment. If a compressible seat is used, the seat must be compressed to compensate for HERMI's construction. The intersection of HERMI's base and "spine" represents the base of the buttocks.

HERMI is constructed of foam-core board, but could be made of sheet metal, plastic or wood. As configured, HERMI represents reasonable operator postures. An actual operator might lean forward to improve visibility or flex more than 35° from side to side. It was decided that vehicles should not be designed to require such movement from the operator in order to see important visual features. The 35° flex angles were considered reasonable. It was assumed that the operator should be able to use a seat back provided without sacrificing visibility.

Procedure for assessing visibility. The procedure for assessing visibility from continuous miners, shuttle cars, and scoops involves the same basic steps. The procedure will be described according to these steps with particular variations noted for different classes of equipment. The procedure described here is based on a "reasonable worst case" scenario. For example, canopies are set at the lowest positions for visibility assessment. Actually, the canopy can be set at different heights and visibility assessed and compared. At a minimum, however, it is recommended that visibility be assessed with the canopy in the lowest position. It is estimated that the following procedure requires 2 persons approximately 3 hours to complete one series of pictures.

Step 1. Place machine in open area. The machine must be placed on a flat surface, and to facilitate access, it is recommended that a clear area approximately 30 ft. in front, 10 ft. to each side, and 15 ft. to the rear be provided. Configure the equipment as follows:

A. Continuous Miner:

1. Canopy - lowest position
2. Floating cab - at frame, ground clearance
3. Cutter head - tram position, at frame, ground clearance
4. Gathering pan - tram position, at frame, ground clearance
5. Tail boom - at frame, ground clearance, position in maximum boom swing for pictures taken at max boom swing position

B. Shuttle Car:

1. Canopy - lowest position
2. Floating cab - at frame, ground clearance
3. Discharge boom (if adjustable) - median machine height

C. Scoop:

1. Canopy - lowest position
2. Floating cab - at frame, ground clearance
3. Scoop - at frame, ground clearance
4. Articulation - straight, aligned with center line of machine

Note: Visibility can be assessed with other configurations if desired, in addition to the configuration described in Step 1.

Step 2. Position HERMI in operator cab. HERMI must be positioned to simulate an actual operator's posture. Position HERMI to be in contact with the seat back. If a compressable seat is used, the seat must be compressed with a weight of 100 lbs. when HERMI is placed on the seat. The eye arcs must be expanded to contact any obstruction, or to their fullest extent, whichever is less. The eye arcs are then rotated so that they are perpendicular to the ground. A level is useful to insure that the arcs are indeed perpendicular. It is suggested that if a photographic record is to be made, that a remotely activated flash be positioned in the cab to illuminate HERMI when the pictures are taken.

Step 3. Determine the pertinent machine dimensions. The following heights must be determined and recorded.

1. Median Machine Height (MMH): The vertical distance from the ground to the overall height of the machine frame.

2. Highest Machine Point (HMP): The vertical distance from the ground to the highest vertical point on the machine.

3. Operator Eye Height (OEH): The vertical distance from the ground to a point midway between the eye arcs on HERMI.

4. Canopy Height (CH): The vertical distance from the ground to the highest point on the canopy.

5. Seam Height (SH): The anticipated minimum vertical distance from the ground to the roof in which it is reasonably likely the machine will be operated. (For purposes of this report, seam height was assumed to be 12 inches above the highest machine point. Although arbitrary, this value probably represents a reasonable clearance for many mines.)

6. Maximum Boom Height (MBH) - continuous miners only.

7. Maximum Cutter Head Height (MCH) - continuous miners only.

In addition to heights, the following reference points must be identified and marked (see Appendix A):

1. Widest machine points (both sides)
2. Front edge
3. Rear edge
4. Operator's head position
5. Machine center line
6. Operator center line
7. Necessary stopping distance

Step 4. Mark visual attention locations. It has been the project teams experience that the assessment procedure is aided by determining the position of all the visual attention locations first, and marking these on the floor before taking any pictures. Further, a tripod or pole should be used to position the camera (or sight glass if pictures are not made). The pole, or tripod can be marked for the various vertical heights measured in Step 3. This will facilitate Step 5.

Step 5. Sight or photograph HERMI. It is strongly recommended that black and white photographs be taken at each visual attention location, rather than using a sight glass. The camera is positioned at the proper heights, and a picture is taken of the operator's compartment. A flash is recommended. A remote photosensitive cell can be used to trigger a flash positioned inside the cab. It is recommended that a 50mm lens be used. Pictures taken at the necessary stopping distance may even require a 100mm lens.

Step 6. Determine visibility. It is recommended that oversized proof sheets be made (2x2-1/2 inch pictures). This is inexpensive, easy to work with, and provides enough detail to obtain all the necessary information. For each photograph, record what parts of HERMI are visible. The following categories are to be used:

95th percentile eye arc:

- center (solid black)
- neck flexion (striped)
- torso flexion (white)

5th percentile eye arc:

- center (solid black)
- neck flexion (striped)
- torso flexion (white)

Refer to Section 3.7 for a discussion of how good the visibility should be for acceptability.

3.3 Design Limitations of HERMI

HERMI, as designed in this study, must be viewed as a first generation eye reference measurement instrument. During this project, the following limitations with the design of HERMI were noted which should be corrected to improve the validity of the information gathered:

1. The 5th percentile eye ring assumes that such a person would assume the same posture as a 95th male in the cab. Thus, in a low canopy cab, the 95th male would have to move his buttocks forward in the seat. A 5th percentile female, on the other hand, could sit more erect. The current design of HERMI does not permit this. The next generation HERMI should be designed to incorporate such independent posturing.

2. HERMI, as designed, does not automatically take into account clearance requirements between the eyes and the top of the canopy necessary to accomodate the hardhat and cap lamp of the miner. One study (Farrar, Champney, and Weiner, 1974) established that the distance from eye level to the top of the hardhat is 6.5 inches (16.5 cm) and further recommends one to two inches (2.5 - 5.0 cm) clearance between the hard hat and canopy. Taken together, then, approximately 8 inches (20 cm) should be provided above HERMI's eye rings. This will tend to lower the position of the eye rings in the canopy. The photographs to be presented in Sections 3.4, 3.5 and 3.6 of this report, therefore, probably overstate the visibility for the 95th percentile male in the case of low canopies.

3. HERMI incorporates only neck and torso flexion by operators and does not include gross postural changes. Although a limitation, the project team believes that gross postural changes should not be required to see important visual features (except, of course, for turning around to see behind the operator), and, hence, were not incorporated into the design of HERMI.

4. The positioning of HERMI does not take into account the use of "seating aids" such as pillows, wood blocks, etc. which could be used by small operators to increase their seating height. As HERMI is presently configured, such aids, if placed in the cab, would also affect the 95th percentile eye ring. By incorporating independent posturing of the 5th and 95th percentile rings, seating aids could be used. A problem, however, is determining what seat aids to incorporate. Currently, there is no information which describes seating aids used by small operators in underground equipment.

The reader should keep these limitations in mind when reviewing the assessments of continuous miners, shuttle cars, and scoops presented in Sections 3.4, 3.5, and 3.6

3.4 Assessment of Continuous Miners

Two continuous miners, one drum head and one auger, were evaluated using the HERMI methodology and the visual attention areas listed in Section 2.0 of this report. The drum head continuous miner was evaluated twice, once with the canopy in the highest position and once with the canopy in the lowest position. Dimensions of these machines are contained in Table 3-2. These particular machines were selected based on availability. While being representative of drum head and auger continuous miners, these machines were not selected because of any unique visibility problems or attributes.

Figure 3-3 presents a side-by-side comparison of HERMI pictures taken with the drum head miner canopy in the highest and lowest positions. The numbers in the upper right corner of each picture corresponds to the visual attention locations listed in Table 2-5. The quality of some of the pictures is poor; this was caused by changing light conditions, failure of the remote flash to shoot, etc. The philosophy employed in taking the pictures was to simulate an actual HERMI evaluation. In such an evaluation, it should not be necessary to employ elaborate lighting in order to obtain usable pictures. In essence, then, this was a test to determine if simple, "rapid-fire," techniques could be used. The answer is an unqualified "yes." In fact, the pictures of the auger were made outdoors at dusk and were so dark that they could not be reproduced in this report, yet on the original pictures, HERMI's eye rings are clearly visible, but the machine features are not. In Figure 3-3, some of the corresponding pictures look different (e.g., 1, 3, 7, 9). This is because different lenses were used (100 mm and 55 mm).

In some cases, a picture from a series is missing. There are several reasons for this. In some cases, the canopy was not visible, being totally obstructed from view or the picture would be identical to another picture in the series and, hence, there was no need to take them. In other cases, the resulting picture was too dark to reproduce for this report, or the picture could not be taken because objects in the shop prevented the positioning of the camera (e.g., walls, lockers, tables). In such cases, other pictures in the series could be used to "interpolate" what parts of HERMI would be visible from the missing location. Figure 3-3 contains only those pictures for which the corresponding high canopy and low canopy pictures were available.

Figure 3-3 drammatically illustrates the effect of raising or lowering the canopy on visibility. With the canopy in the lowest position, vision is severely restricted. The situation is considerably better with the canopy raised. This is especially obvious in pictures 7, 9, 11, 14, 16, and 17, among others.

TABLE 3-2

Dimensions of Continuous Miners Evaluated

Dimension	Drum Head Canopy Low	Drum Head Canopy High	Auger
Length	32.5 ft.	32.5 ft.	24.0 ft.
Width	10.5	10.5	9.0
Operator's Eye Height	3.6	4.6	2.2
Median Machine Height	3.25	3.25	1.7
Highest Machine Height	4.12	5.25	2.6
Seam Height	5.12	6.25	2.7
Maximum Cutter Height	12.10	12.10	2.7
Canopy Height	4.12	5.25	None

Figure 3-3. Visibility comparison of a continuous miner with canopy in highest and lowest positions.

Canopy High

Canopy Low

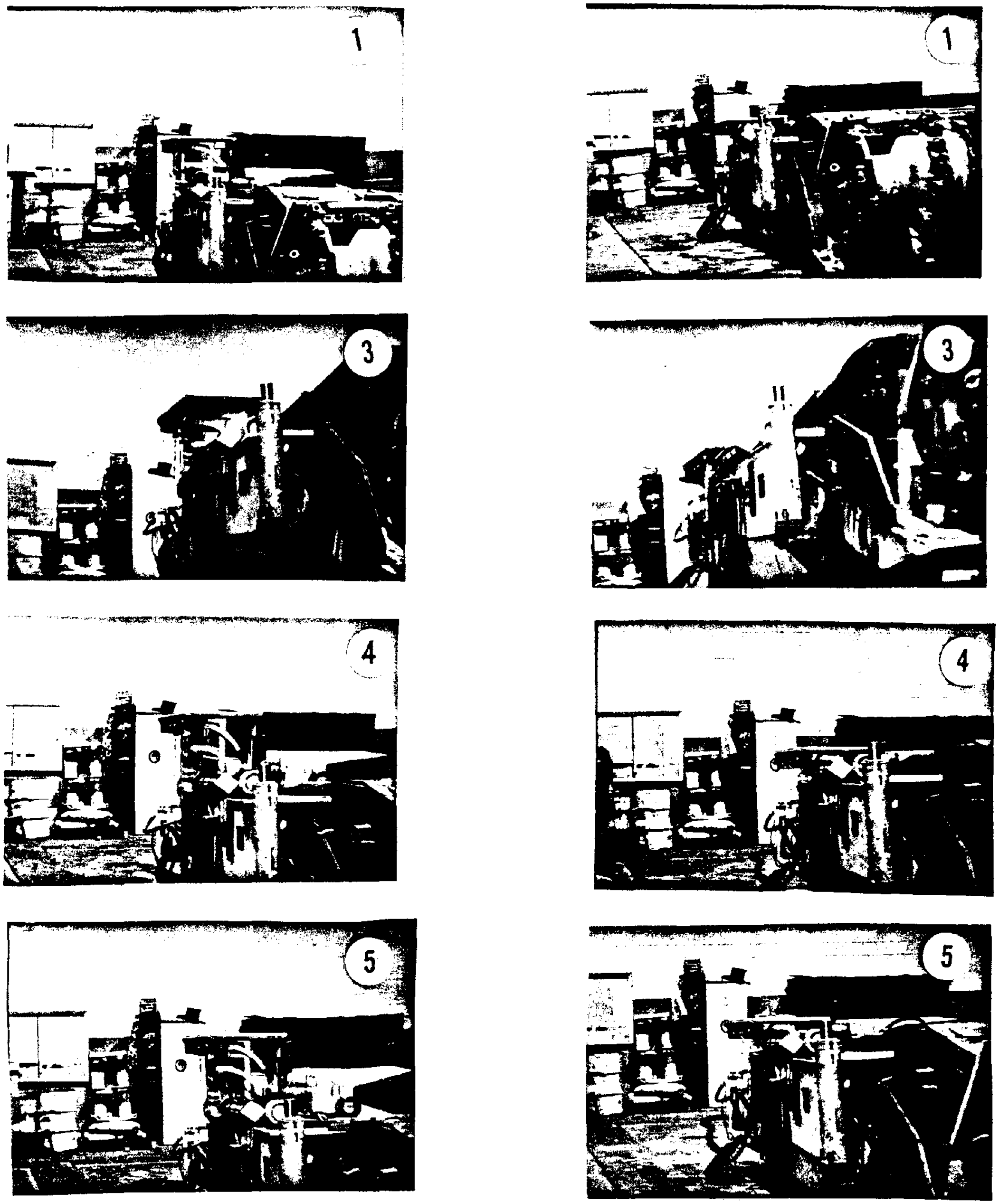


Figure 3-3. Visibility comparison of a continuous miner with canopy in highest and lowest positions. (Cont.)

Canopy High | Canopy Low

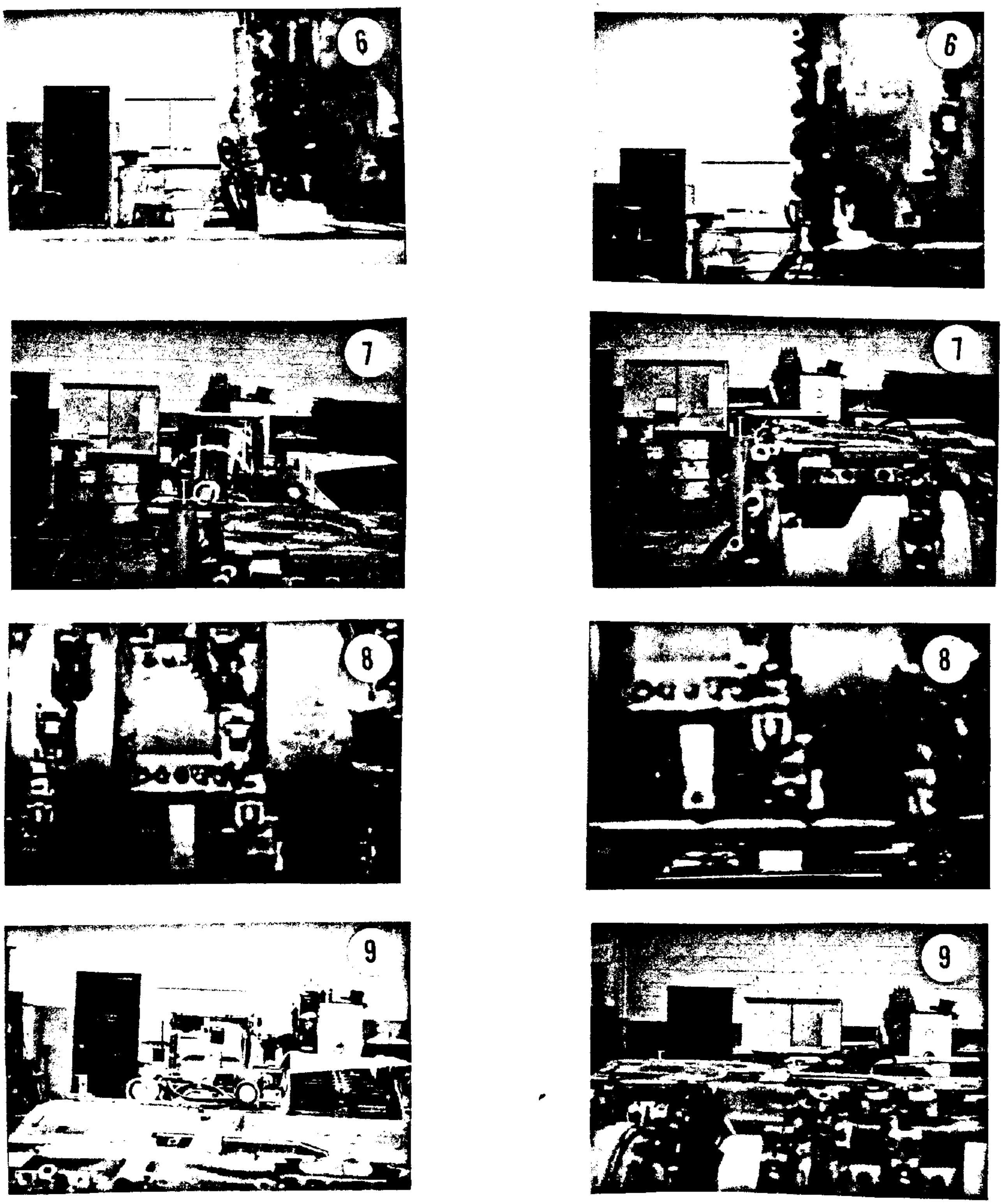


Figure 3-3. Visibility comparison of a continuous miner with canopy in highest and lowest positions.

Canopy High

Canopy Low

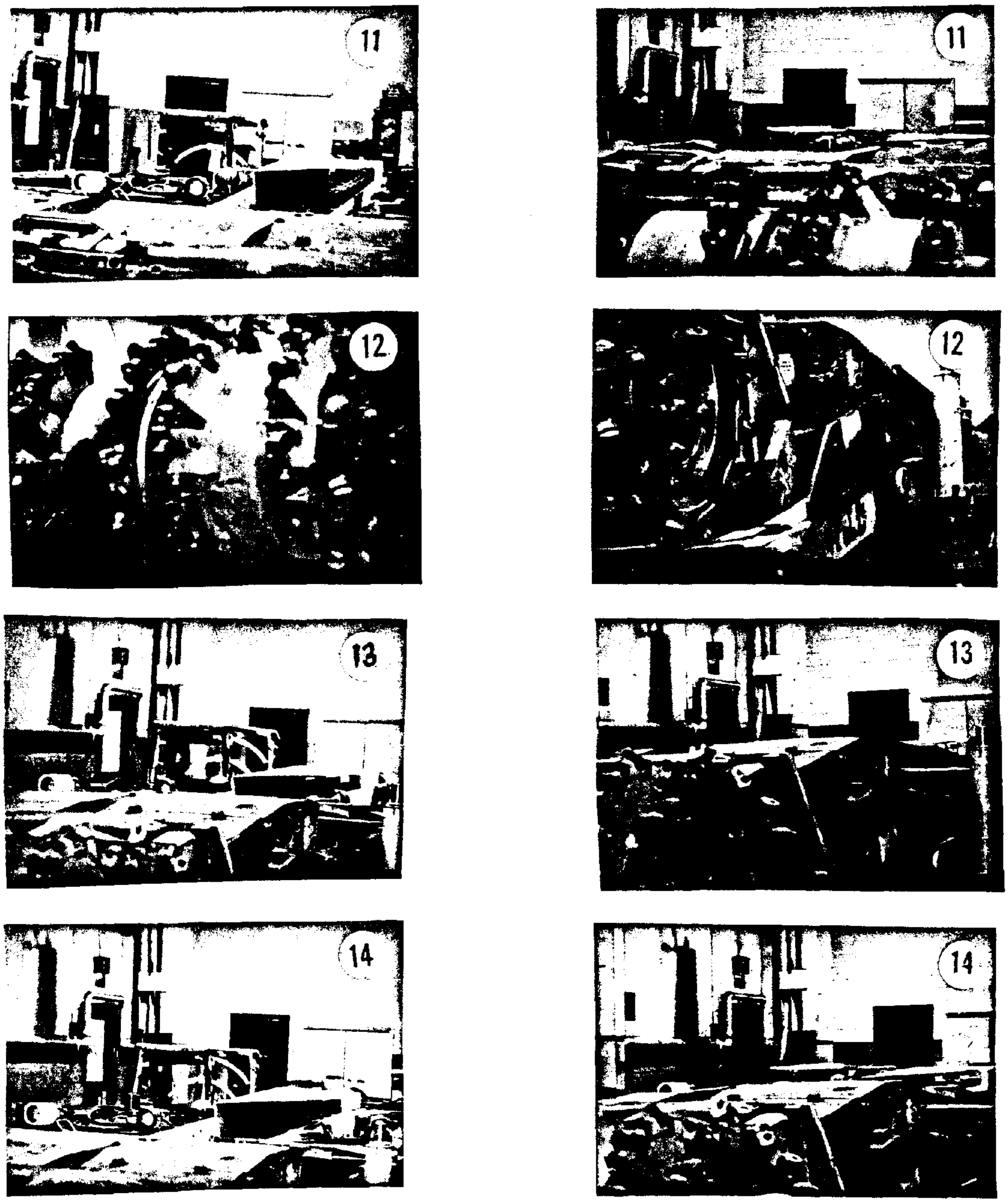


Figure 3-3. Visibility comparison of a continuous miner with canopy in highest and lowest positions. (Cont.)

Canopy High

Canopy Low

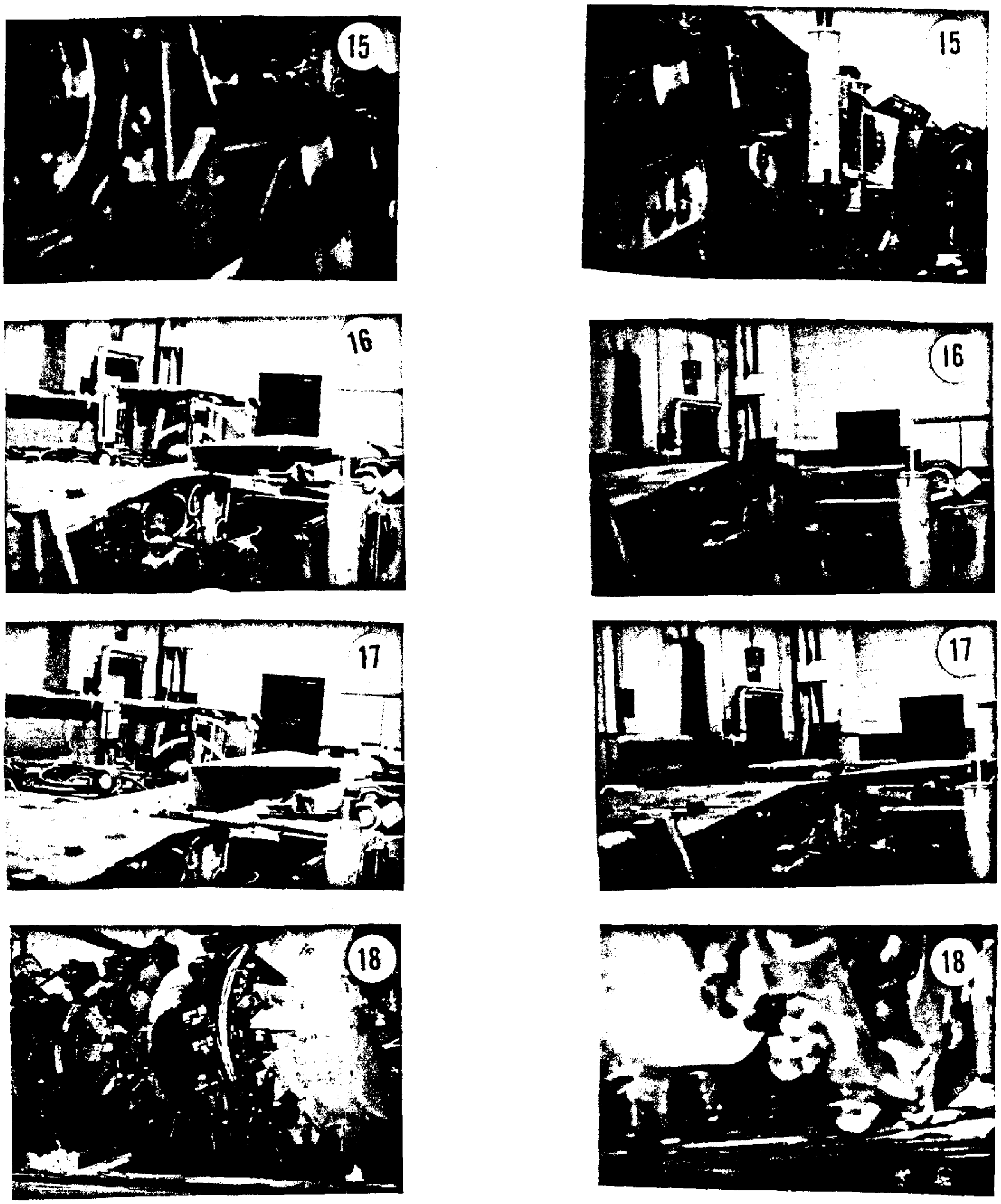


Figure 3-3. Visibility comparison of a continuous miner with canopy in highest and lowest positions. (Cont.)

Canopy High | Canopy Low

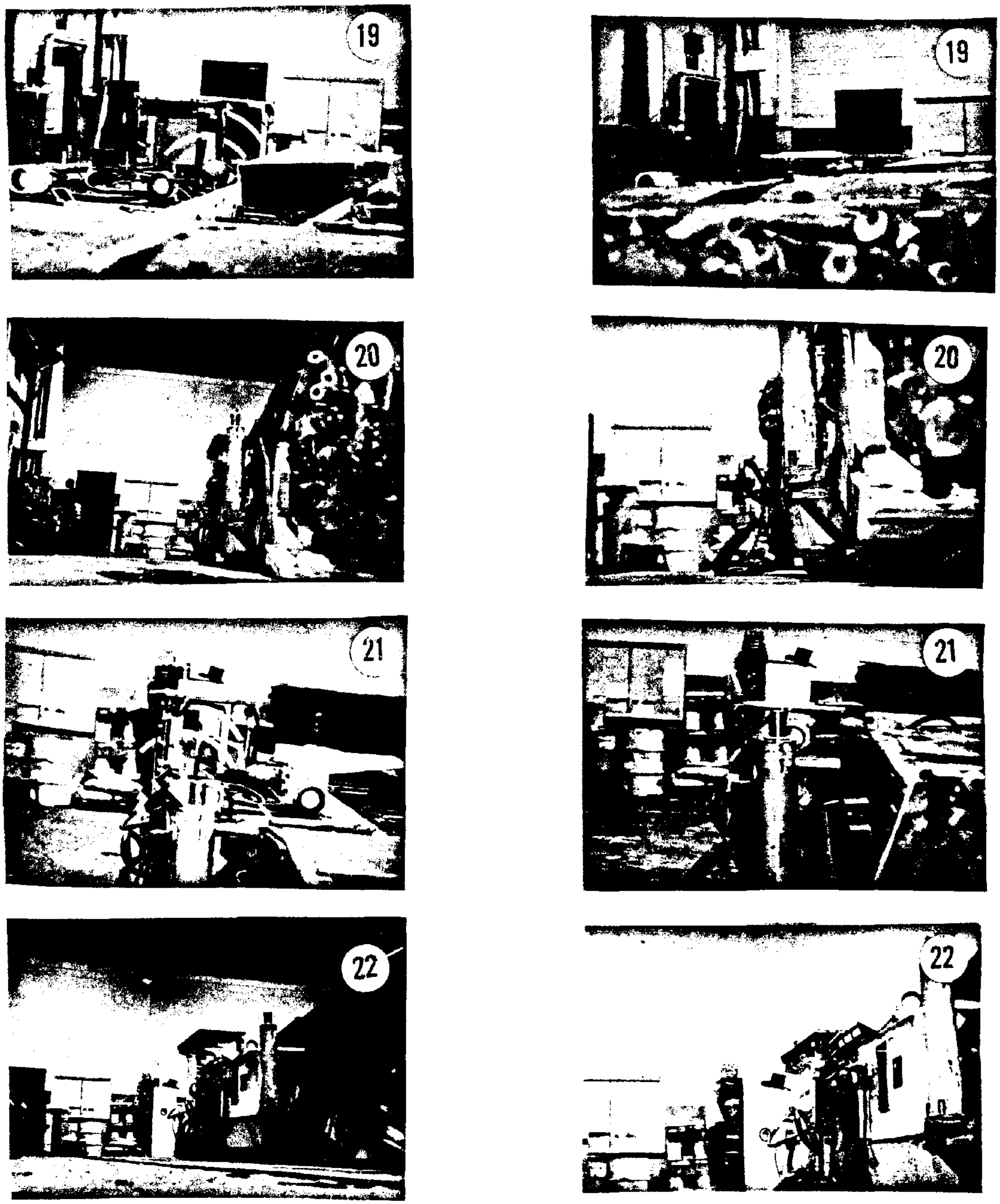


Figure 3-3. Visibility comparison of a continuous miner with canopy in highest and lowest positions. (Cont.)

Canopy High

Canopy Low

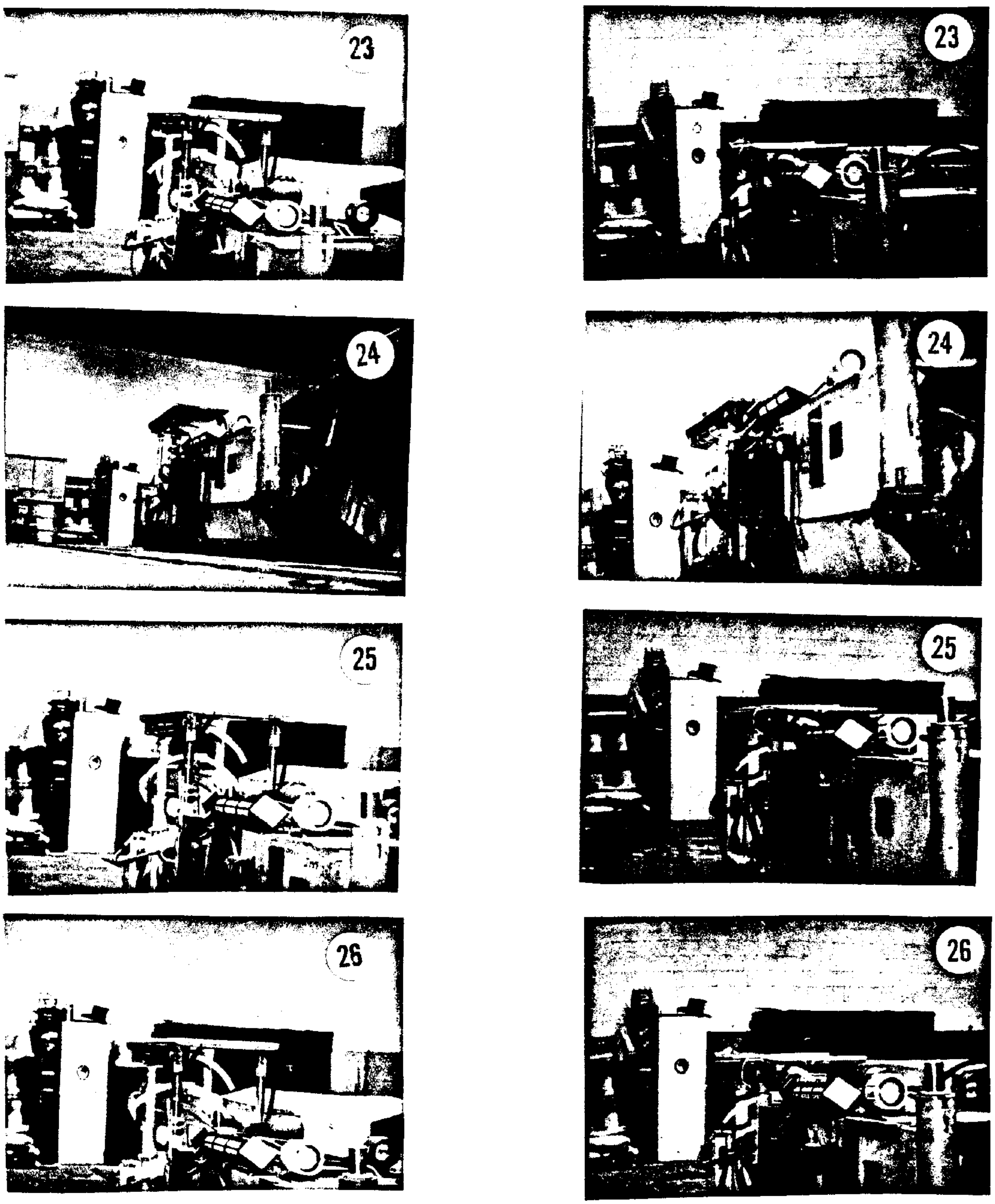


Figure 3-3. Visibility comparison of a continuous miner with canopy in highest and lowest positions. (Cont.)

Canopy High | Canopy Low

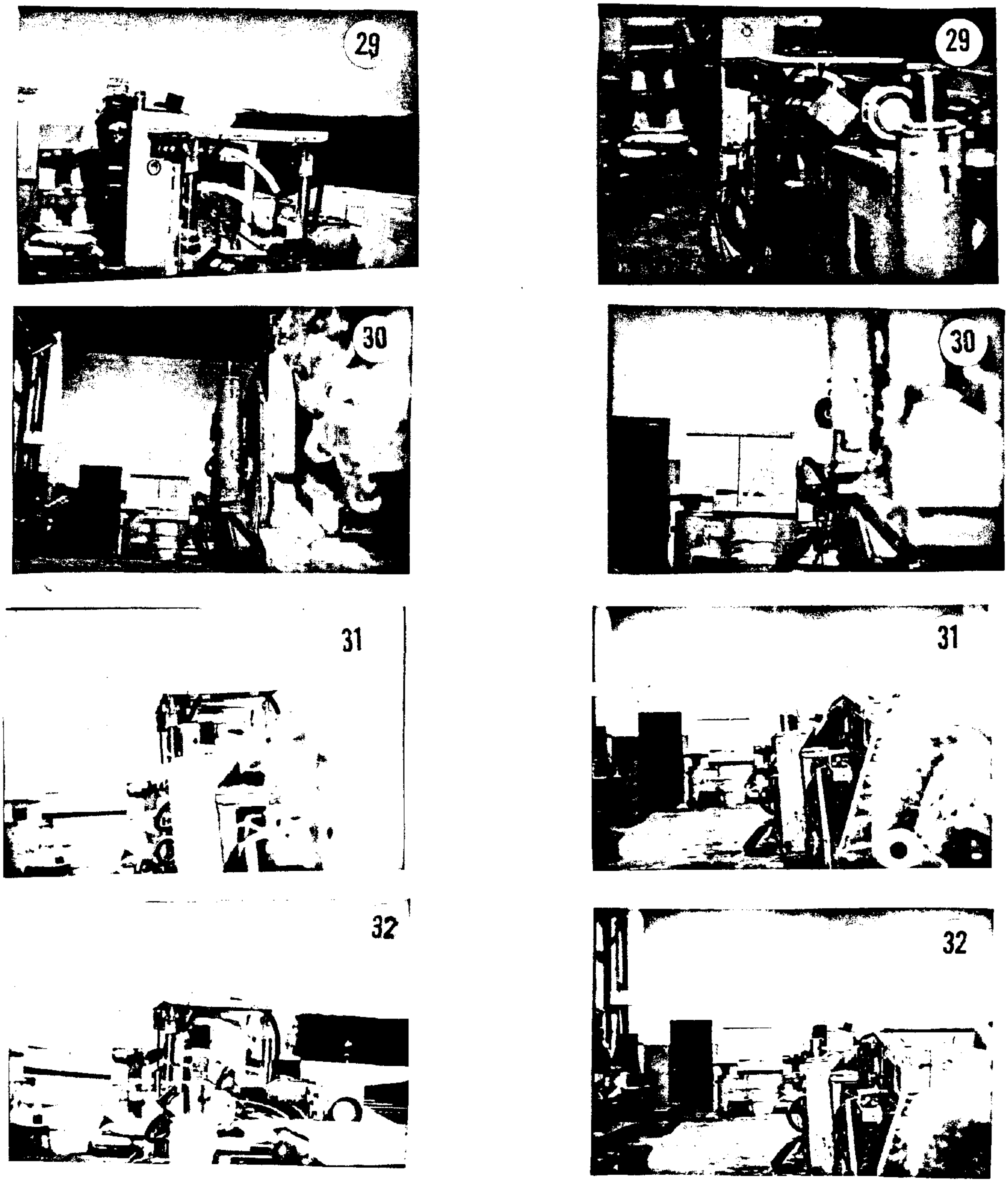
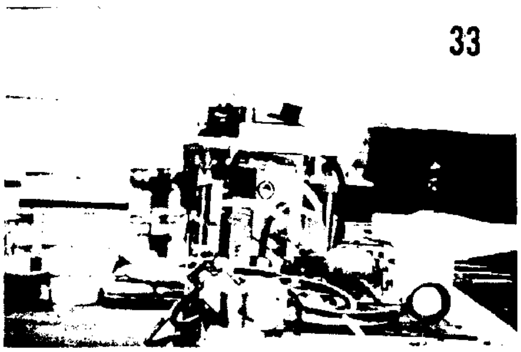
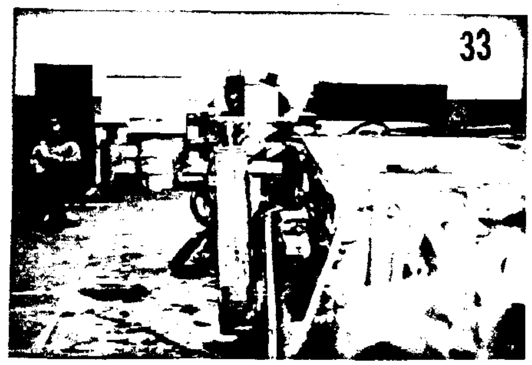
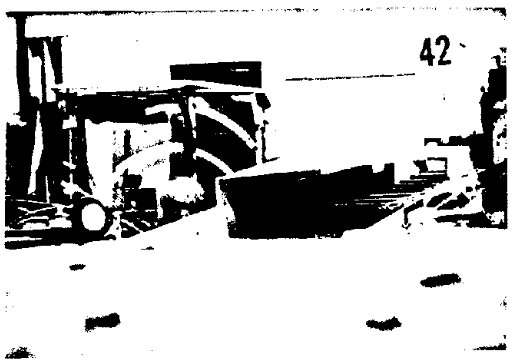


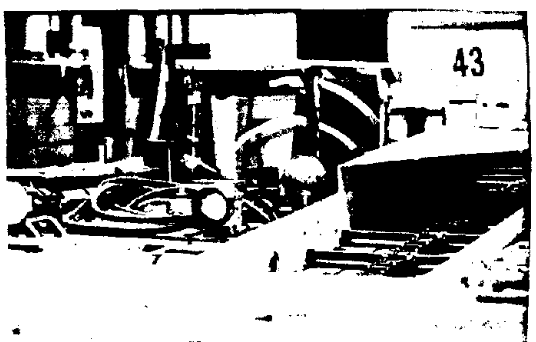
Figure 3-3. Visibility comparison of a continuous miner with canopy in highest and lowest positions. (Cont.)

Canopy High | Canopy Low









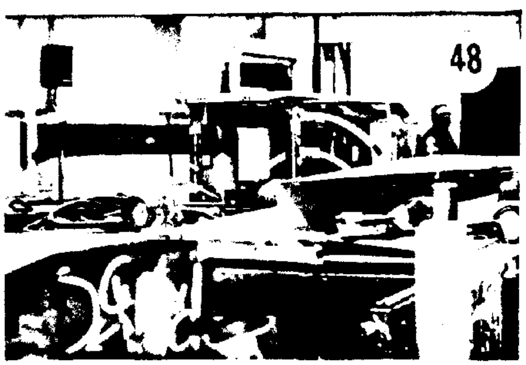


Figure 3-3. Visibility comparison of a continuous miner with canopy in highest and lowest positions. (Cont.)

Canopy High

Canopy Low

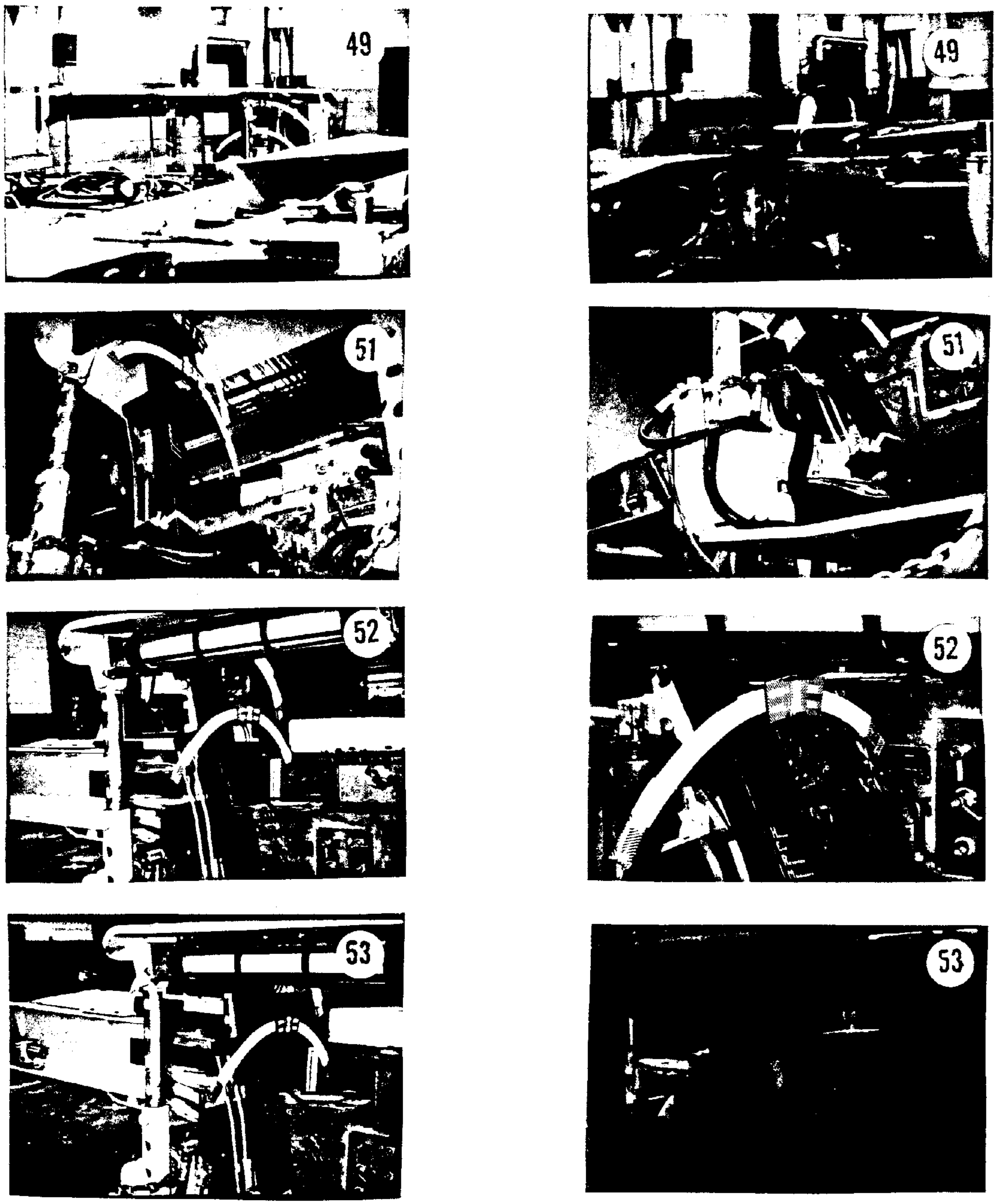
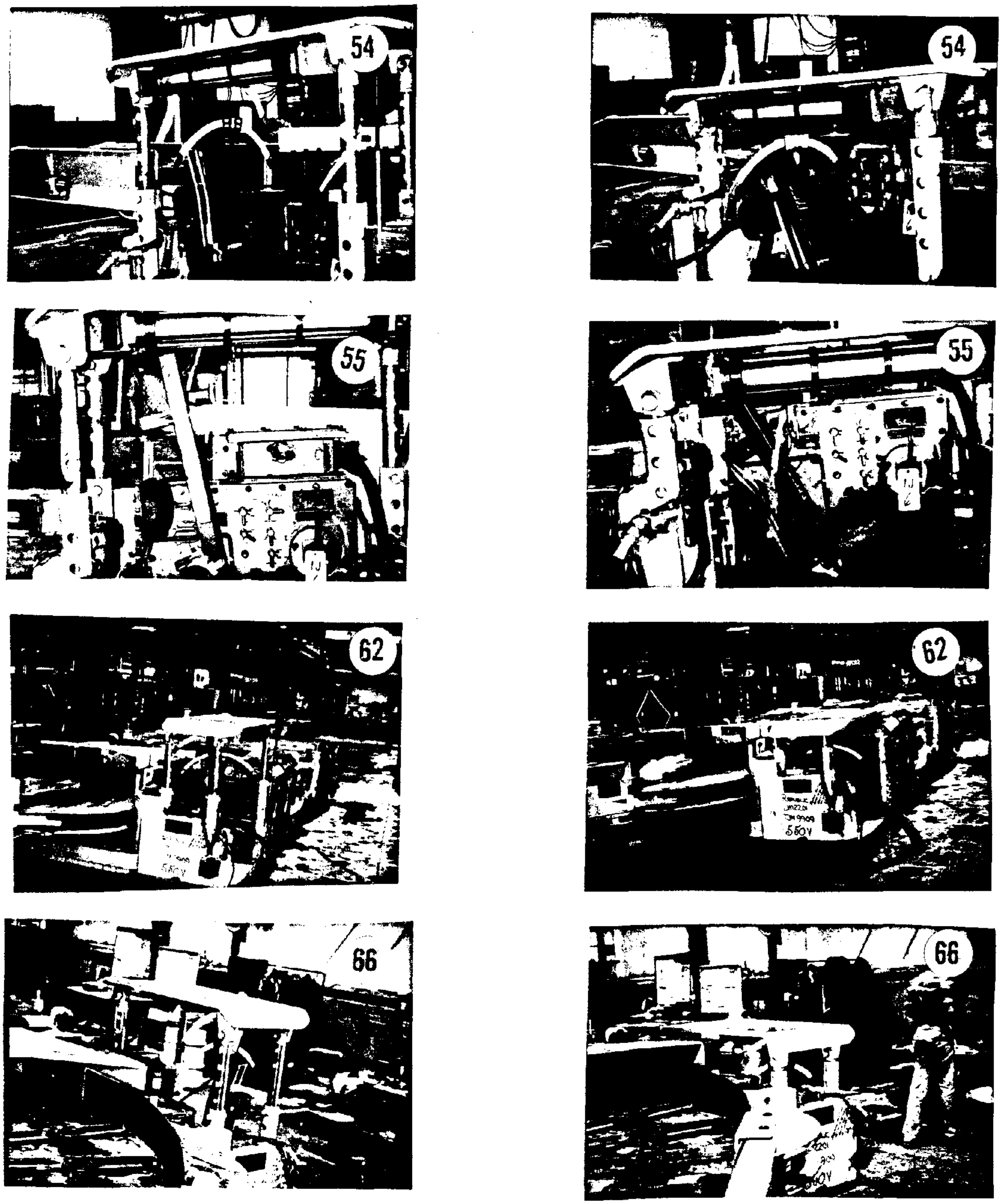


Figure 3-3. Visibility comparison of a continuous miner with canopy in highest and lowest positions. (Cont.)

Canopy High | Canopy Low



Several design features of this particular machine result in restricted visibility. The position of the fluorescent lights on the side and in front of the operator's cab is one example. The light on the side of the cab prevents the 95th percentile operator from flexing his torso to see. This is shown vividly in pictures 25 high, 52 high, 53 high, and 54 high and low. The light in front of the cab obstructs vision in the low canopy condition for the small operator as shown in pictures 4 low, 5 low, 23 low, and 26 low.

Another example of design obstructions is the placement of the canopy supports and hoses. Pictures 23 high, 25 low and high, 29 high and 43 high show how the canopy post and hose obstructs vision in the center of HERMI's eye arcs, thus requiring an operator to flex his torso to see the visual attention area. Pictures 62 high and low, also show the effect of the slope in the rear of the canopy. The large operator, to see behind, must turn and bend to see under the rear of the canopy.

These pictures show the consequence of design on visibility, and suggest alterations to improve visibility.

As previously mentioned, the pictures of the auger came out too dark to reproduce here. In lieu of presenting the HERMI pictures, a 360 degree panorama picture was produced from the auger. Figure 3-4 diagrammatically presents the distances from the operator where the floor is and is not visible. The eye position was the same as used to produce the HERMI pictures. Note, Figure 3-4 shows only the visibility of the ground; an entirely different diagram would result if visibility were measured from a height of, say, three feet rather than ground level. Additional panorama graphics of the auger were not produced due to the time and effort required and the limited resources of this project.

3.5 Assessment of Shuttle Cars

Two shuttle cars were evaluated using the HERMI methodology. One shuttle car was configured with the operator compartment located between the wheels. The pictures of this car were taken outdoors at dusk, and the photographs were too dark to reproduce for this report. The second car evaluated was configured with the cab forward of the wheels, thus the operator is in the front traveling in one direction, and in the rear traveling in the other direction. For this car, the complete series of pictures was produced for each direction of travel. Table 3-3 presents the salient dimensions of the shuttle cars evaluated.

Figures 3-5 and 3-6 present selected pictures comparing visual attention location visibility for the two directions of travel (operator in front versus operator at rear). Figure 3-5 shows corresponding pictures in which visibility of that location is better when the operator is in front, as would be expected. However, at some visual attention locations, visibility was

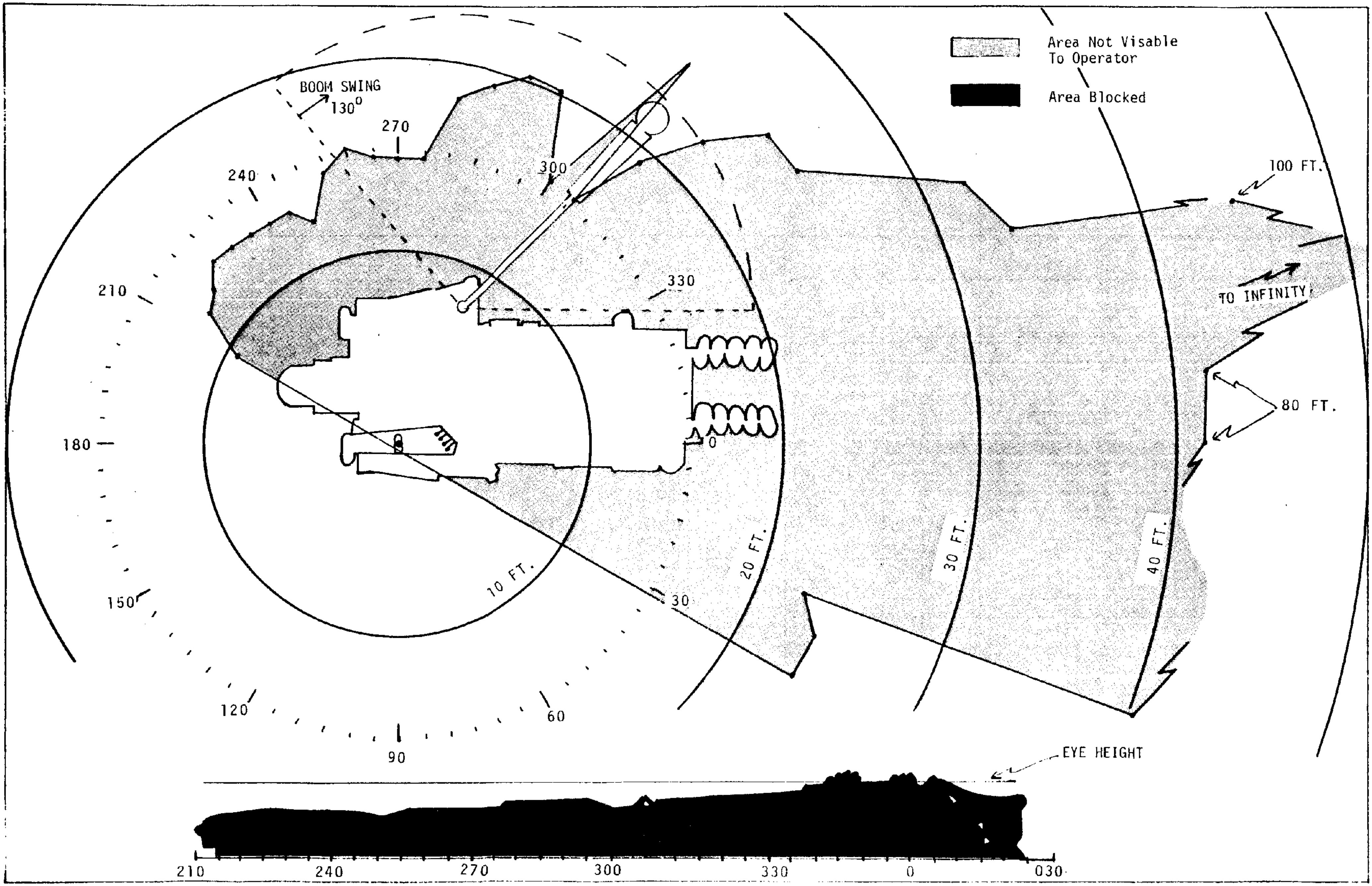


Figure 3-4. Visibility at ground level for auger continuous miner, produced from 360 degree panorama photograph.

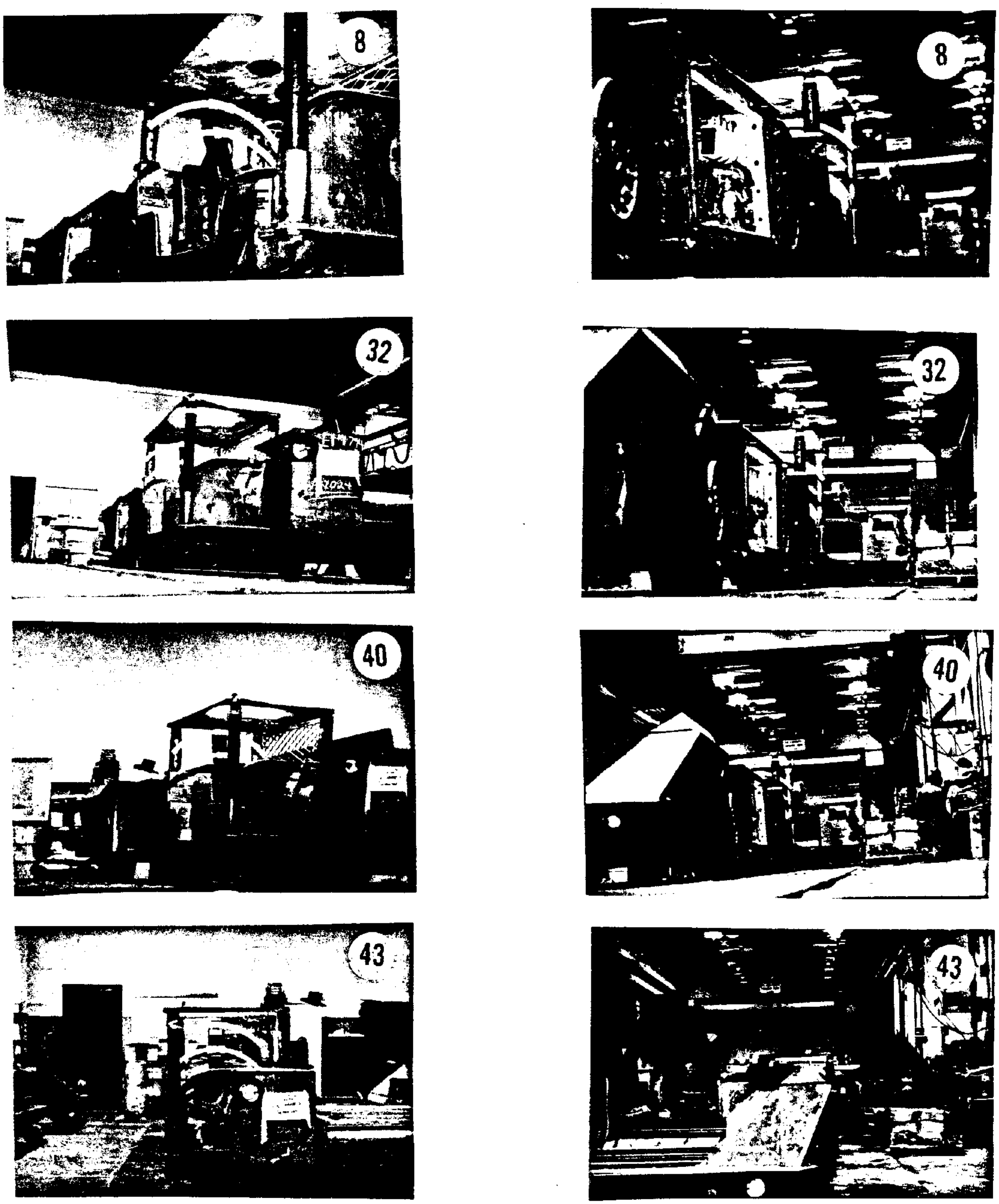
TABLE 3-3

Dimensions of Shuttle Cars Evaluated

Dimension	Cab Between Wheels	Cab Ahead of Wheels
Length	24.75 ft.	27.25 ft.
Width	9.12	9.00
Operator's Eye Height	3.00	3.37
Median Machine Height	2.62	2.81
Highest Machine Height	2.63	3.92
Seam Height	3.33	4.92
Canopy Height	None	3.92

Figure 3-5. Sample of visual attention locations in which visibility is better when the shuttle car operator is in the front.

Operator in Front | Operator at Rear



actually better with the operator at the rear. A sample of these is shown in Figure 3-6. The numbers in the upper right hand corner of the pictures corresponds to the visual attention locations listed in Table 2-6.

The cases where visibility is better when the operator is at the rear of the machine as compared to the front are due to the canopy and support posts obscuring vision to that visual attention location. Theodore Barry and Associates (1972) report that 75 percent of all shuttle car fatalities occur when traveling from the face to the dump when the operator is in the front of the vehicle. This is counter to any expectations based upon assuming lack of visibility as the causal factor in accidents. One explanation is that contacts with roof, ribs, overhangs, etc. are more likely to kill the operator if he is at the front of the machine. When he is at the rear, the front of the machine itself may contact the obstruction first, rather than hitting the operator.

Figure 3-7 presents a diagrammatic picture taken from one eye position of ground visibility when the operator is at the rear of the machine. This diagram was generated based on data from a panorama picture. Virtually none of the ground is visible ahead or behind the machine. Note, however, that obstructions at, or a little above eye level, would be visible everywhere except in the areas blocked by the canopy support posts (dark areas in Figure 3-7).

3.6 Assessment of a Scoop

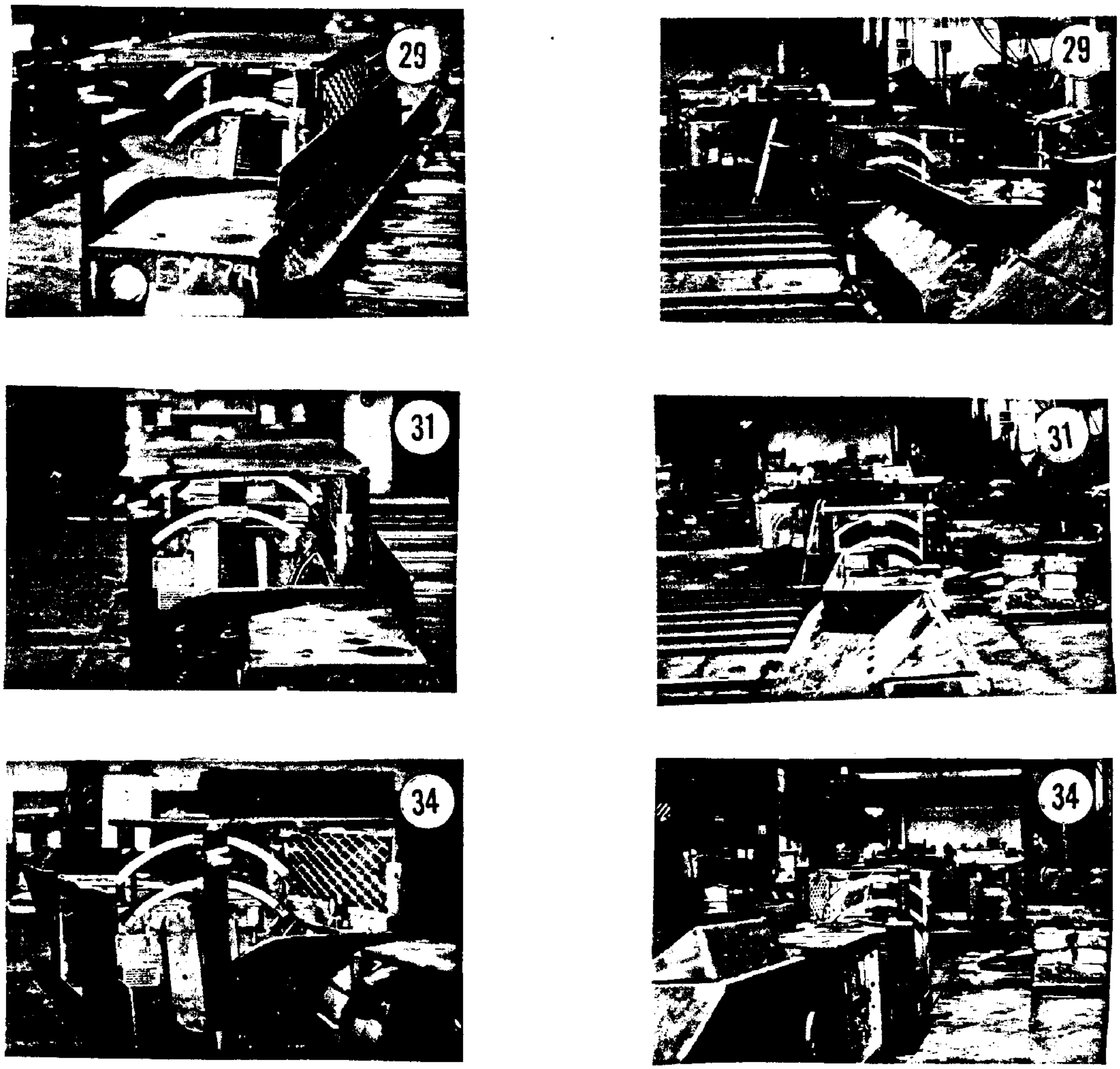
A single scoop was evaluated using the HERMI technique. The dimensions of the scoop are as follows:

Length	27.50 ft.
Width	9.42
Operator's Eye Height	3.58
Median Machine Height	2.67
Highest Machine Height	4.17
Seam Height	5.17
Canopy Height	4.17

Figure 3-8 presents selected photographs from the various visual attention locations. Rather than present the full set of photographs, only one photograph at each location is presented. The other pictures differ from those presented in terms of camera height. The numbers in the upper right corner of each picture correspond to the visual attention locations listed in Table 2-7. Overall, visibility from this particular scoop is very good.

Figure 3-6. Sample of visual attention locations in which visibility is better when the shuttle car operator is at the rear.

Operator in Front | Operator at Rear



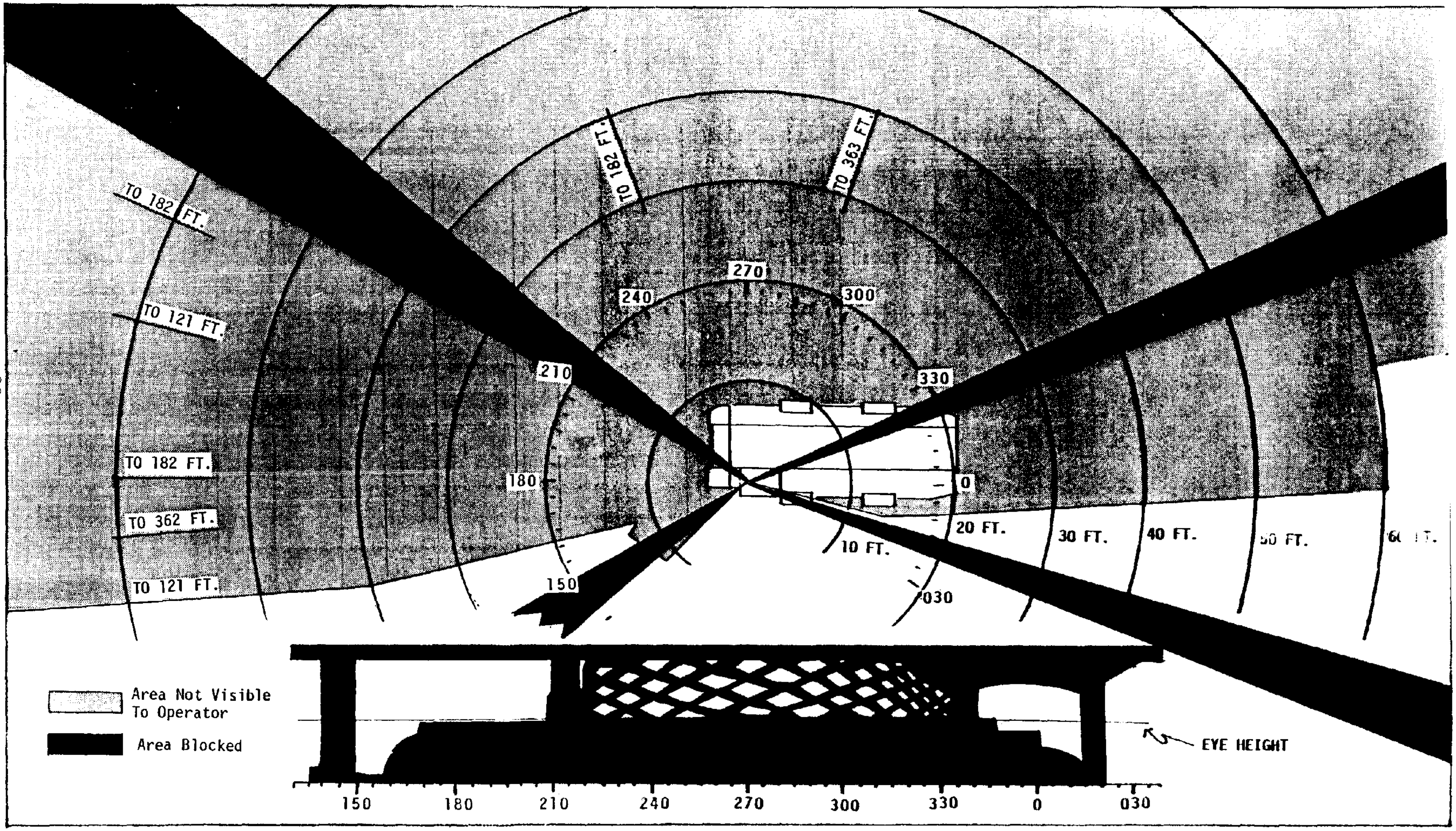


Figure 3-7. Visibility at ground level for shuttle car with operator at the rear, provided from 360 degree panorama photograph.

Figure 3-8. Selected HERMI pictures showing visibility from a scoop.

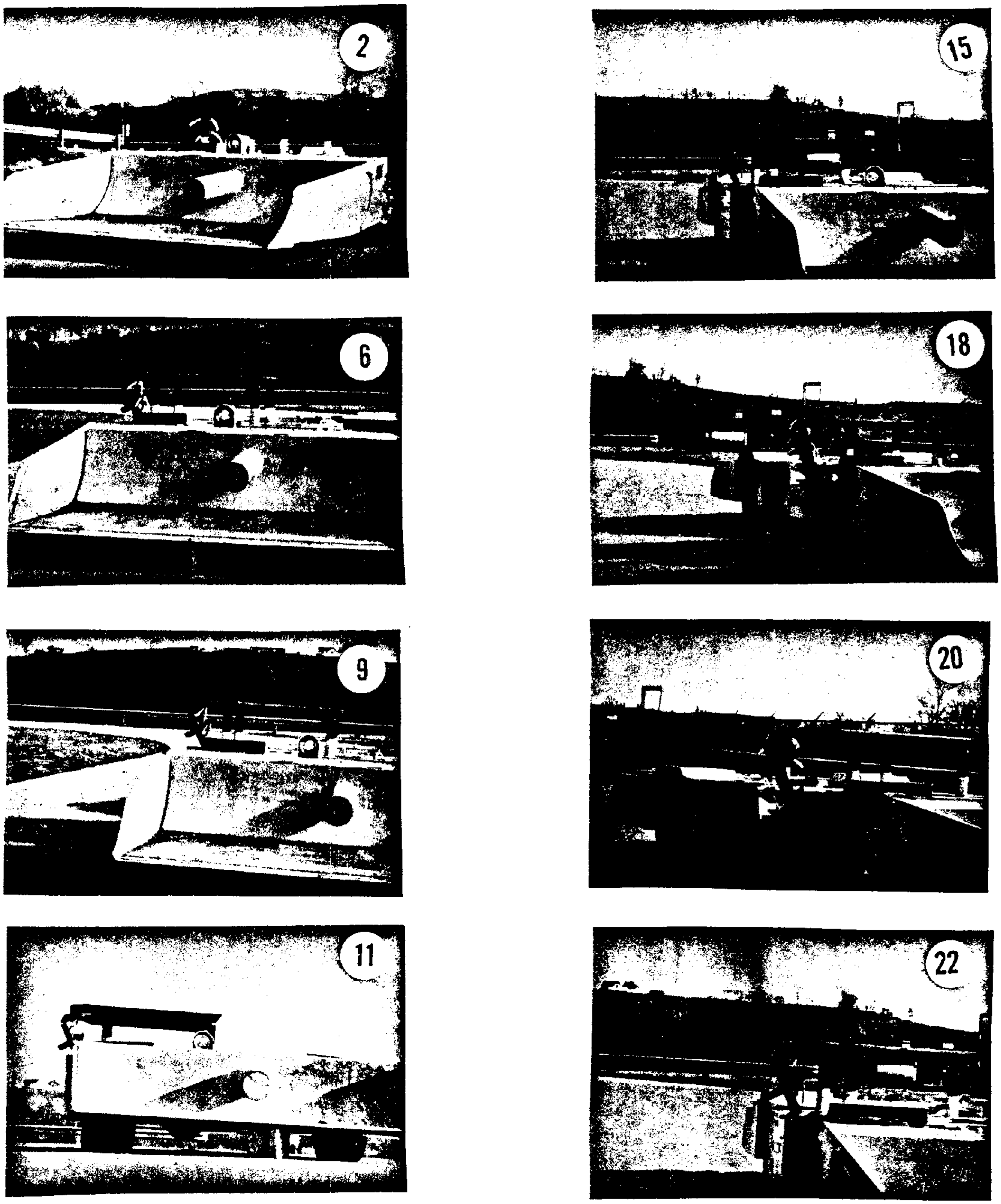


Figure 3-8. Selected HERMI pictures showing visibility from a scoop. (Cont.)

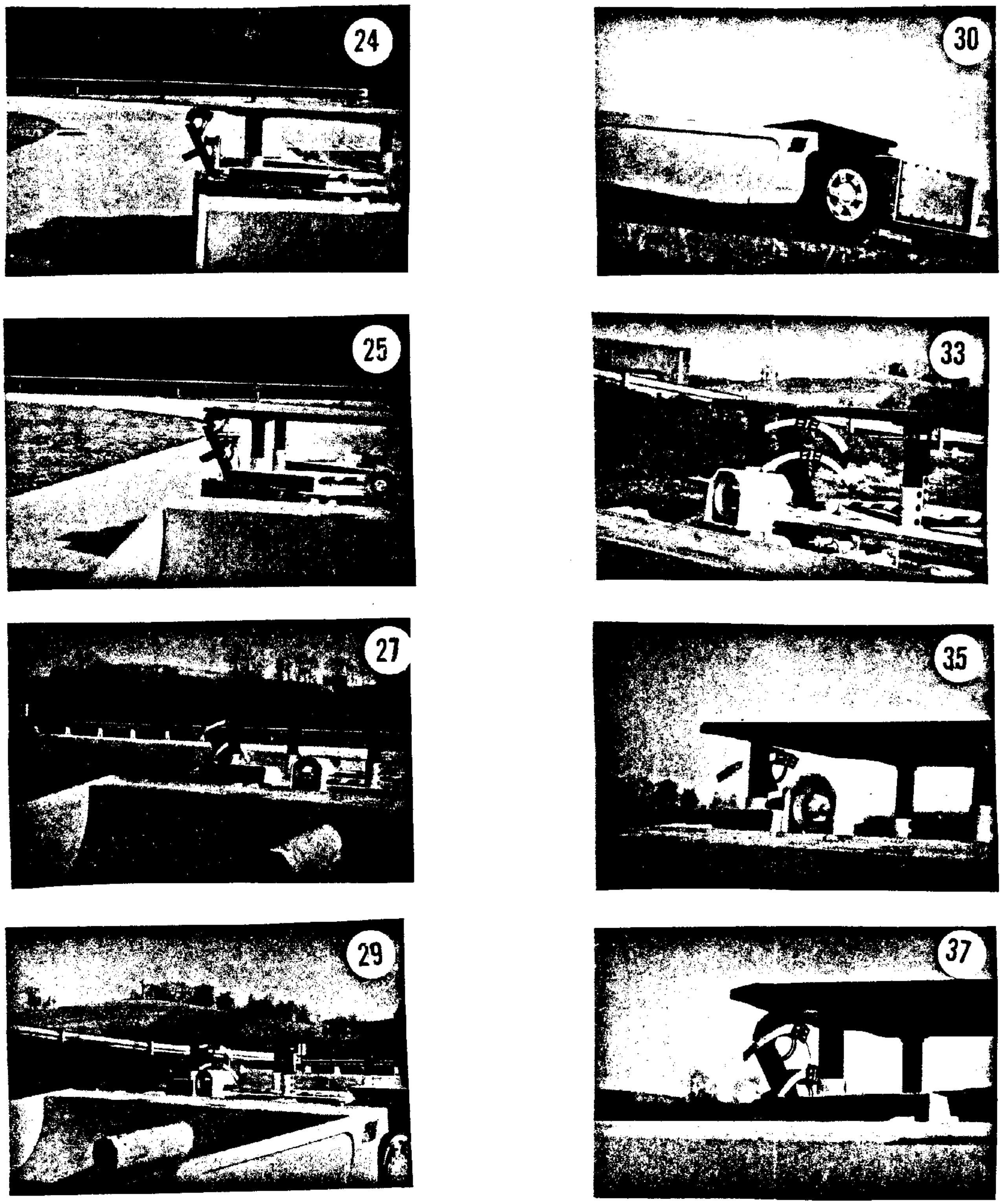
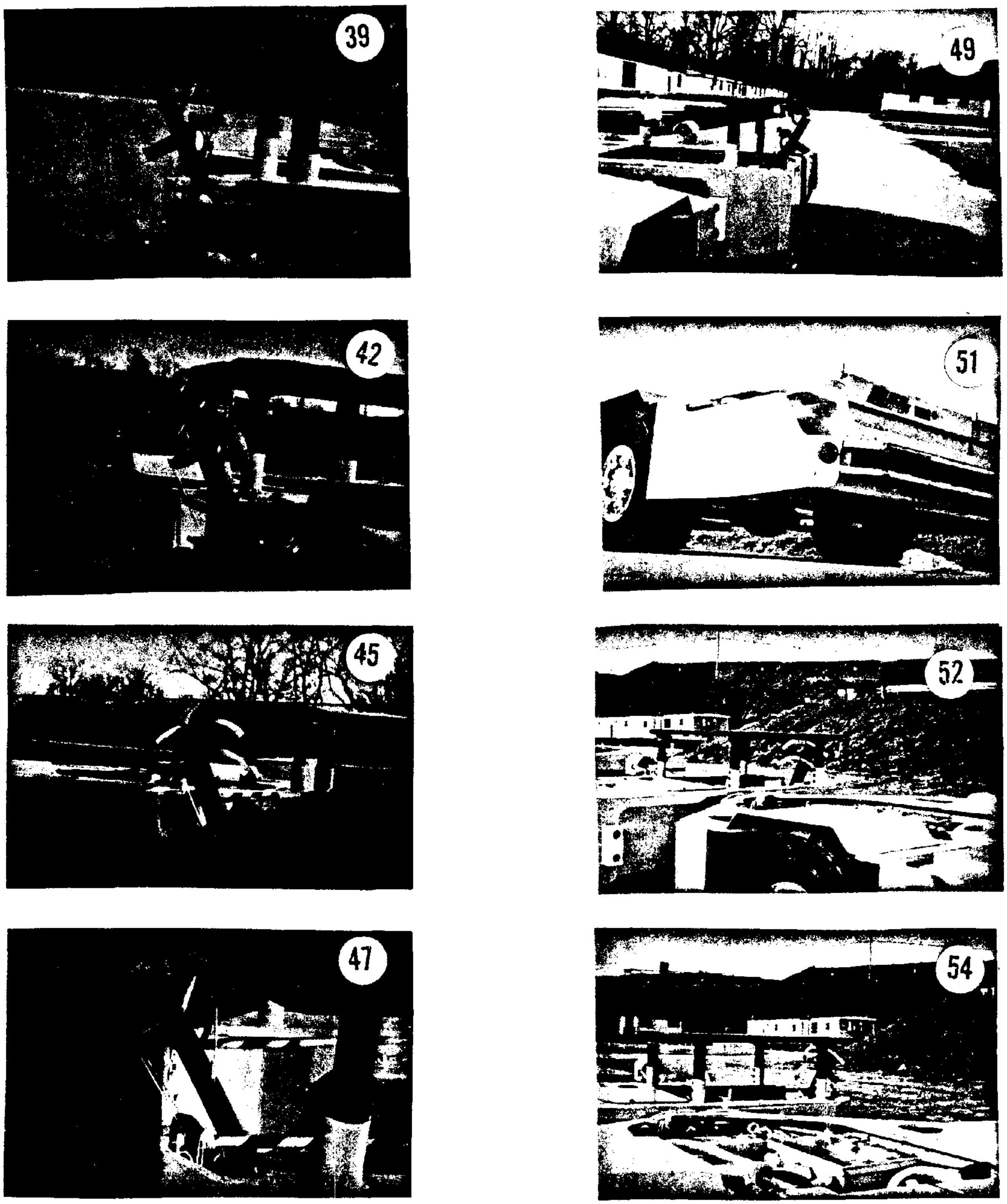


Figure 3-8. Selected HERMI pictures showing visibility from a scoop. (Cont.)



Only 4 of the 54 visual attention locations can not be seen at all from the operator's position. The principal reason for the good visibility is that the operator's eye height is above the median machine height. Figure 3-9 presents a diagram of the ground visibility produced from a panorama photograph. Compared to the continuous miner and shuttle car previously presented, ground visibility for this scoop is distinctly better.

3.7 How Good is Acceptability?

From the limited sample of shuttle cars, continuous miners, and scoops evaluated in Sections 3.4, 3.5, and 3.6, it is readily apparent that it will be virtually impossible to see some of the visual attention locations unless equipment is radically reconfigured. The critical question is whether all the visual attention locations must be seen in order for a machine to have an adequate field of view. The answer, undoubtedly, is "no." This is the logical consequence of the fact that visual features located at one visual attention location can be redundant sources of information to visual features located at another visual attention location.

In approaching the question of how good is acceptable, one can envision a scale of "goodness" ranging from high to low. The question then transforms itself into assigning a cut-off point along the scale which separates acceptable from unacceptable levels of goodness. The first step toward establishing this cut-off is to attempt to quantify the evaluation of visibility so that specific equipment can be placed on the scale of goodness. To do this, we can list some factors which should influence the level of goodness associated with a particular machine. Generally speaking, the more visual attention locations that can be seen, the better it is (i.e., the higher the level of goodness). Further, the less body movement (i.e., neck and torso flexion) required to see the visual attention location, the better the visibility from the equipment. In addition, the greater the percentage of operators that can see a visual attention location, the better the visibility from the machine. Thus, if the 95th percentile operator could see the location but the 5th percentile operator could not, this would be less acceptable than if both the 95th and 5th percentile operators could see the location. Lastly, the higher the priority (i.e., 1, 2, 3, 4) of the visual attention location that can be seen, the better is the visibility from the machine. Thus, if an operator can see a priority 1 visual attention location, that should get more "credit" than if a priority 3 visual attention location can be seen.

Based on the above factors, and the notion of a scale of goodness, it is possible to develop a scoring system by which a visibility score from a particular machine can be computed using the HERMI technique. The procedure assigns points to each visual attention location based on the amount of body movement required to see the location, and the priority of the location. These points are determined separately for the 95th percentile male

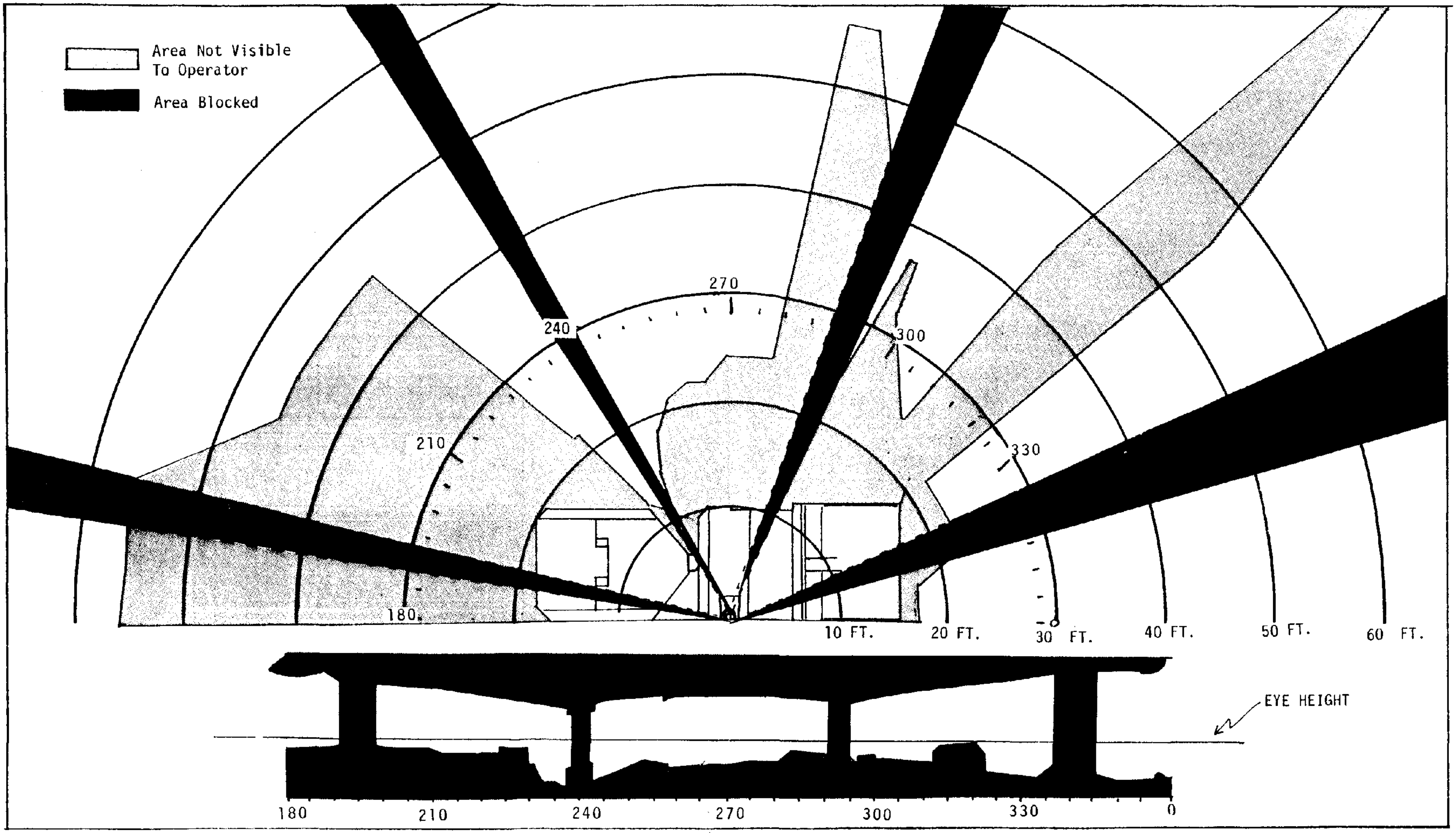


Figure 3-9. Visibility at ground level for a scoop, produced from a 360 degree panorama photograph.

operator and the 5th percentile female operator and added together. The total is then weighted by the priority of the visual attention area. This composite is then summed over all visual attention areas. This can be expressed by the following formula:

$$V = \sum_{i=1}^{n} P_i (U_i + L_i)$$

where: V = visibility score

P_i = priority weight for visual attention location i

U_i = 95th percentile (upper eye arc) points for visual attention location i

L_i = 5th percentile (lower eye arc) points for visual attention location i

The upper and lower eye arc points (i.e., U_i and L_i), corresponding to the 95th percentile male and 5th percentile female operator, are determined using Table 3-4. The logic behind Table 3-4 is as follows. Priority 1 visual attention locations should require no neck or torso flexion in order to see them. Thus, if the location can be seen without flexion, three (3) points are assigned. If neck flexion is required, only two (2) points are given; if neck and trunk flexion are required one (1) point is given. No points are given if the location is not visible at all. Priority 2 locations, it was felt, could require neck flexion to be seen. Thus, if no flexion or just neck flexion are required, three (3) points are assigned. If torso flexion is required, two (2) points are assigned, and if the location is not visible, no points are assigned. Priority 3 locations, it was felt, could require neck and torso flexion to be seen, since they are of less importance to the safe and efficient operation of the machine. Thus, three (3) points are assigned if the location is visible, and no points, if it is not. This scheme is applied to both the upper and lower eye arcs of HERMI. In each case, the highest number of points attained are assigned. For example, if at a priority 1 visual attention area, the photograph shows that the entire upper eye arc is visible, but only a part of the white torso-flexion portion of the lower eye arc is visible, the following points would be assigned:

$U_i = 3$

$L_i = 1$

TABLE 3-4

Points to be Assigned to Upper and Lower Eye Arc of HERMI for Determining Visibility Index

	Visual Attention Location Priority Level		
Body Movement Required	1	2	3
None	3	3	3
Neck flexion only	2	3	3
Neck and torso flexion	1	2	3
Not visible	0	0	0

The priority weight (P_i) is equal to:

$$P_i = 4 - \text{priority}$$

Thus, a priority 1 has a priority weight of 3, a priority 2 has a priority weight of 2, and a priority 3 has a priority weight of 1. (There are no visual attention areas with priority values of 4.)

Applying this scoring scheme to the machines discussed in Sections 3.4, 3.5, and 3.6 yields the results summarized in Table 3-5. Shown in Table 3-5 are the total visibility scores, maximum possible scores, and visibility as a percent of maximum possible. The procedure appears to be sensitive to changes in equipment configurations. For example, the effect of changing the canopy height on a drum head continuous miner is dramatically shown in Table 3-5. With the canopy in the highest position, and HERMI in a more upright posture, the visibility score as a percent of maximum was 69.6%. Lowering the canopy, thus reclining HERMI, reduced the visibility to 30.9%. The reader should keep in mind the design limitations of HERMI discussed in Section 3.3.

The data from the shuttle cars provide another test of the sensitivity of the scoring system. Shuttle cars that have the operator positioned at one end of the vehicle, so he is in front of the wheels going in one direction, but behind the wheels when traveling in the opposite direction, should provide different degrees of visibility depending on the direction of travel. The data confirm this, although the differences are not as large as one might have expected. With the cab in front of the wheels, the visibility (as percent of maximum) is 63.4%; travelling in the opposite direction (cab behind the wheels) reduces the visibility to 58.4%. As would be expected, when the cab is positioned between the wheels (on a different model vehicle), the visibility falls between the 58.4 and 63.4% values, i.e., 62.0%.

Thus, even this limited sample demonstrates that this particular scoring system is sensitive to differences in equipment configuration, and yields data which agree with expectations.

Assuming that this scoring technique for computing visibility indices is reasonable, there remains the task of assigning a cut-off point to define acceptable and unacceptable. The project team believes that it would be premature to establish such a demarcation point until a more exhaustive visibility survey is conducted on existing equipment. The results of such a survey would serve two purposes:

1. It would supply data on the proportion of machines that afford various levels of visibility at each visual attention location. These data would be useful for reevaluating the priority of the visual attention

TABLE 3-5

Results of Applying Scoring Procedure to a Sample of Machines

Continuous Miners	Visibility Score	Max Possible	Percentage of Max
Drum head with canopy in lowest position	384	1242	30.9%
Drum head with canopy in highest position	864	1242	69.6
Auger miner (no canopy)	849	1242	68.4
Shuttle Cars			
Cab between wheels	517	834	62.0
Cab in front of wheels	547	834	63.4
Cab behind wheels	487	834	58.4
Scoops			
Canopy mid height	828	942	87.9

locations. Visual attention locations that are not visible from any currently designed machine should be reevaluated in terms of its importance.

2. It would supply a distribution of visibility indices for current equipment. The proportion of existing equipment which would be judged unacceptable at any cut-off point could then be readily established.

Therefore, at this stage, this particular visibility index scoring system must be considered experimental, pending a more exhaustive application of the procedures. Currently, the information, HERMI technique, and visibility index scoring system can be used to explore alternative equipment designs, the impact of canopy height, etc. on visibility for safe operation of underground equipment.

The particular scoring technique used in this report is only one of several that could be employed. For example, a machine might be considered acceptable if, and only if, all Priority 1 visual attention locations are visible. Such a system, however, must take into account rendundancy between visual features located at different visual attention locations. Further, such a system would not be sensitive to design changes which reduce or enhance visibility above the acceptable level. The particular scoring technique chosen depends on the purpose for which it is intended to serve. For evaluating design changes, the visibility index scoring system suggested in this report would be useful. For specifying minimum requirements, perhaps the if-and-only-if Priority 1 system would be more appropriate. Of course, a third alternative might be a combination of the two.

The visibility index system used in this report has one drawback which must be recognized. It is an additive system (i.e., totaling up points across visual attention locations) and as such, it is a compensatory system. It is possible that a machine design could obstruct vision to a few Priority 1 visual attention locations and yet still obtain a relatively "high" visibility index by affording visibility to all Priority 2 and 3 locations. In like manner, a machine could afford visibility to all Priority 1 visual attention locations and yet score relatively "low" because vision is obstructed to all Priority 2 and 3 locations.

4.0 FUTURE VALIDATION AND RESEARCH RECOMMENDATIONS

It should be stressed that the HERMI technique and the weightings assigned to the visual attention locations are still in an experimental, formative stage. Before any regulations can be formulated based on this methodology, additional data and experience with the technique must be accumulated. The following five project recommendations are aimed at validating the methodology and exploring the utility of the system for visibility assessment.

4.1 Comprehensive Evaluation of Current Equipment

It is strongly recommended that the HERMI technique be applied on a large sample of shuttle cars. Shuttle cars are recommended because they represent the clearest danger due to their prevalence and speed of locomotion. A sample of shuttle cars, low and high seam, should be selected to represent 95 percent of vehicle sales. Comprehensive evaluations for both directions of travel and canopy in high and low positions should be made. The data generated would allow the following:

1. Refinement of the design and utilization of HERMI.

2. Reassessment of visual attention location weights.

3. Determination of minimum acceptable visibility score.

The resulting data base would pinpoint visual attention locations which are not visible from a significant proportion of equipment configurations. These locations should be reevaluated to determine if the visual features located there are redundant to other more visible visual features. The data base would also allow the determination of the visibility score above which a specific percentage of equipment would score.

4.2 Relate Visibility to Accident Frequency

Based on the comprehensive evaluation of current equipment (4.1), the equipment with the worst and best visibility would be identified. Mines using that equipment would be surveyed as to the number of accidents, related to visibility, which occurred using that equipment. The data would have to be carefully sorted to include only those accidents which might be induced because of lack of adequate visibility.

4.3 Determine Illumination Levels at Visual Attention Locations

For a sample of machines, the illumination level at each visual attention location would be determined. Machine mounted luminares have been designed to distribute light in the working face in accordance with federal illumination standards. It is possible, and highly likely, that some visual attention areas do not receive an adequate level of illumination with current systems. As part of this project, lighting redesigns could be made to improve the illumination where necessary.

4.4 Determine Effects of Canopy Height and Configuration on Visibility

On a sample of equipment, or using full scale mock-ups, determine the effect on visibility of different canopy heights and configurations. Perhaps there is a point of diminishing returns as the canopy is raised on a particular piece of equipment. Currently, canopies are not required on equipment used in seams under 42 inches, due to the restriction in visibility. One could objectively determine the effect on visibility of operating equipment with no canopy and at various seam heights (i.e., canopy heights).

4.5 Determine the Effect of Changes in the Size and/or Location of the Operators Compartment

This might best be done using mock-ups to alter the shape, size and location of the operator compartment. Visibility would be assessed and recommendations for future design would be made.

5.0 REFERENCES

Farrar, R., R. Champney, and L. Weiner: Survey on Protective Canopy Design. OF-50-76. Bureau of Mines, Pittsburgh, PA, 1976 (PB 251-672).

HEL: Human Engineering Design Data Digest, Human Engineering Laboratory Detachment, U.S. Army Missile Command, Redstone Arsenal, Alabama, 1978.

Johansson, G. and K. Rumar: Driver's brake reaction times, Human Factors, 1971, Vol. 13, No. 1, pp. 23-28.

Mason, S., R. Rhodes, and C. Best: Summary of sight line techniques for use with mining machinery ON79/58. National Coal Board, England, 1979.

Rogers, S.: Anthropometric Data Application Mannikin, S. P. Rogers, Santa Barbara, CA, 1976.

SAE: Measurement and Evaluation of Visibility SAE XJ1091, Society of Automotive Engineers, Warrendale, PA, 1980.

SAE Subcommittee 29, Working Group 8: Recommended minimum performance criteria for braking systems for rubber-tired, self propelled underground mining machines. Society of Automotive Engineers, Warrendale, PA, 1979.

Theodore Barry and Associates: Equipment Operation Safety Study of 24-72, Bureau of Mines, Washington, DC, 1972, (PB 211-472).

Appendix A

LOCATION OF VISUAL FEATURES

List of Abbreviations Used to Specify Locations

CH - Canopy Height

FE - Front Edge

HMP - Highest Machine Point

MBH - Maximum Boom Height

MBS - Maximum Boom Swing

MCL - Machine Center Line

MCH - Maximum Cutter Height

MMH - Median Machine Height

NSD - Necessary Stopping Distance

OCL - Operator Center Line

OEH - Operator Eye Height

OH - Operator's Head

OS - Opposite Side from Operator

RE - Rear End

SH - Seam Height

SS - Same Side as Operator

SST - Safe Stopping Time

WE< - Whichever is Less

WMP - Widest Machine Point

Figure A-1 schematically depicts many of these abbreviations.

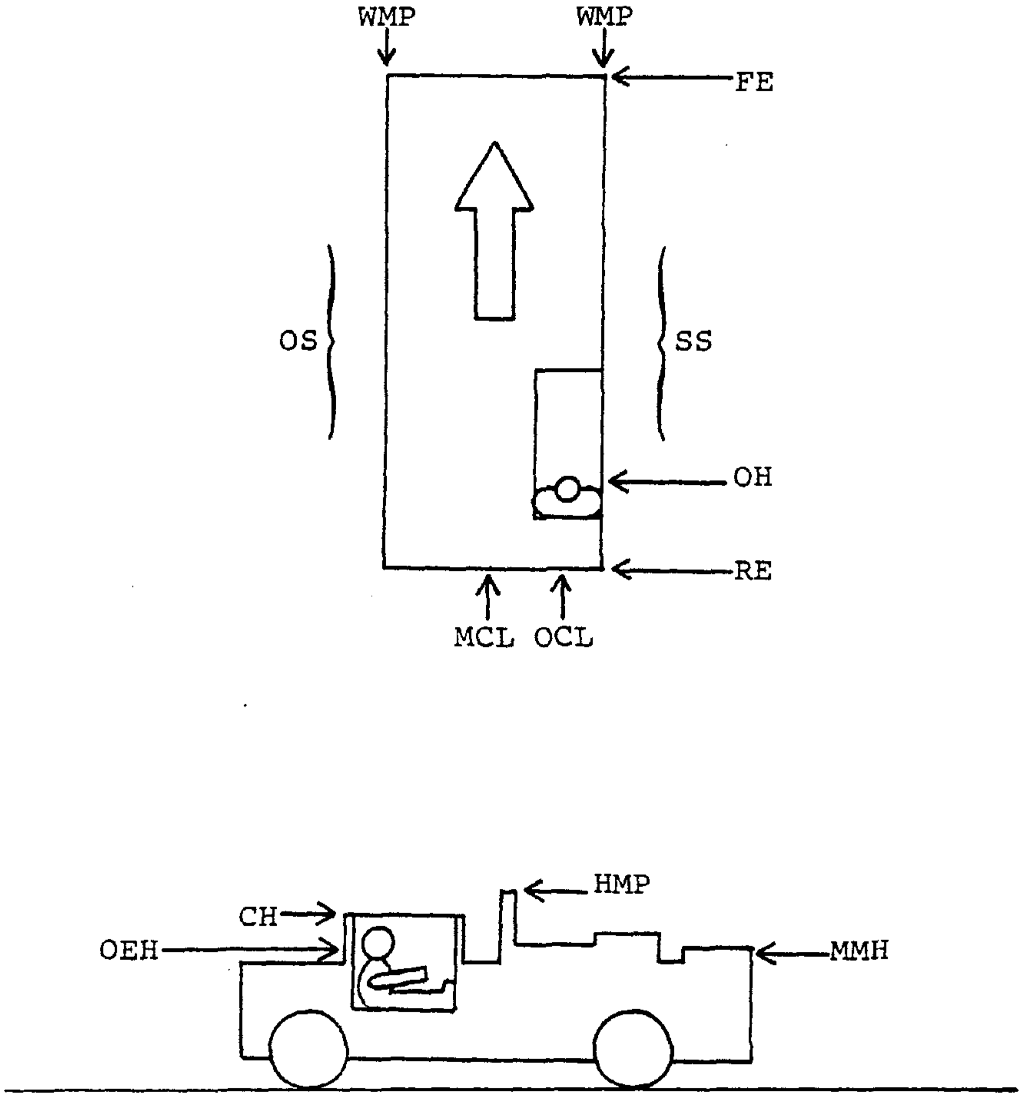


Figure A-1. Schematic representation of abbreviations.

Directions in Planes:

Fore-aft:	+ forward - rearward
Side-side:	+ away from center - toward center
Up-down:	+ up - down

Assumptions

1. 20 ft. wide roadways

2. Width of:

continuous miner	10.5 ft.
shuttle car	9.5
scoop	8.0

3. Tramming: Distance from WMP(SS) to rib:

continuous miner	5 ft.
shuttle car	3 ft.
scoop	4 ft.

4. Extraction: Distance from WMP(SS) to rib:

continuous miner	2 ft.

Determination of NSD (Necessary Stopping Distance)

NSD is determined by adding reaction time distance (the distance the vehicle will move from the time the operator detects a target to the time he applies the brakes) to the maximum braking distance (the distance required to stop the vehicle after the brakes have been applied). As discussed in this report, reaction time is assumed to be 2 seconds, braking distance is taken from recommendations made by SAE Subcommittee 29, Working Group 8 "Brake Standards for Underground Machines." Maximum tram speeds are assumed. The following summarizes NSD for various tram speeds. Where computed NSD is less than 10 ft., a value of 10 ft. is substituted, as discussed in the body of this report.

Tram Speed	RT Distance	+ Max Brake Distance	=	NSD
1 mph	3.0 ft.	0.7 ft.		10.0 ft.
2	6.0	1.4		10.0
2.5	7.0	1.8		10.0
3	9.0	2.3		11.0
4	12.0	3.4		15.0
5	15.0	4.7		20.0
6	18.0	6.1		24.0
7	21.0	7.7		29.0
8	23.0	9.5		33.0
9	26.0	11.4		37.0
10	29.0	13.5		43.0

For purposes of illustration, the diagrams in this appendix showing the location of the visual features at each vertical height assume the following tram speeds and NSD values:

	Tram	NSD
Continuous Miner	1 mph	10 ft.
Shuttle Cars	5 mph	20 ft.
Scoops	6 mph	24 ft.

These tram speeds are representative of actual tram speeds as reported by manufacturers in their sales literature.

I. TRAMMING   List of Visual Features for: CONTINUOUS MINER

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
A. Position of Machine in the Roadway			Priority 1
SS Rib	OH + 1/2 NSD	WMP(SS) + 5'	OEH
OS Rib	FE + 1/2 NSD	WMP(OS) + 5'	OEH
Crosscut Corners	FE + 20'	WMP(SS) + 5'	OEH
	FE + 20'	WMP(OS) + 5'	OEH
	FE	WMP(SS) + 5'	OEH
Roof Irregularities	FE + 1/2 NSD	OCL	SH
Center Line Roof Marks	FE + 1/2 NSD	MCL	SH
SS Lead Corner of Machine	FE	WMP(SS)	MMH
OS Lead Corner of Machine	FE	WMP(OS)	MMH
SS Trailing Corner of Machine	RE	MBS(SS)	MMH
	RE	MCL	MMH
	RE	MBS(OS)	MMH
Helpers Cap Lamp	FE + NSD	WMP(SS) + 5'	OEH
	FE + NSD	WMP(OS) + 5'	OEH
	OH - 5'	WMP(SS) + 5'	OEH
	OH - 5'	WMP(OS) + 5'	OEH
B. Location of Obstacles and Hazards			Priority 1
Roadway Obstacles	FE + 2'	WMP(SS) + 1'	Floor
	FE + 2'	WMP(SS) + 1/2 NSD	Floor
	FE + 1/2 NSD	WMP(SS) + 1'	Floor
	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	Floor
	FE + NSD	WMP(SS)	Floor
	FE + NSD	WMP(SS) + 1/2 NSD	Floor
	FE + NSD	MCL	Floor
	FE + 2'	WMP(OS) + 1'	Floor
	FE + 2'	WMP(OS) + 1/2 NSD	Floor
	FE + 1/2 NSD	WMP(OS) + 2'	Floor
	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	Floor
	FE + NSD	WMP(OS)	Floor
	FE + NSD	WMP(OS) + 1/2 NSD	Floor
Roof Obstructions	FE + 2'	WMP(SS) + 1'	HMP
	FE + 2'	WMP(SS) + 1/2 NSD	HMP
	FE + 1/2 NSD	WMP(SS) + 1'	HMP
	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	HMP
	FE + NSD	WMP(SS)	HMP
	FE + NSD	WMP(SS) + 1/2 NSD	HMP

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
C. Location of Obstacles and Hazards (Cont.)			**Priority 1**
Roof Obstructions (Continued)	FE + NSD	MCL	HMP
	FE + 2'	WMP(OS) + 1'	HMP
	FE + 2'	WMP(OS) + 1/2 NSD	HMP
	FE + 1/2 NSD	WMP(OS) + 1'	HMP
	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	HMP
	FE + NSD	WMP(OS)	HMP
	FE + NSD	WMP(OS) + 1/2 NSD	HMP
Rib Obstructions	FE + 2'	WMP(SS) + 5'	Floor
	FE + 1/2 NSD	WMP(SS) + 5'	Floor
	FE + NSD	WMP(SS) + 5'	Floor
	FE + 2'	WMP(SS) + 5'	HMP
	FE + 1/2 NSD	WMP(SS) + 5'	HMP
	FE + NSD	WMP(SS) + 5'	HMP
D. Speed of Movement			**Priority 2**
SS Rib	OH + 1/2 NSD	WMP(SS) + 5'	OEH
Roof	FE + NSD	OCL	SH
Roadway	FE + NSD	OCL	Floor
E. Location of Machine Within Mine			**Priority 4**
Signs	FE + NSD	WMP(SS) + 5'	8' or SH, WE<
General Surroundings	FE + NSD	WMP(SS) + 5'	OEH
	FE + NSD	WMP(OS) + 5'	OEH
	FE + NSD	MCL	OEH

II. EXTRACTION CONTINUOUS MINER

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
A. Position of Cutting Head			**Priority 3**
SS Edge of Head	FE	WMP(SS)	Floor
	FE	WMP(SS)	MCH or SH, WE<

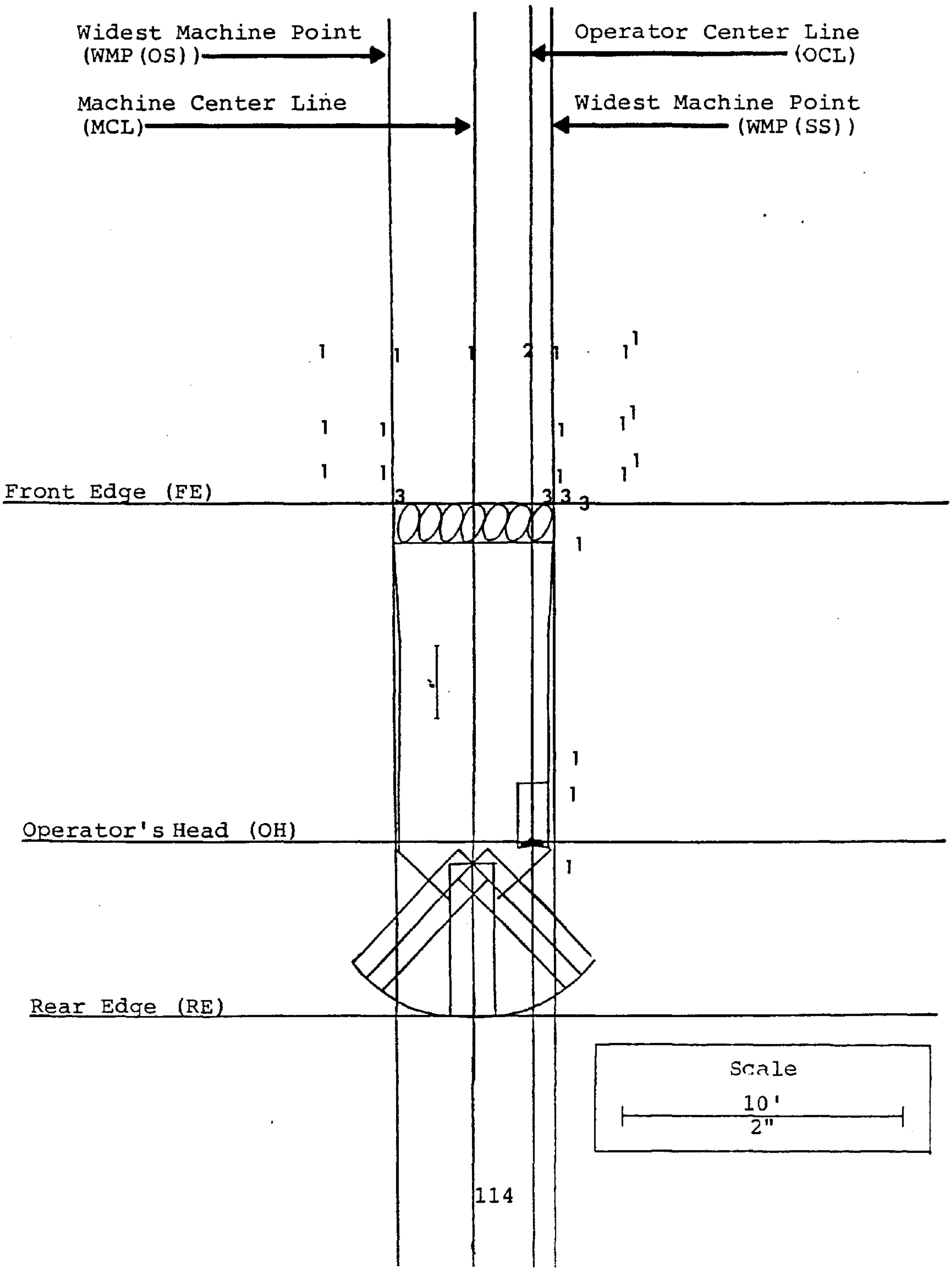
Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
B. Position of Cutting Head (Continued)			Priority 3
OS Edge of Head	FE	WMP(OS)	Floor
	FE	WMP(OS)	MCH or SH, WE<
Intersection Roof and Face	FE	WMP(SS)	SH
	FE	MCL	SH
	FE	WMP(OS)	SH
Floor	FE	WMP(SS)	Floor
Top Edge Cutter Head	FE	MCL	MCH or SH, WE<
C. Alignment of Cutting Head to Face			Priority 1
SS Edge of Head	FE	WMP(SS)	OEH
OS Edge of Head	FE	WMP(OS)	OEH
Intersection of Roof and Face	FE	WMP(SS)	SH
	FE	MCL	SH
	FE	WMP(OS)	SH
SS Side of Machine	OH + 10'	WMP(SS)	MMH
SS Rib or Brattice	OH	WMP(SS) + 2'	OEH
	FE	WMP(SS) + 2'	OEH
OS Rib or Brattice	FE - 3'	WMP(OS) + 8'	OEH
Surveyor Marks	FE	MCL	SH
Helper's Cap Lamp	OH	WMP(SS) + 5'	OEH
	OH - 3'	WMP(SS) + 5'	OEH
D. Location of Machine Relative to Roof Supports			Priority 1
Roof Supports	OH + 5'	MCL	SH
Helper's Cap Lamp	OH	WMP(SS) + 5'	OEH
	OH - 3'	WMP(SS) + 5'	OEH
Rib Spot Marker	OH + 3'	WMP(SS) + 2'	OEH

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
E. Location of Obstacles and Hazards			**Priority 1**
Rib Obstructions	FE - 3'	WMP(SS) + 2'	Floor
	FE - 3'	WMP(SS) + 2'	OEH
	FE - 3'	WMP(SS) + 2'	HMP
	OH + 3'	WMP(SS) + 2'	Floor
	OH + 3'	WMP(SS) + 2'	OEH
	OH + 3'	WMP(SS) + 2'	HMP
Roof Hazards	FE	WMP(SS)	MBH
	FE	WMP(OS)	MBH
	FE	MCL	MBH
	OH + 10'	WMP(SS)	MBH
	OH + 10'	WMP(OS)	MBH
	OH + 10'	MCL	MBH
Temp Roof Supports	FE	WMP(SS) + 5'	OEH
	FE	WMP(OS) + 5'	OEH
	OH	WMP(SS) + 5'	OEH
	OH	WMP(OS) + 5'	OEH
Trailing Cable	OH + 5'	WMP(SS) + 2'	Floor
	OH - 2'	WMP(SS) + 2'	Floor
Personnel	FE - 3'	WMP(SS) + 5'	OEH
	FE - 3'	WMP(OS) + 5'	OEH
	OH - 3'	WMP(SS) + 5'	OEH
	OH - 3'	WMP(OS) + 5'	OEH
F. Rate of Cutting Coal from Face			**Priority 3**
Tail Conveyor	RE	MBS(SS)	MBH
	RE	MBS(OS)	MBH
	RE	MCL	MBH
	RE	MBS(SS)	MMH
	RE	MBS(OS)	MMH
	RE	MCL	MMH
G. Condition of Working Face			**Priority 3**
Intersection Roof & Face	FE	WMP(SS)	SH
	FE	MCL	SH
	FE	WMP(OS)	SH
Intersection Rib & Face	FE	WMP(SS) + 2'	Floor
	FE	WMP(SS) + 2'	OEH
	FE	WMP(SS) + 2'	SH

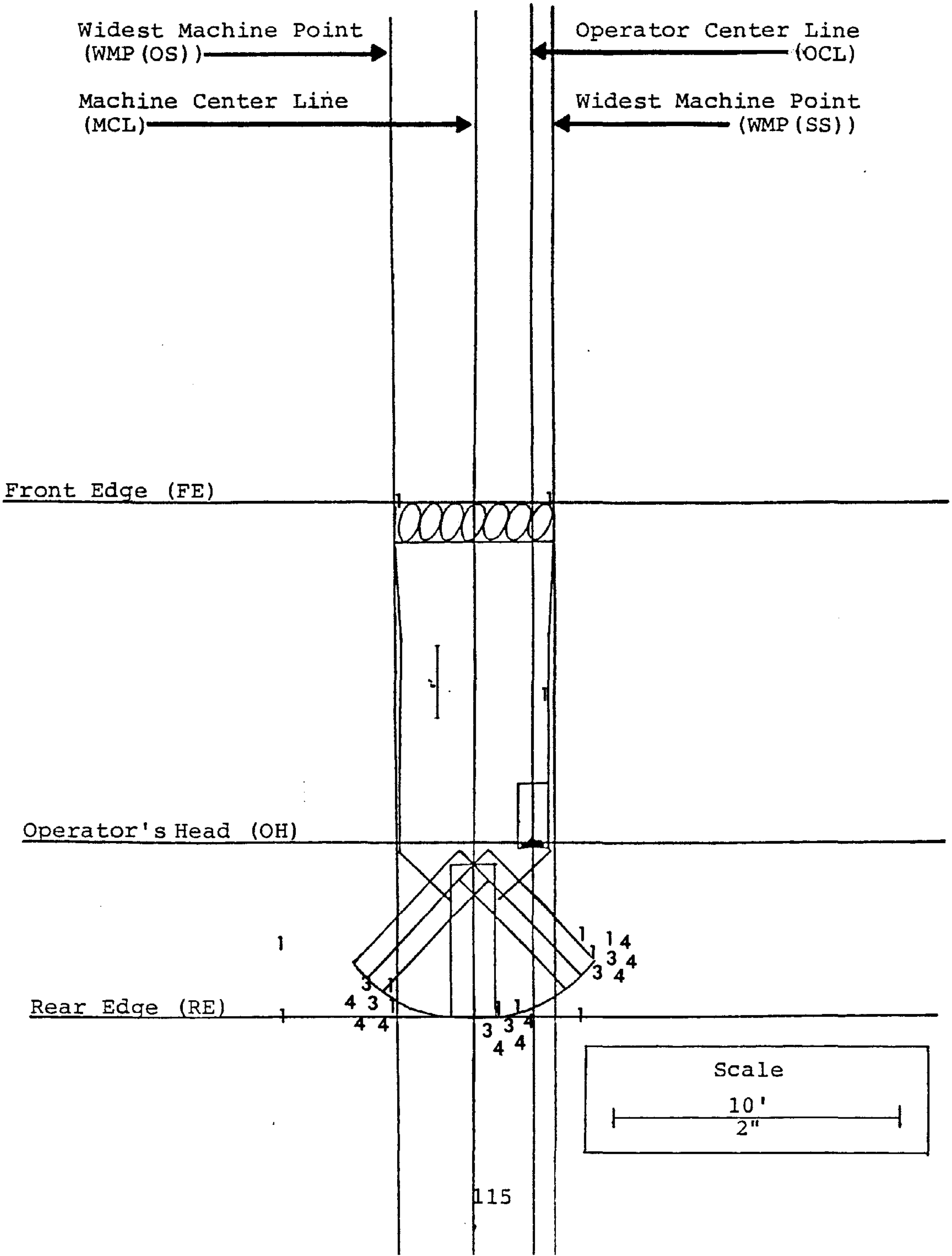
Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
A. Position of Tail Boom			**Priority 3**
Tail Boom	RE	MBS(SS)	MBH
	RE	MBS(SS)	MMH
	RE	MBS(OS)	MBH
	RE	MBS(OS)	MMH
	RE	MCL	MBH
	RE	MCL	MMH
Shuttle Car	RE	MBS(OS)	MMH
	RE	MBS(SS)	MMH
	RE	MCL	MMH
B. Available Load Space			**Priority 4**
Top of Pile	RE	MBS(SS)	MMH
	RE	MBS(OS)	MMH
	RE	MCL	MMH
Shuttle Car	RE	MBS(SS)	MMH
	RE	MBS(OS)	MMH
	RE	MCL	MMH
Helper Cap Lamp	OH - 5'	WMP(SS) + 5'	OEH
Shuttle Car Operator Cap Lamp	RE	MBS(SS)	OEH
	RE	MBS(OS)	OEH
	RE	MCL	OEH
C. Relative Rate of Material Off Tail Boom			**Priority 4**
Material Coming Off Tail Boom	RE	MBS(SS)	MBH
	RE	MBS(OS	MBH
	RE	MCL	MBH
	RE	MBS(SS)	MMH
	RE	MBS(OS)	MMH
	RE	MCL	MMH

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
D. Location of Obstacles and Hazards			**Priority 1**
Roof Hazards	RE	MBS(SS)	MBH or SH, WE<
	RE	MBS(OS)	MBH or SH, WE<
	RE	MCL	MBH or SH, WE<
	RE - 5'	MBS(SS)	MBH or SH, WE<
	RE - 5'	MBS(OS)	MBH or SH, WE<
	RE - 5'	MCL	MBH or SH, WE<
Rib Obstructions	RE	WMP(SS) + 2'	MMH
	RE	WMP(OS) + 8'	MMH
	RE - 5'	WMP(SS) + 2'	MMH
	RE - 5'	WMP(OS) + 8'	MMH
Roadway Obstructions (Temporary Roof Supports and Personnel)	RE	WMP(SS) + 5'	OEH
	RE	WMP(OS) + 5'	OEH
	RE - 5'	WMP(SS) + 5'	OEH
	RE - 5'	WMP(OS) + 5'	OEH
E. Position of Vehicle Relative to Roof Bolts			**Priority 1**
Roof Supports	OH + 5'	MCL	SH
Helper's Cap Lamp	OH	WMP(SS) + 5'	OEH
	OH - 3'	WMP(SS) + 5'	OEH
Rib Spot Marker	OH + 3'	WMP(SS) + 2'	OEH

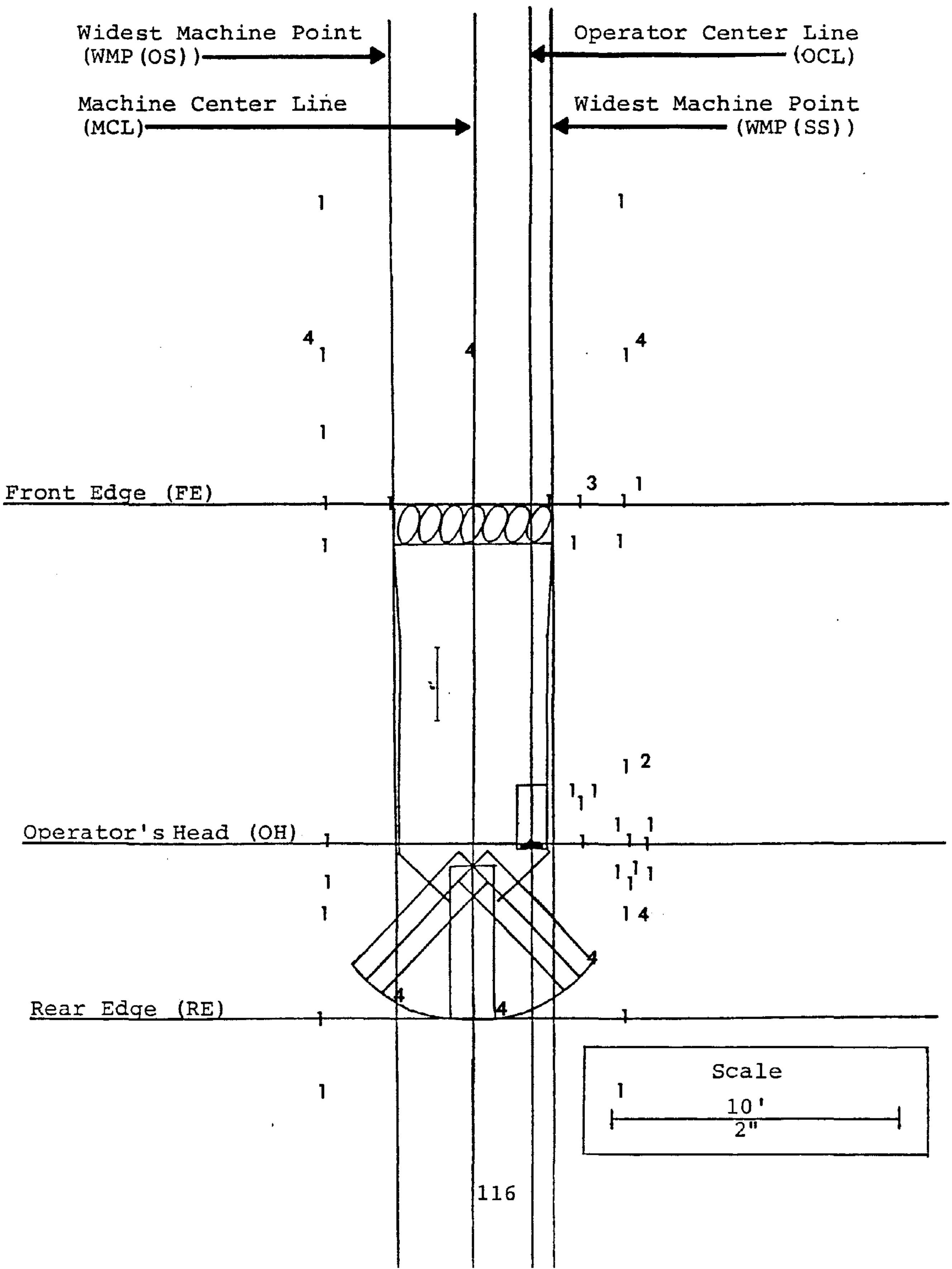
CONTINUOUS MINER (Floor)



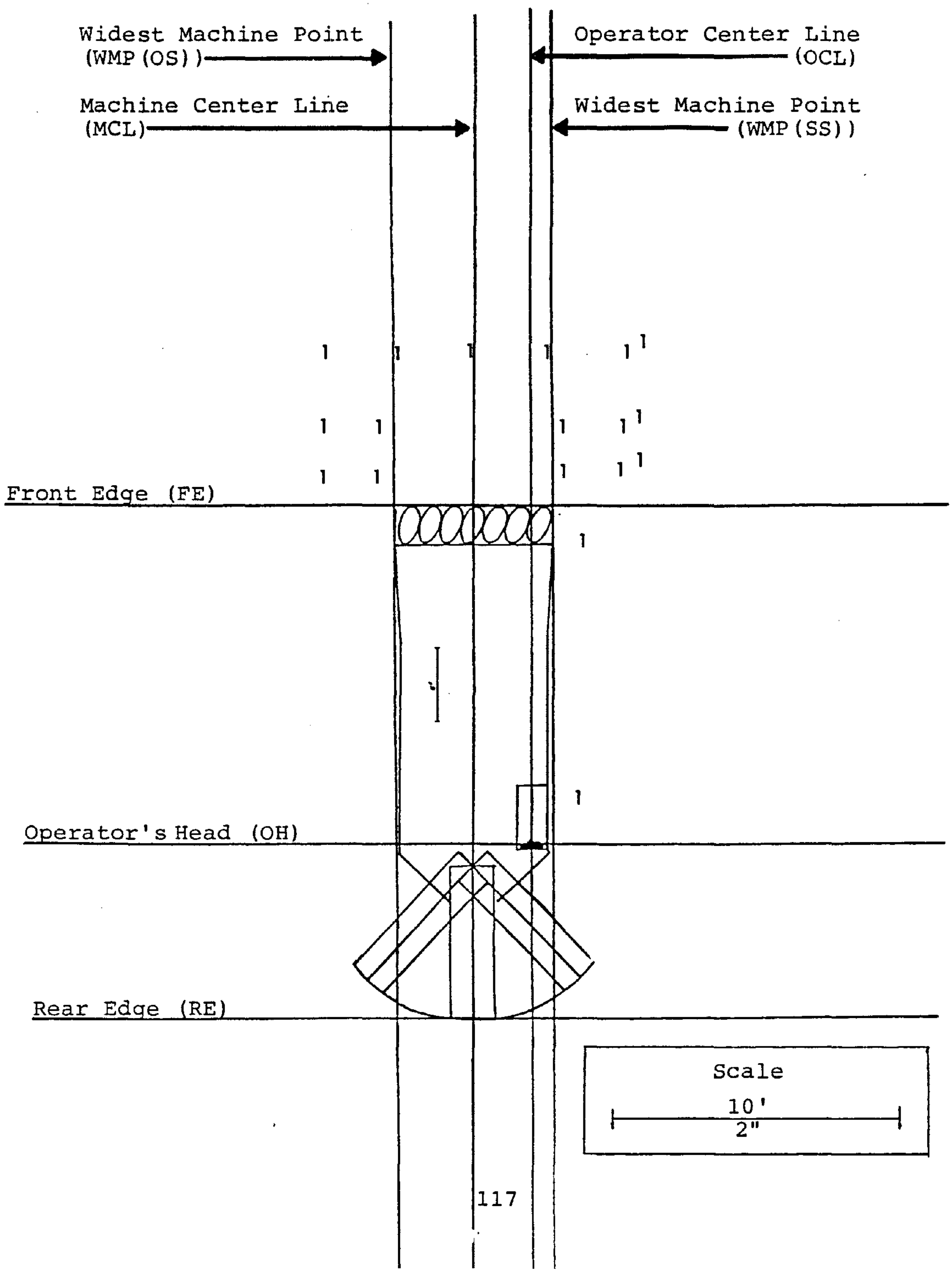
CONTINUOUS MINER (MMH)



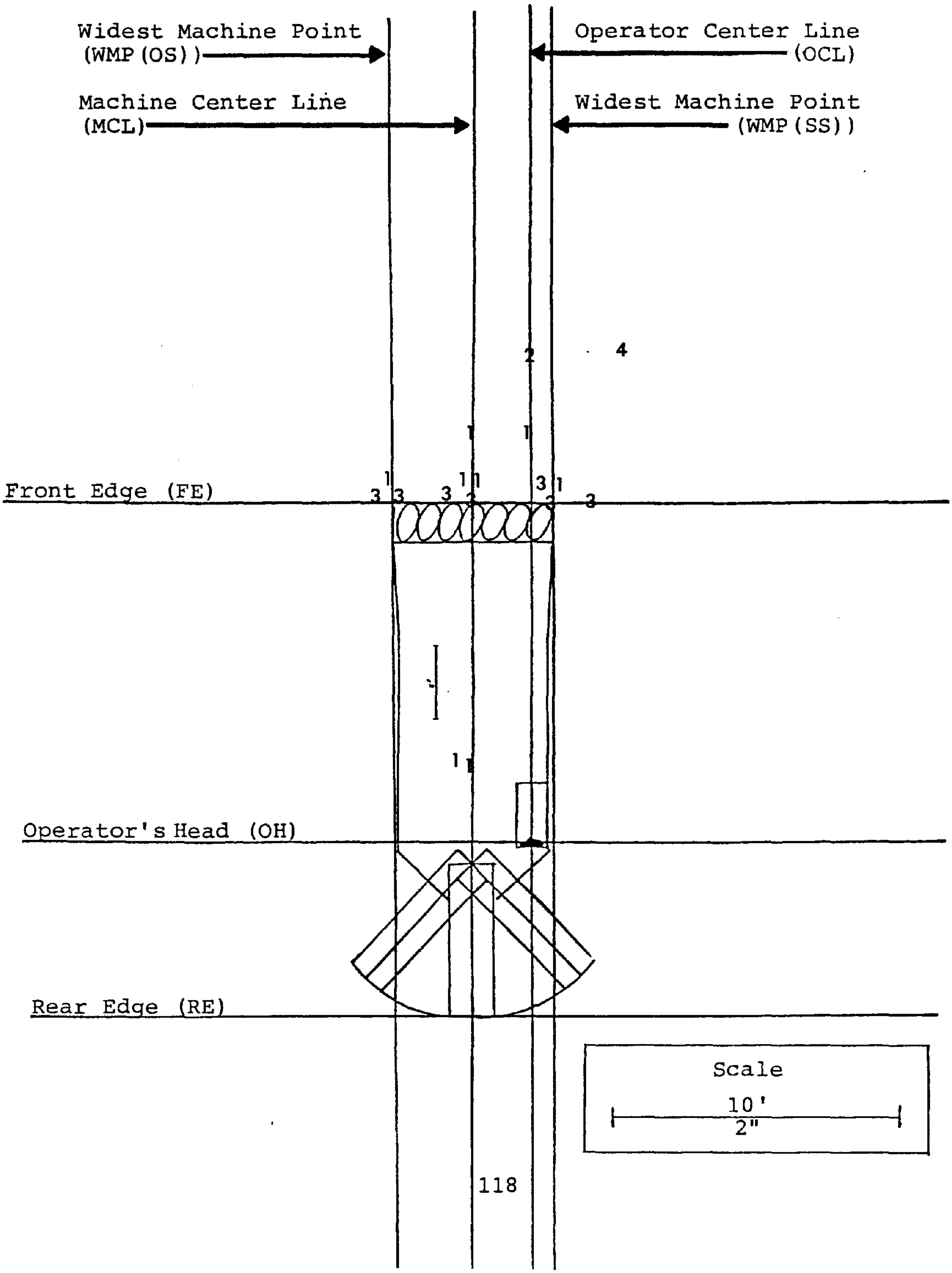
CONTINUOUS MINER (OEH)



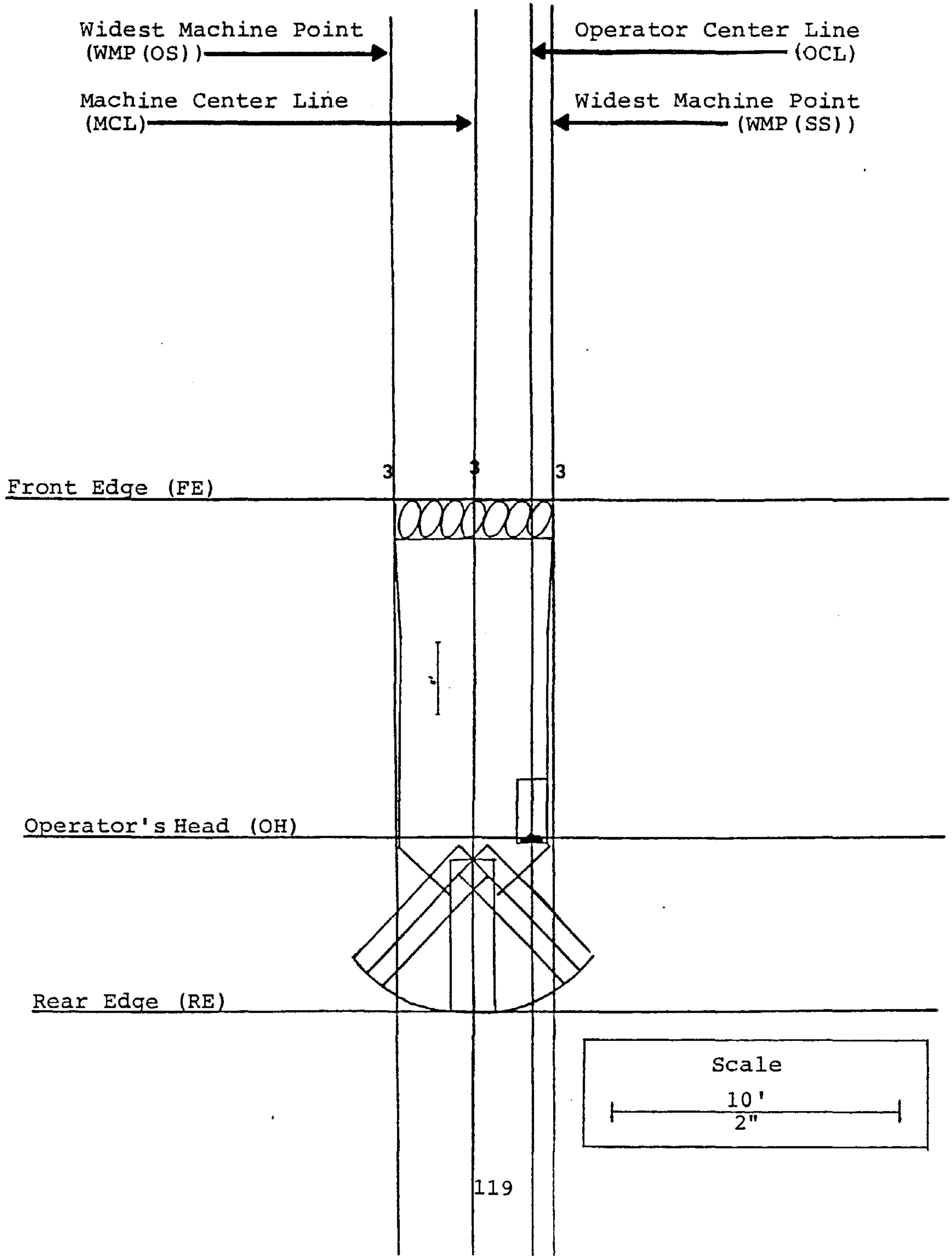
CONTINUOUS MINER (HMP)



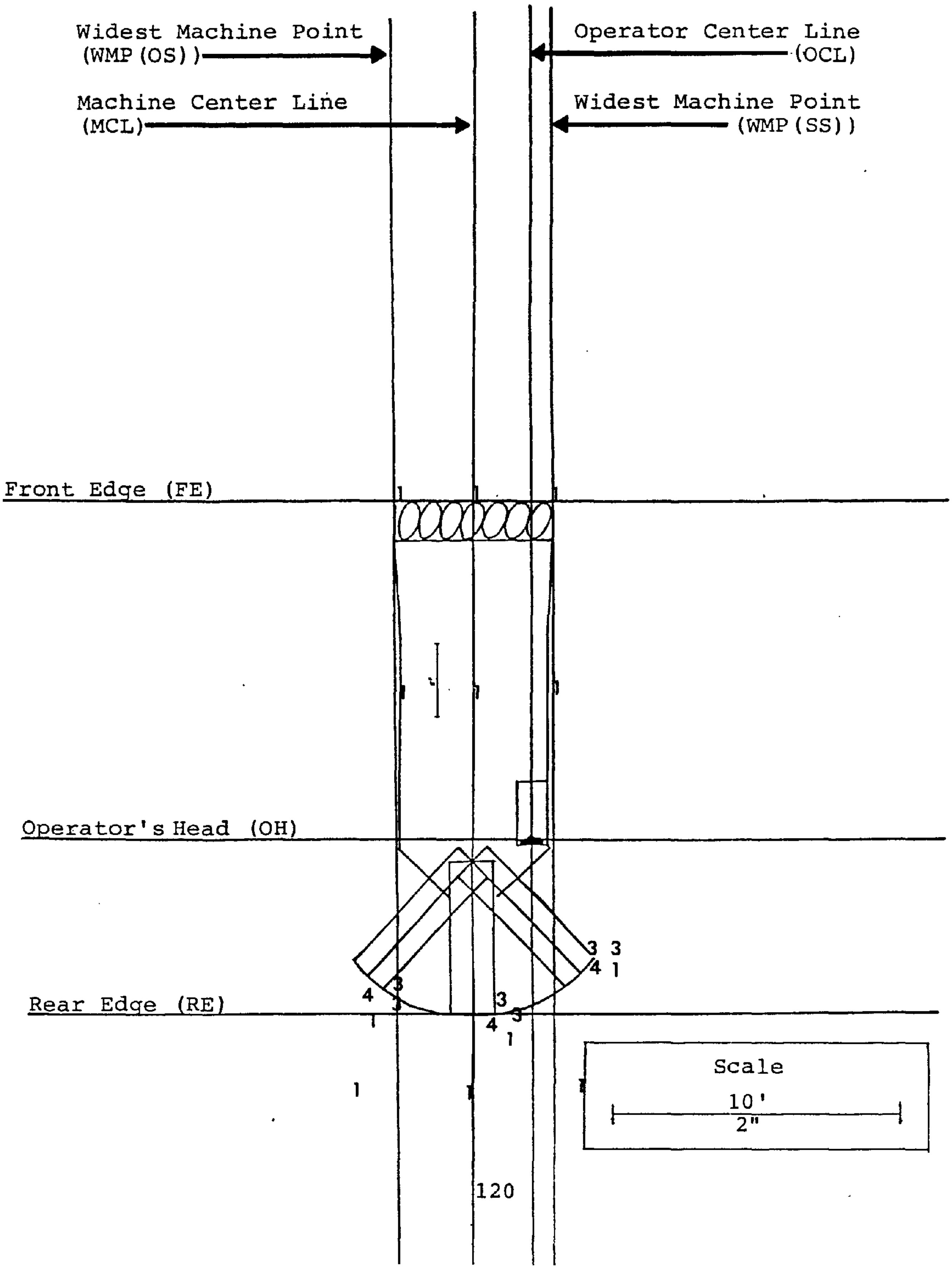
CONTINUOUS MINER (SH)



CONTINUOUS MINER (MCH)



CONTINUOUS MINER (MBH)



I. TRAMMING List of Visual Features for: SHUTTLE CAR

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
A. Position of Machine in the Roadway			Priority 1
SS Rib	OH + 1/2 NSD	WMP(SS) + 3'	OEH
OS Rib	FE + 1/2 NSD	WMP(OS) + 7'	OEH
Cross Cut Centers	FE + 20'	WMP(SS) + 3'	OEH
	FE + 20'	WMP(OS) + 7'	OEH
	FE	WMP(SS) + 3'	OEH
Roof Irregularities	FE + 1/2 NSD	OCL	SH
Center Line Roof Marks	FE + 1/2 NSD	MCL	SH
SS Lead Corner of Machine	FE	WMP(SS)	MMH
OS Lead Corner of Machine	FE	WMP(OS)	MMH
B. Location of Obstructions and Hazards			Priority 1
Roadway Obstacles	FE + 2'	WMP(SS) + 2'	Floor
	FE + 2'	WMP(SS) + 1/2 NSD	Floor
	FE + 1/2 NSD	WMP(SS) + 2'	Floor
	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	Floor
	FE + NSD	WMP(SS)	Floor
	FE + NSD	WMP(SS) + 1/2 NSD	Floor
	FE + NSD	MCL	Floor
	FE + 2'	WMP(OS) + 2'	Floor
	FE + 2'	WMP(OS) + 1/2 NSD	Floor
	FE + 1/2 NSD	WMP(OS) + 2'	Floor
	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	Floor
	FE + NSD	WMP(OS)	Floor
	FE + NSD	WMP(OS) + 1/2 NSD	Floor
Roof Obstructions	FE + 2'	WMP(SS) + 2'	HMP
	FE + 2'	WMP(SS) + 1/2 NSD	HMP
	FE + 1/2 NSD	WMP(SS) + 2'	HMP
	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	HMP
	FE + NSD	WMP(SS)	HMP
	FE + NSD	WMP(SS) + 1/2 NSD	HMP
	FE + NSD	MCL	HMP
	FE + 2'	WMP(OS) + 2'	HMP
	FE + 2'	WMP(OS) + 1/2 NSD	HMP
	FE + 1/2 NSD	WMP(OS) + 2'	HMP
	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	HMP
	FE + NSD	WMP(OS)	HMP
	FE + NSD	WMP(OS) + 1/2 NSD	HMP

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
C. Location of Obstructions and Hazards (Cont.)			**Priority 1**
Rib Obstructions	FE + 2'	WMP(SS) + 3'	Floor
	FE + 1/2 NSD	WMP(SS) + 3'	Floor
	FE + NSD	WMP(SS) + 3'	Floor
	FE + 2'	WMP(SS) + 3'	HMP
	FE + 1/2 NSD	WMP(SS) + 3'	HMP
	FE + NSD	WMP(SS) + 3'	HMP
D. Speed of Movement			**Priority 2**
SS Rib	OH + 1/2 NSD	WMP(SS) + 3'	OEH
Roof	FE + 1/2 NSD	OCL	SH
Roadway	FE + 1/2 NSD	OCL	Floor
E. Location of Machine Within Mine			**Priority 4**
Signs	FE + NSD	WMP(SS) + 3'	8' or SH, WE<
General Surroundings	FE + NSD	WMP(SS) + 3'	OEH
	FE + NSD	WMP(OS) + 7'	OEH
	FE + NSD	MCL	OEH

II. LOADING SHUTTLE CAR

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
A. Relative Rate of Material Off Tail Boom			**Priority 3**
Material off the Tail Boom	FE	MCL	MBH or SH, WE<
	FE	MCL	MMH

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height

B. Position of Vehicle Relative to CM Priority 3

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
Tail Boom	FE + 1/2 NSD	MCL	MBH or SH, WE<
	FE + 1/2 NSD	MCL	MMH
Rear Corner of CM	FE + 1/2 NSD	WMP(SS)	MMH

C. Location of Obstructions and Hazards Priority 2

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
Roof Hazards	FE	WMP(SS)	HMP
	FE	WMP(OS)	HMP
Rib Obstructions	FE	WMP(SS) + 2'	MMH
	FE	WMP(OS) + 8'	MMH
Roadway Obstruc-tions	FE	WMP(SS) + 5'	OEH
	FE	WMP(OS) + 5'	OEH

D. Position and Height of Load Priority 2

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
Top of Load	FE	MCL	HMP
	OH	MCL	HMP
	RE	MCL	HMP
Slope of Pile	RE	MCL	OEH
	OH	MCL	OEH
	FE	MCL	OEH

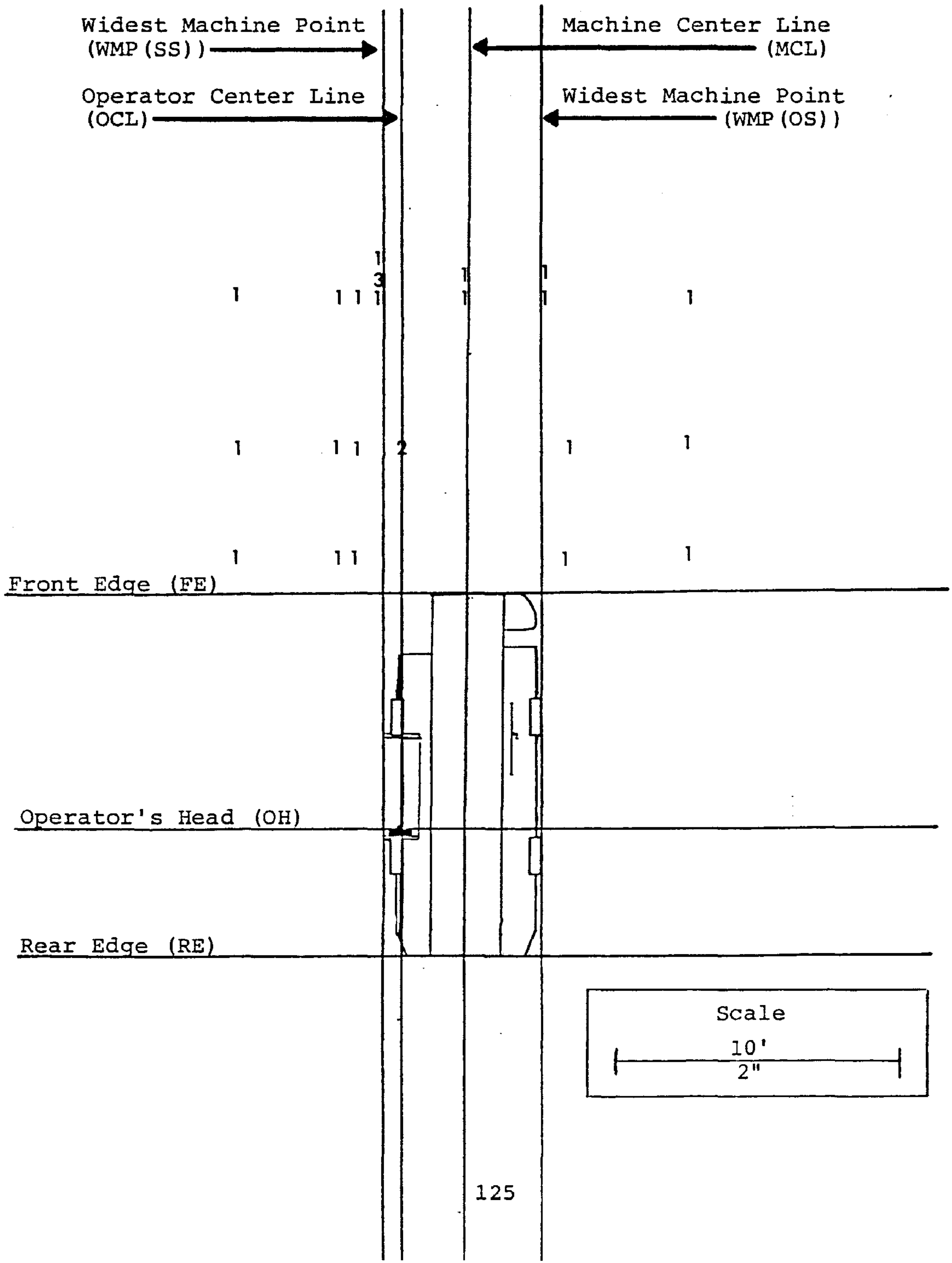
III. DUMPING SHUTTLE CAR

A. Position of Vehicle Relative to Dump Site Priority 3

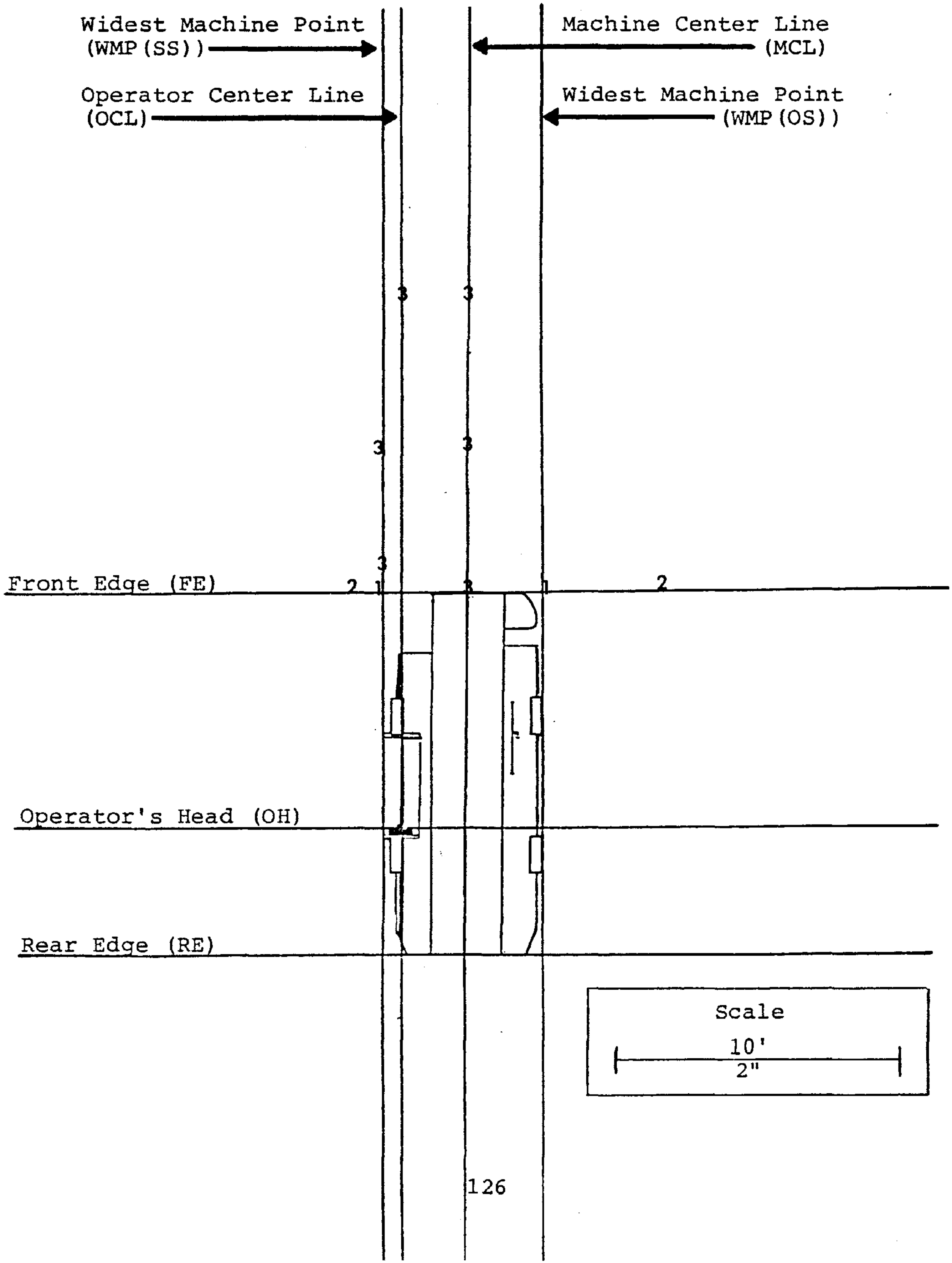
Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
Front End of Dump	FE + NSD	OCL	MMH
SS Lead Corner of Machine	FE	WMP(SS)	MMH
Dumpsite Activa-tion Lever	OH	OCL + 2'	OEH
Ramp	FE + NSD	WMP(SS)	Floor

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
B. Position of Load on Vehicle			**Priority 4**
Top of Load	FE	MCL	HMP
Back Slope of Load	FE - 4'	MCL	OEH
C. Location of Obstacles and Hazards			**Priority 1**
Edge of Loading Ramp	FE + NSD	WMP(SS) + 2'	Floor
Personnel	FE + NSD	WMP(SS)	OEH
	FE + NSD	WMP(OS)	OEH
	FE + NSD	WMP(SS) + 1/2 NSD	OEH
	FE + NSD	WMP(OS) + 1/2 NSD	OEH
	FE + NSD	MCL	OEH
Tools and Supplies	FE + NSD	WMP(SS)	Floor
	FE + NSD	WMP(OS)	Floor
	FE + NSD	MCL	Floor
Roof Hazards	FE + NSD	HMP	HMP
D. Status of Dump Site			**Priority 3**
Center of Dump Site	FE + NSD	MCL	MMH
Status Lights	FE + NSD	WMP(SS)	OEH
Tender's Cap Lamp	FE + NSD	WMP(SS) + 5'	HMP
	FE + NSD	WMP(OS) + 5'	HMP

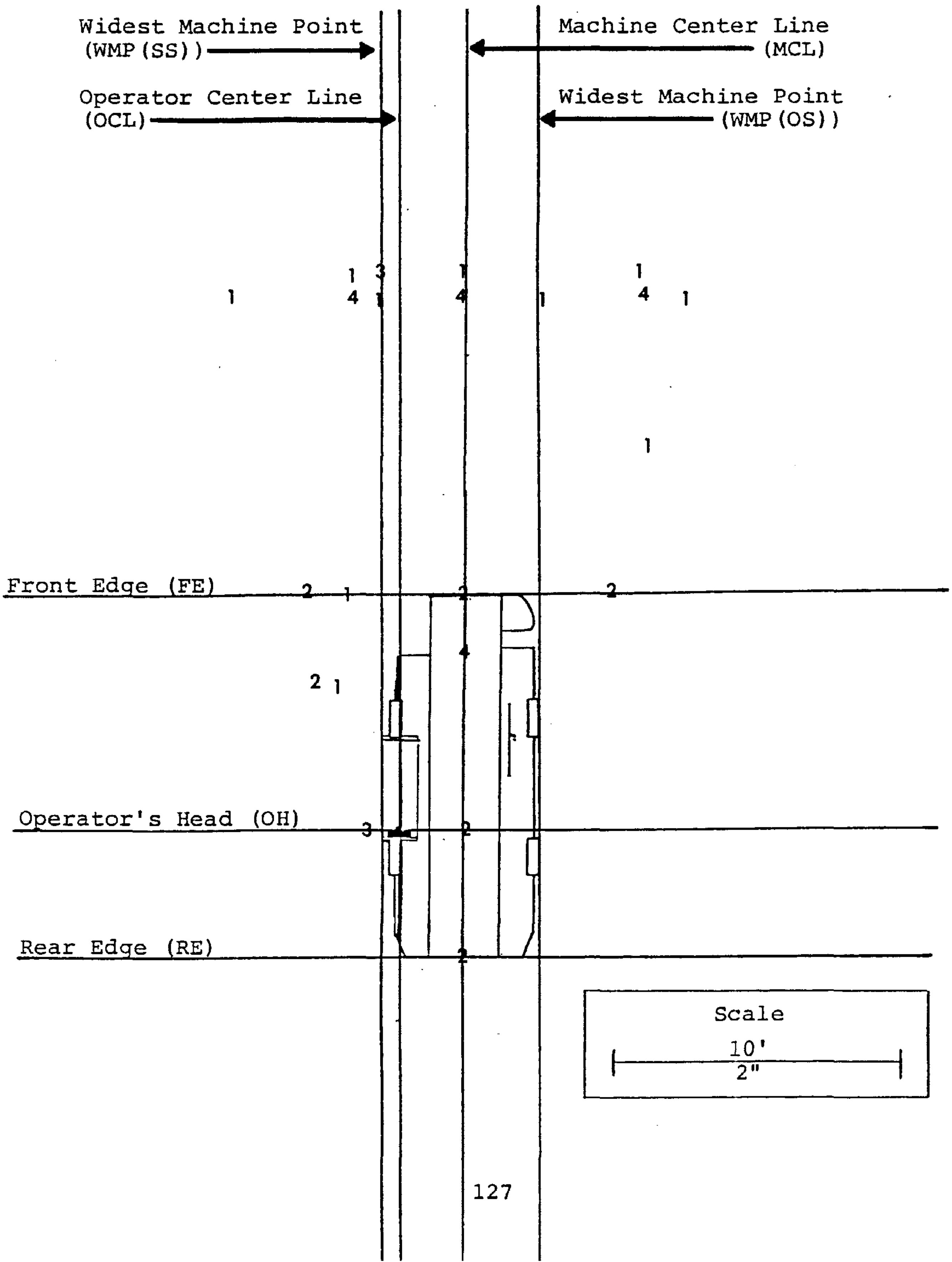
SHUTTLE CAR (Floor)



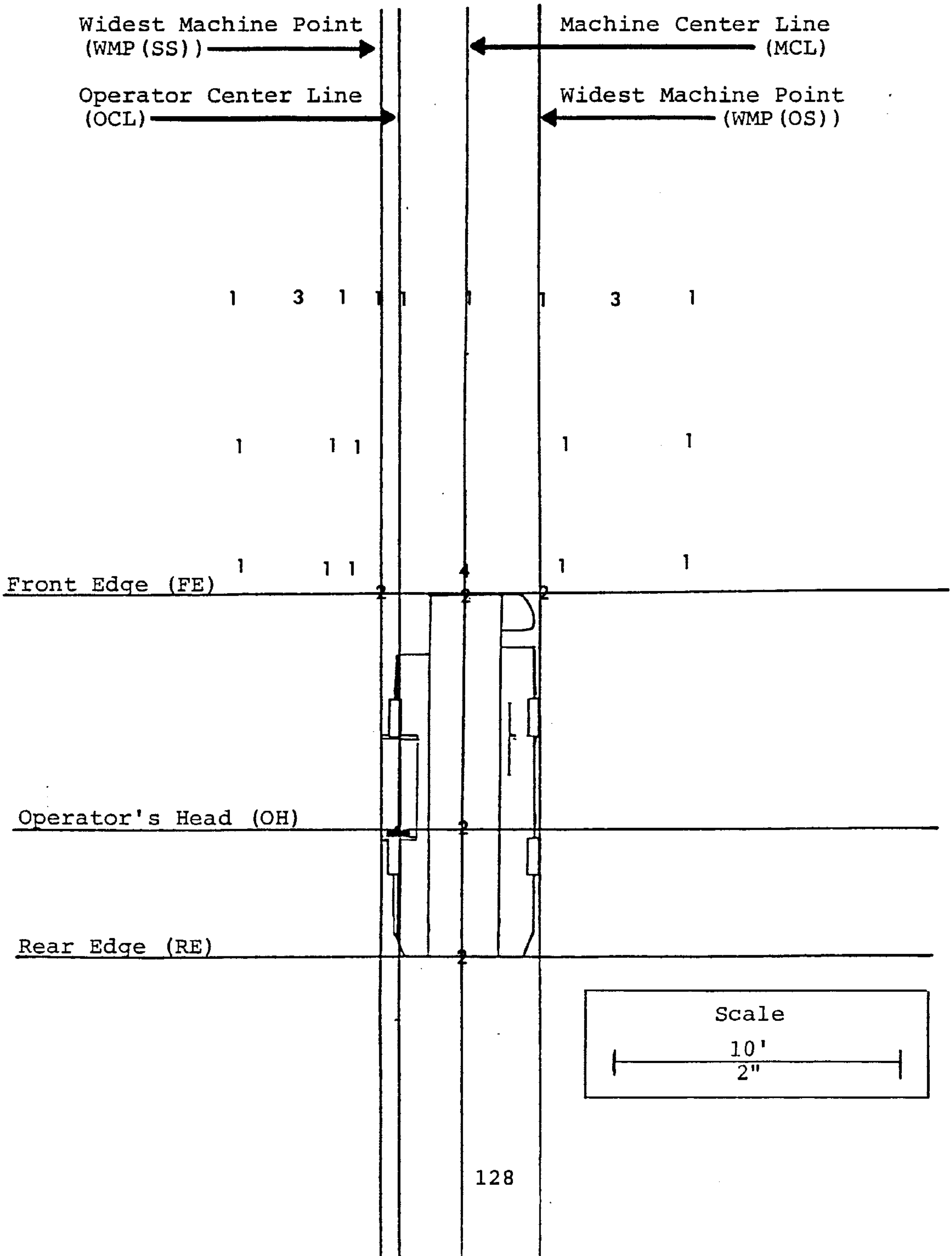
SHUTTLE CAR (MMH)



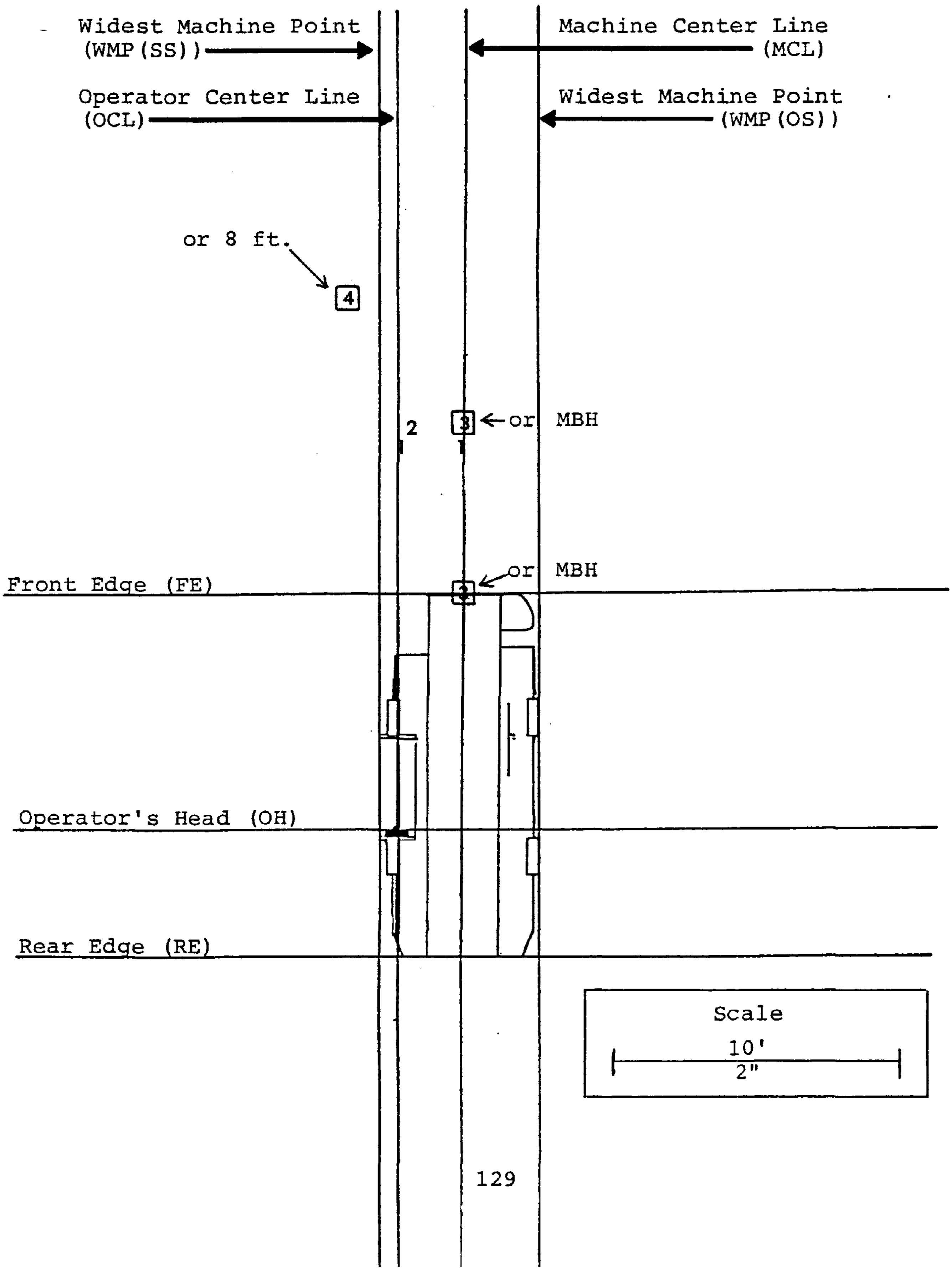
SHUTTLE CAR (OEH)



SHUTTLE CAR (HMP)



SHUTTLE CAR (SH)



I. TRAMMING List of Visual Features for: SCOOP

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
A. Position of Machine in the Roadway			Priority 1
SS Rib	OH + 1/2 NSD	WMP(SS) + 4'	OEH
OS Rib	FE + 1/2 NSD	WMP(OS) + 8'	OEH
Crosscut Corners	FE + 20'	WMP(SS) + 4'	OEH
	FE + 20'	WMP(OS) + 8'	OEH
	FE	WMP(SS) + 4'	OEH
Roof Irregularities	FE + 1/2 NSD	OCL	SH
Center Line Roof Marks	FE + 1/2 NSD	MCL	SH
SS Lead Corner of Machine	FE	WMP(SS)	MMH
OS Lead Corner of Machine	FE	WMP(OS)	MMH
SS Trailing Corner of Machine	RE	WMP(SS)	MMH
OS Trailing Corner of Machine	RE	WMP(OS)	MMH
B. Location of Obstacles and Hazards			Priority 1
Roadway Obstacles	FE + 2'	WMP(SS) + 2'	Floor
	FE + 2'	WMP(SS) + 1/2 NSD	Floor
	FE + 1/2 NSD	WMP(SS) + 2'	Floor
	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	Floor
	FE + NSD	WMP(SS)	Floor
	FE + NSD	WMP(SS) + 1/2 NSD	Floor
	FE + NSD	MCL	Floor
	FE + 2'	WMP(OS) + 2'	Floor
	FE + 2'	WMP(OS) + 1/2 NSD	Floor
	FE + 1/2 NSD	WMP(OS) + 2'	Floor
	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	Floor
	FE + NSD	WMP(OS)	Floor
	FE + NSD	WMP(OS) + 1/2 NSD	Floor
Roof Obstructions	FE + 2'	WMP(SS) + 2'	HMP
	FE + 2'	WMP(SS) + 1/2 NSD	HMP
	FE + 1/2 NSD	WMP(SS) + 2'	HMP
	FE + 1/2 NSD	WMP(SS) + 1/2 NSD	HMP
	FE + NSD	WMP(SS)	HMP
	FE + NSD	WMP(SS) + 1/2 NSD	HMP
	FE + NSD	MCL	HMP
	FE + 2'	WMP(OS) + 2'	HMP
	FE + 2'	WMP(OS) + 1/2 NSD	HMP
	FE + 1/2 NSD	WMP(OS) + 2'	HMP

I. TRAMMING (Continued) SCOOP

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
C. Location of Obstacles and Hazards (Continued)			**Priority 1**
Roof Obstructions (Continued)	FE + 1/2 NSD	WMP(OS) + 1/2 NSD	HMP
	FE + NSD	WMP(OS)	HMP
	FE + NSD	WMP(OS) + 1/2 NSD	HMP
Rib Obstructions	FE + 2'	WMP(SS) + 4'	Floor
	FE + 1/2 NSD	WMP(SS) + 4'	Floor
	FE + NSD	WMP(SS) + 4'	Floor
	FE + 2'	WMP(SS) + 4'	HMP
	FE + 1/2 NSD	WMP(SS) + 4'	HMP
	FE + NSD	WMP(SS) + 4'	HMP
D. Speed of Movement			**Priority 2**
SS Rib	OH + 1/2 NSD	WMP(SS) + 4'	OEH
Roof	FE + 1/2 NSD	OCL	SH
Roadway	FE + 1/2 NSD	OCL	Floor
E. Location of Machine within Mine			**Priority 4**
Signs	FE + NSD	WMP(SS) + 4'	8' or SH, WE<
General Surrounds	FE + NSD	WMP(SS) + 4'	OEH
	FE + NSD	WMP(OS) + 8'	OEH
	FE + NSD	MCL	OEH

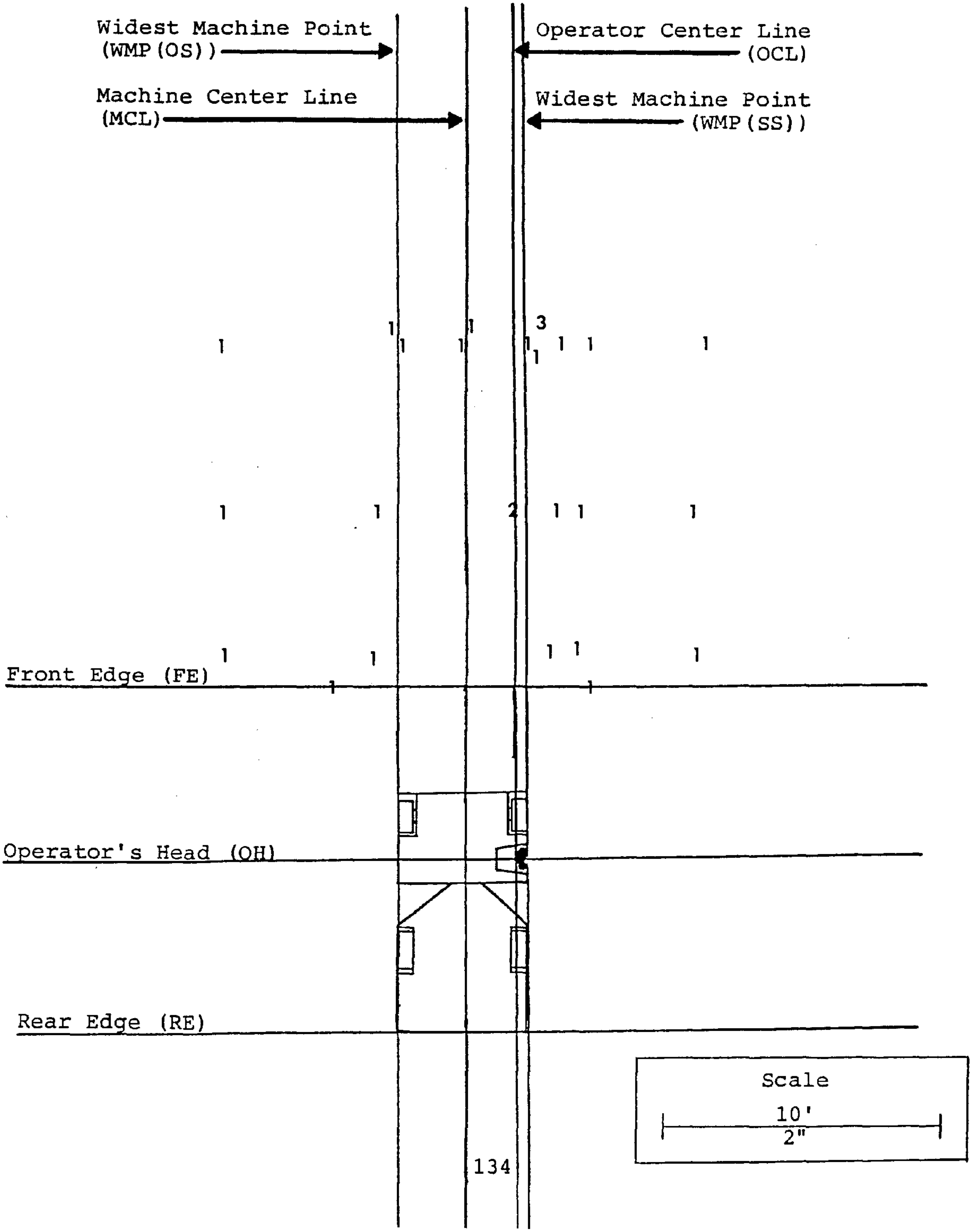
II. LOADING SCOOP

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
A. Available Load Space			**Priority 3**
Top of Pile	FE - 5'	MCL	HMP
Bucket	Back of Scoop Bucket	WMP(SS)	MMH

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
B. Position of Blade Relative to Coal Pile			**Priority 3**
Coal Pile	FE	WMP(SS)	MMH
	FE	MCL	MMH
Bucket	Back of Scoop Bucket	WMP(SS)	MMH
C. Location of Obstructions and Hazards			**Priority 1**
Roof Obstructions	FE	WMP(SS)	HMP
	FE	WMP(OS)	HMP
	FE	WMP(SS) + 5'	HMP
	FE	WMP(OS) + 5'	HMP
	RE	WMP(SS)	HMP
	RE	WMP(OS)	HMP
	RE	WMP(SS) + 5'	HMP
	RE	WMP(OS) + 5'	HMP
Rib Obstructions	FE	WMP(SS) + 2'	MMH
	FE	WMP(OS) + 10'	MMH
	RE	WMP(SS) + 2'	MMH
	RE	WMP(OS) + 10'	MMH
Roadway Obstructions	FE	WMP(SS) + 5'	Floor
	FE	WMP(OS) + 5'	Floor
	RE + 5'	WMP(SS) + 5'	Floor
	RE + 5'	WMP(OS) + 5'	Floor
D. Position and Height of Load in Vehicle			**Priority 3**
Coal Pile	FE - 5'	MCL	MMH
E. Position of Vehicle Relative to Roof Bolts			**Priority 1**
Roof Bolts	OH + 5'	OCL	SH

Visual Feature	Fore-Aft	Side-Side Lateral	Up-Down Height
A. Position of Vehicle Relative to Dump Site			**Priority 3**
Front End of Dump	FE + NSD	OCL	MMH
SS Lead Corner of Machine	FE	WMP(SS)	MMH
Dump Site Activation Lever	OH	OCL + 2'	OEH
Ramp	FE + NSD	WMP(SS)	Floor
B. Position of Load on Vehicle			**Priority 4**
Top of Load	FE	MCL	HMP
Back Slope of Load	FE - 3'	MCL	OEH
SS Blade Ram	FE	WMP(SS)	MMH
C. Location of Obstacles and Hazards			**Priority 1**
Edge of Loading Ramp	FE + NSD	WMP(SS) + 2'	Floor
Personnel	FE + NSD	WMP(SS)	OEH
	FE + NSD	WMP(OS)	OEH
	FE + NSD	WMP(SS) + 1/2 NSD	OEH
	FE + NSD	WMP(OS) + 1/2 NSD	OEH
	FE + NSD	MCL	OEH
Tools and Supplies	FE + NSD	WMP(SS)	Floor
	FE + NSD	WMP(OS)	Floor
	FE + NSD	MCL	Floor
Roof Hazards	FE + NSD	OCL	HMP
D. Status of Dump Site			**Priority 3**
Center of Dump	FE + NSD	MCL	MMH
Status Lights	FE + NSD	WMP(SS)	OEH
Tender's Cap Lamp	FE + NSD	WMP(SS) + 5'	HMP
	FE + NSD	WMP(OS) + 5'	HMP

SCOOP (Floor)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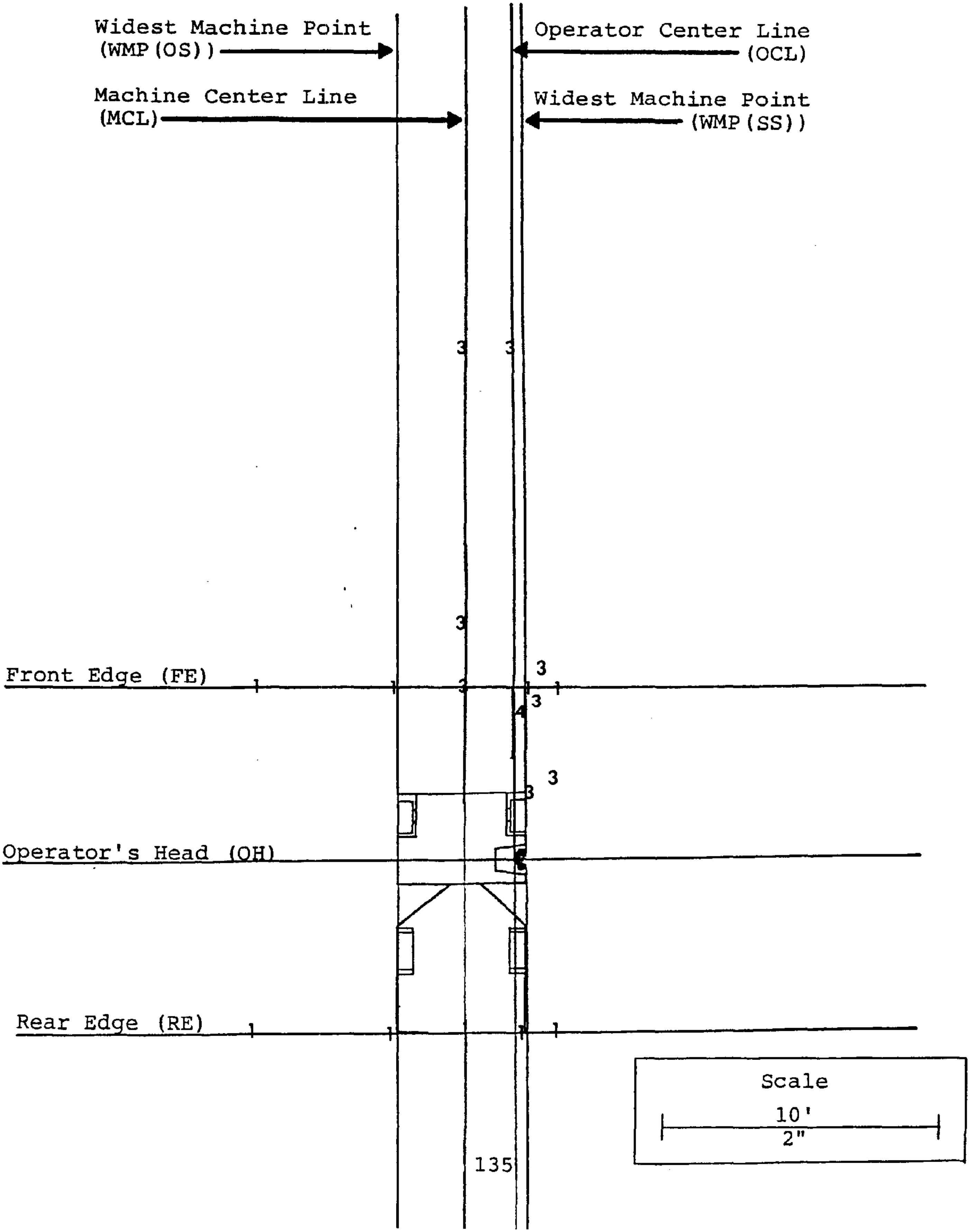
(WMP(OS))
Operator Center Line
(OCL)
Machine Center Line
(MCL)
Widest Machine Point
(WMP(SS))
Front Edge (FE)
Operator's Head (OH)
Rear Edge (RE)
Scale
10'
2"

SCOOP (MMH)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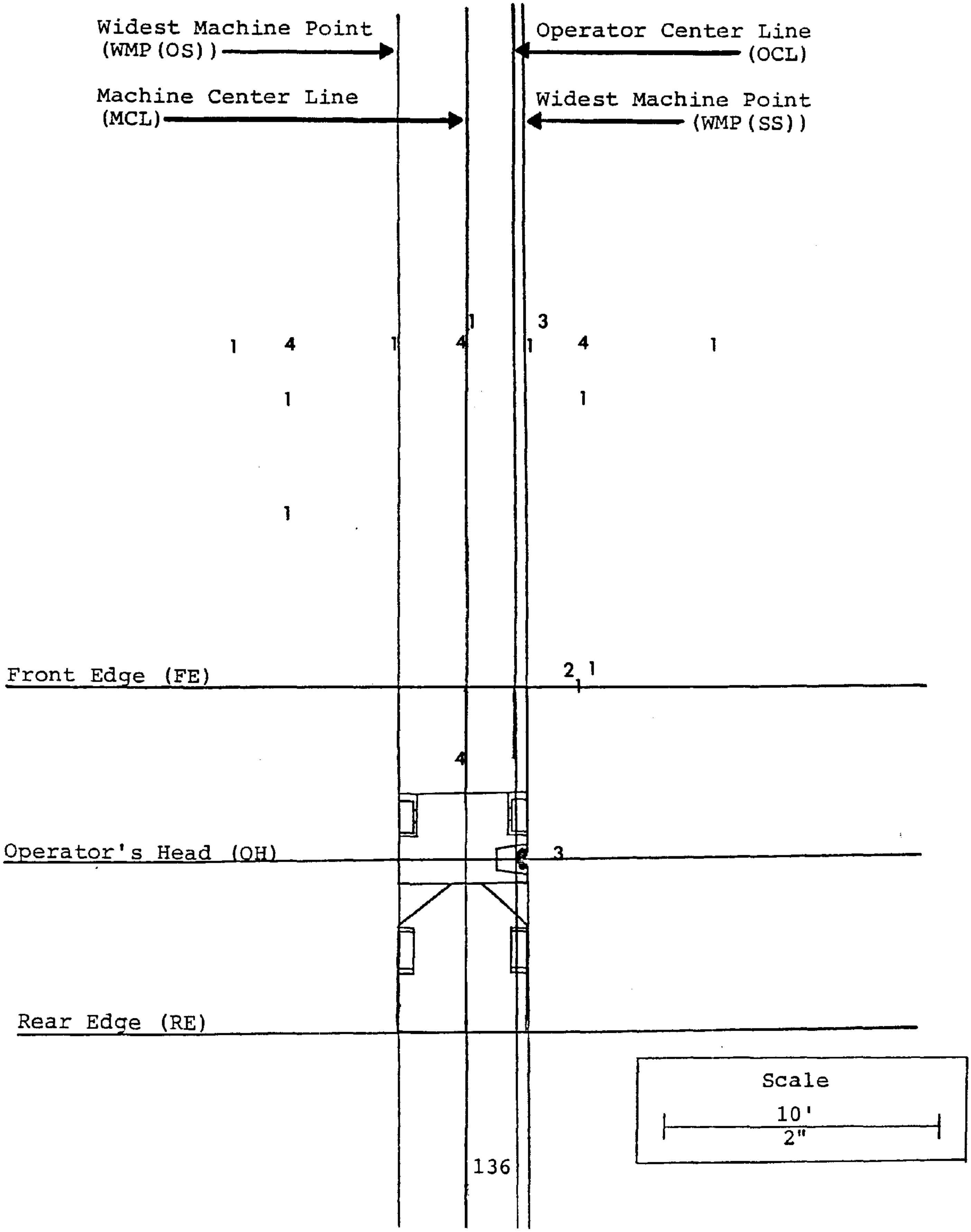
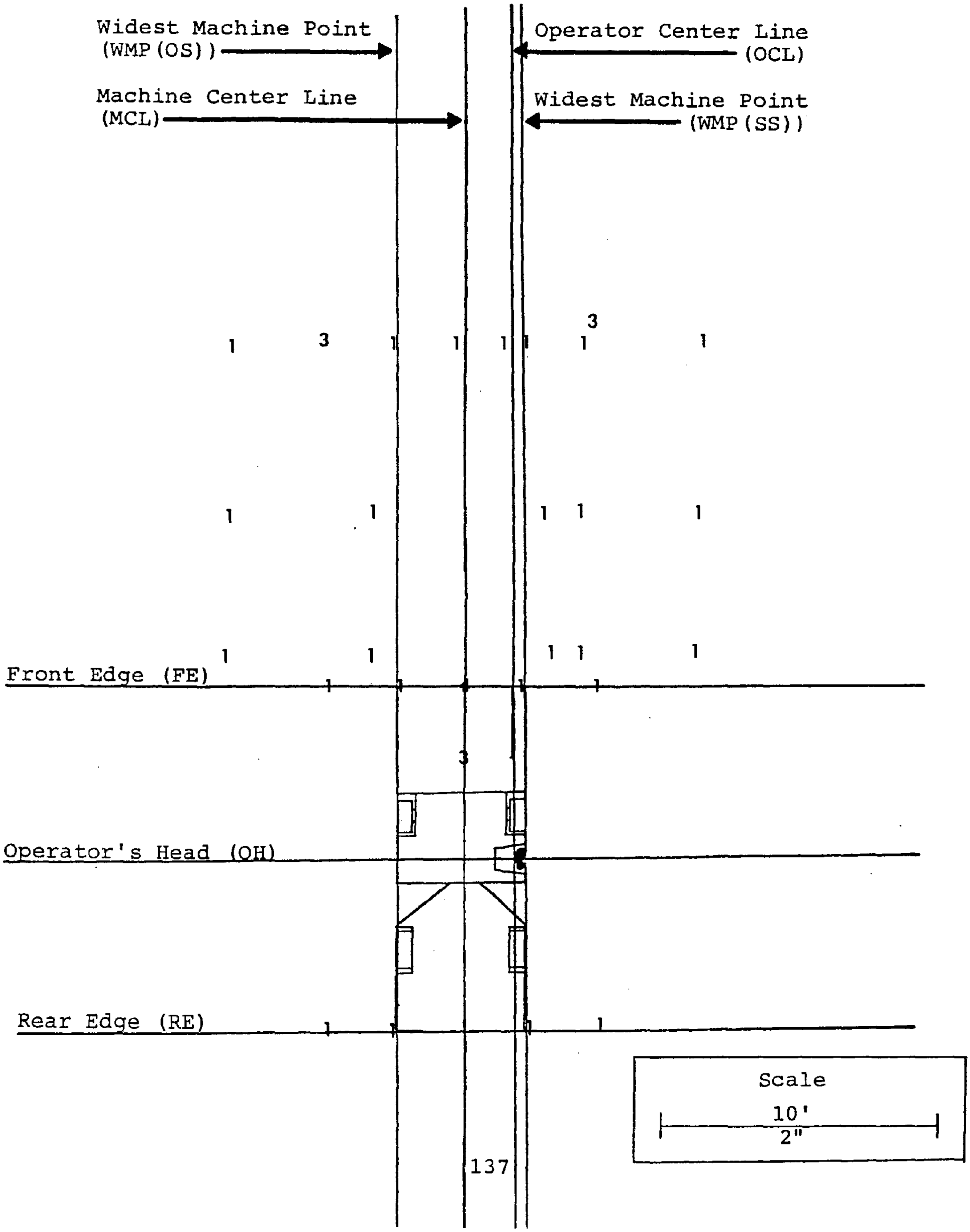
(WMP(OS))
Operator Center Line
(OCL)
Machine Center Line
(MCL)
Widest Machine Point
(WMP(SS))
Front Edge (FE)
Operator's Head (OH)
Rear Edge (RE)
Scale
10'
2"

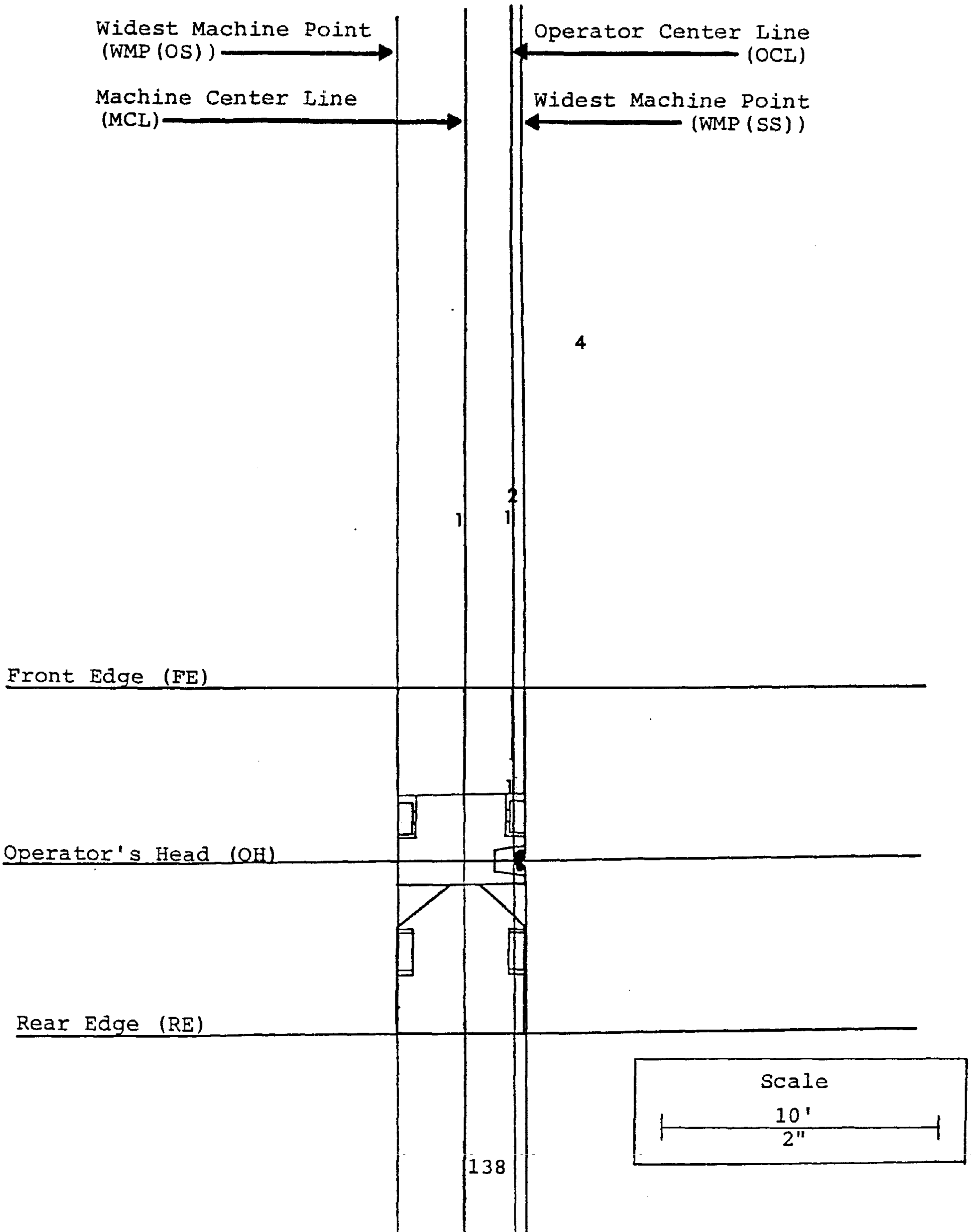
SCOOP (OEH)


Widest Machine Point
(WMP(OS))
Operator Center Line
(OCL)
Machine Center Line
(MCL)
Widest Machine Point
(WMP(SS))
1
3
1
4
1
4
1
4
1
1
1
1
Front Edge (FE)
2
1
1
4
Operator's Head (OH)
3
Rear Edge (RE)
Scale
10'
2"

SCOOP (HMP)


Widest Machine Point (WMP(OS))
Operator Center Line (OCL)
Machine Center Line (MCL)
Widest Machine Point (WMP(SS))
Front Edge (FE)
Operator's Head (OH)
Rear Edge (RE)
Scale
10'
2"

SCOOP (SH)



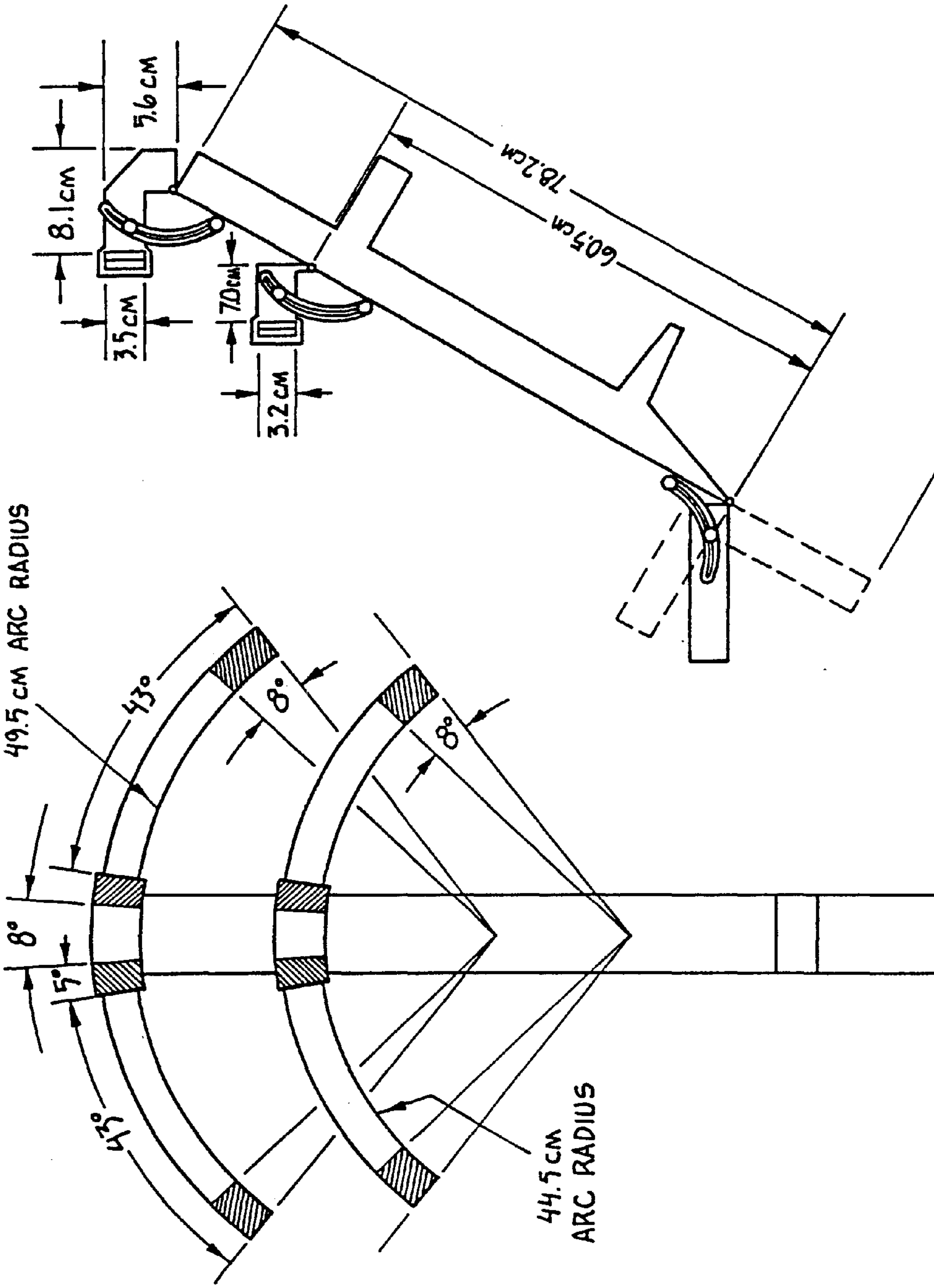
Widest Machine Point (WMP(OS))
Operator Center Line (OCL)
Machine Center Line (MCL)
Widest Machine Point (WMP(SS))
4
2
1
1
Front Edge (FE)
Operator's Head (OH)
Rear Edge (RE)
Scale
10'
2"

Appendix B

DIMENSIONAL SKETCH

OF

HERMI



7.6 CM
8.1 CM
3.5 CM
7.0 CM
3.2 CM
78.2 CM
60.5 CM
49.5 CM ARC RADIUS
43°
8°
8°
8°
5°
43°
44.5 CM
ARC RADIUS

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