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Development of Protective Operator Compartment for Thin-Seam Mobile Bridge Carrier

By A. J. Kwitowski and Robert J. Gunderman

UNITED STATES DEPARTMENT OF THE INTERIOR

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Donald Paul Hodel, Secretary

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Robert C. Horton, Director

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	in/ft	inch per foot
h	hour	min	minute
in	inch	st/min	short ton per minute

DEVELOPMENT OF A PROTECTIVE OPERATOR COMPARTMENT FOR A THIN-SEAM MOBILE BRIDGE CARRIER

By August J. Kwitowski[1] and Robert J. Gunderman[2]

ABSTRACT

This Bureau of Mines report summarizes the development of a protective operator compartment for a new generation thin-seam mobile bridge carrier. The developed compartment is commercially available and is currently employed on approximately 15 bridge carriers used in the mining industry. The design of the compartment, which employed human factors engineering and small- and full-scale mockup models, is fully described. Details of the compartment's fabrication, evaluation, and demonstration in a commercial low-seam coal mine are also provided.

[1]Civil engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.
[2]Former project manager, Jeffrey Mining Machinery Division, Columbus, OH.

INTRODUCTION

Since January 1, 1974, Federal law has required cabs and canopies on underground face equipment, and this has successfully reduced the seriousness of injuries sustained on face equipment operators during ground fall accidents. The Labor Department's Mine Safety and Health Administration (MSHA) has estimated that between January 1974 and January 1982, cabs and canopies saved 200 lives from roof fall fatalities.[2]

MSHA also estimated that approximately 70% of the total 2,212 fatal and nonfatal equipment accidents occurring in seams below 48 in during the above period could have been prevented if protective structures had been employed on all face equipment.

The coal mining industry's successful use of protective cabs and canopies has occurred almost exclusively in mines where the floor-to-roof height is 48 in or greater. Industry problems with attempts to employ protective operator structures in thinner seams were so severe that on July 1, 1977, MSHA rescinded requirements for operator protective structures on face equipment operating in coal seams with a working height of 42 in or less.

Additionally, many coal operators have been successful in obtaining variances relieving legal requirements for cabs and canopies on machines working in heights above 42 in. Variances are granted primarily because operators have proven under some circumstances that the addition of a cab or canopy to a particular machine constitutes a safety hazard.

The pricipal argument used in obtaining variances is that cabs and canopies can so impair the operator's field of view and comfort that machine control becomes difficult and hazardous. The addition of a cab or canopy to a machine that operates in low-coal can block the visual cues that an operator needs for safe performance through the mining cycle. If operators cannot properly perceive the position of their machines relative to their surroundings and other workers, the safety aspects of cabs and canopies can be negated to the point where safety is improved by removing the structures.

This Bureau of Mines project originated with the objective of developing and demonstrating a protective operator compartment for a low-seam double bridge carrier—a primary component of continuous face haulage systems. The end product was to be usable in seams below 48 in. The contractor, Jeffrey Minning Machinery Division of Dresser Industries, Inc.,[1] selected a goal of 34 in as the minimum operating seam height. This was based on development of a canopy for use on Jeffrey's model 506C-5 bridge carrier, a primary machine used in seam heights as low as 28 in.

The final product was not a protected operator compartment that could be installed on the model 506C-5 bridge carrier on a retrofit basis; instead, it was designed for inclusion on a new mobile bridge carrier, the Jeffrey model 5010. The initial phases of the reported work assumed that the compartment would be used with the model 506C-5 bridge carrier. The decision to switch to the model 5010 bridge carrier occurred just prior to the detailed design phase.

DESCRIPTION OF DOUBLE BRIDGE CARRIER

The double bridge carrier is a unit of continuous haulage systems which convey coal from the continuous mining machine to the room conveyor. The machine is self-propelled, crawler mounted, and manually operated. Figure 1 shows a double bridge carrier linking two bridge conveyors between the continuous miner and the room conveyor. The reach of this system is sufficient for a three-entry section. If necessary, a second double bridge carrier and another bridge conveyor can be linked into the system to provide enough reach for a five-entry section. The double bridge carrier operator(s) must maneuver the machine(s) to snake the conveyors through the cuts and entries. When repositioning the miner during a face change, the entire system must be backed up parallel to the room conveyor. (See figure 2.)

Figure 3 shows the Jeffrey model 506C-5 bridge carrier in operation; it is intended for use with thin-seam continuous mining machines and is less than 25-in high. The operator controls are located on the left inby side, just above the crawler treads.

The inby bridge conveyor is supported by a carriage (or dolly) riding on the receiving conveyor of the double bridge carrier. The bridge carrier operator is responsible for positioning the machine to allow continuous miner movement in either direction. The dolly is free to move approximately 6½ ft along the conveyor, allowing for small movements of the continuous miner without having to reposition the bridge carrier.

The model 506C-5 operator controls are pictured in figure 4. The most frequently used controls, the hydraulic actuators, are shown on the right side of the figure. The control functions are, from left to right: the receiving section raise-lower; the discharge section raise-lower; the left-hand tram; and the right-hand tram. The electrical controls shown in the figure are of the push-type and include power on, power off, conveyor forward, conveyor off, jog, jog-reverse, automatic, and manual. The system also provides an emergency stop bar.

[1]Sawyer, S. G., and J. A. McCormick. Cabs and Canopies Underground Do Protect Miners. Coal Min. and Proc., v. 10, No. 2, 1975, pp. 40-44.

[2]Zona, A. (Mine Safety and Health Administration, Pittsburgh, PA). Private communicatiion, Jan. 1982; available from A. J. Kwitowski, BuMines, Pittsburgh, PA.

[3]The work was done under Bureau contract H0387027; this publication was prepared jointly by the contractor and the Bureau in lieu of a contractor final report.

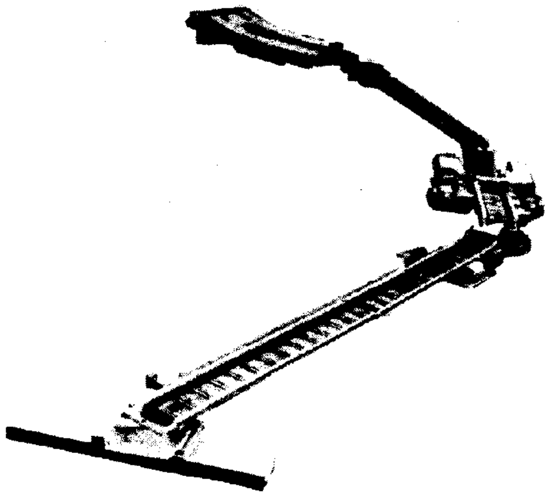

FIGURE 1.—View of double bridge carrier.

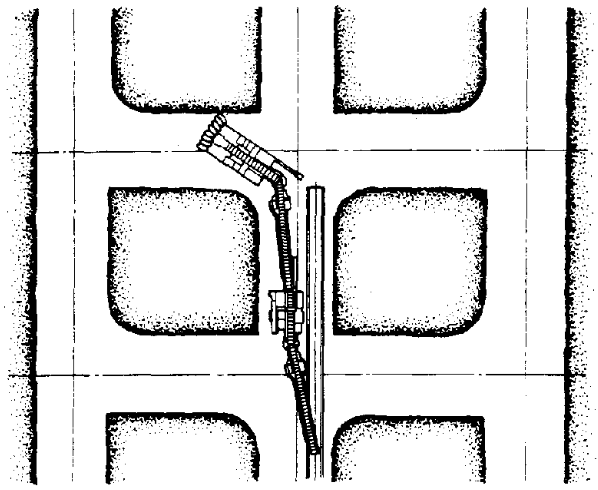

FIGURE 2.—Position of bridge carrier during face change.

FIGURE 3.—View of Jeffrey model 506C-5 bridge carrier.

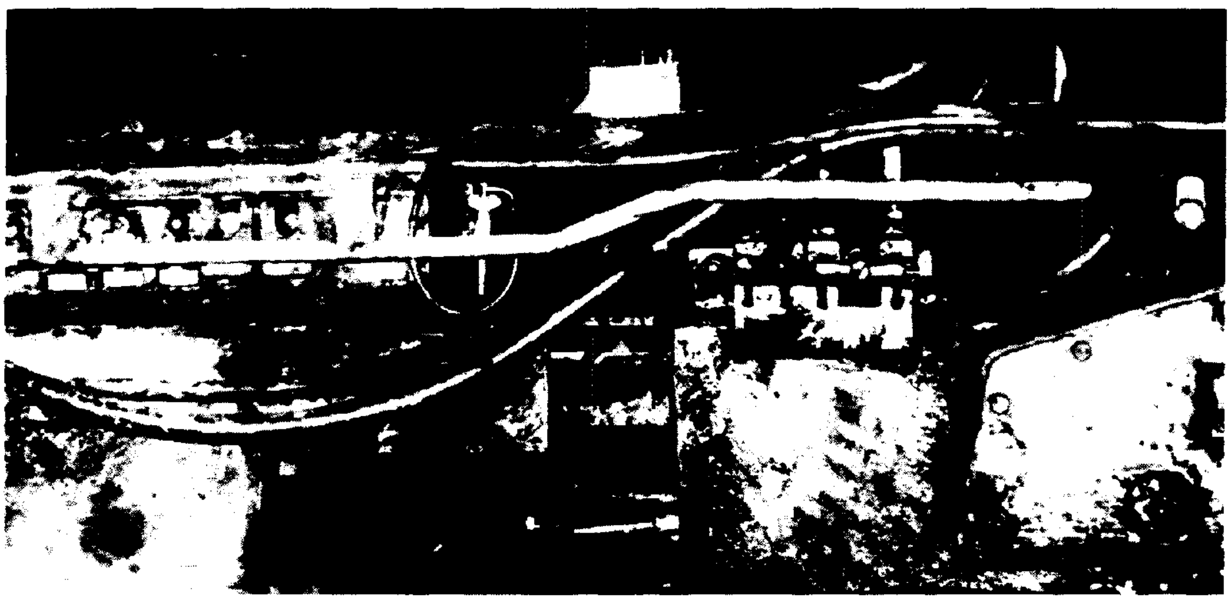

FIGURE 4.—Model 506C-5 controls.

CONCEPTUAL DEVELOPMENT OF THE OPERATOR COMPARTMENT

Jeffrey's approach to the conceptual development of the operator compartment included mine visits, consultations on human factors, widely varied idea generation, and evaluation using small and full-scale mockup fabrications.

The 506C-5 machine was not originally designed to allow for the inclusion of an operator compartment and/or canopy. It seemed doubtful that a satisfactory compartment could be designed to employ the controls at their standard location at the left inby side of the bridge carrier. The first step in the compartment development was to schedule mine visits allowing first-hand observation of the operator-machine interaction. The idea was to improve the odds that the design would contain the full inclusion of various operational modes and styles. Considerations of human factors were used to formulate a list of questions and items to observe while in the mines.

OPERATOR FUNCTIONS OBSERVED UNDERGROUND

Visits were made to three operating underground coal mines to help the designers understand what the operator of a double bridge carrier does during a shift. This information was essential to the compartment development in indicating correct operator placement, sufficient mobility of the machine, and ability of the operator to perform all necessary functions from the operating location.

The working heights in the visited mines were 29, 32, and 46 to 51 in. A five entry system with two double bridge carriers was used in the 32-in mine. The other two mines used one double bridge carrier. Roof conditions were extremely good in the 29- and 32-in mines.

Detailed notes were kept for each mine visit. The significant items are discussed in the following paragraphs. Prior to the visits, a human factors consultant helped prepare two lists of things to look for and questions to ask.

The general category list included:

1. Mine conditions.
2. Gloves.
3. Mining plan.
4. Operations observed.
5. Modifications to machinery by mine operator.
6. Cycle times.
7. Delays and causes.
8. Records of accidents or near accidents.
9. Suggestions for improving controls.

The observations of the operator list included:

1. Operator position.
2. Operator size.
3. Method of communication.
4. Pattern of head and eye positions.
5. Present field of view conditions.
6. Critical field of view areas.
7. Average time at controls.
8. Task breakdown (safety, skill, and time).
9. Order and frequency of control usage.
10. Operator movement.
11. Position changes to relieve fatigue.
12. Ease of learning to operate.
13. Basis for recognizing good operation.
14. Causes of poor operation.
15. Difficulties in reversing.
16. Operational problems related to control application.
17. Apparent hazards.
18. Operator's mistakes in control use and how this factor affects safety and production.

When running coal, the operators stayed close to the machine controls. When events were occurring at a relatively rapid pace, the operator kept one hand on the tram controls. When the pace slowed or was interrupted, the operators would often recline against a rib.

As needed, operators took a shovel from atop the machine and cleaned up spillage at transfer points. Cleanup was not performed on a fixed schedule, but typically was done once per hour. At one installation, the routing of cables and water hose coming from the outby point toward the continuous mining machine was arranged at the coal transfer points so that no manual cable and/or hose handling was required. At the other two installations, the operator had to leave the controls to move the cable and hose when tramming the system. Some operators occasionally left their stations to check roof conditions.

The principal operator tasks involved machine positioning to keep the dolly centered on the receiving conveyor and watching the coal flow for clogs. Occasionally, the operator had to clear blockage at the transfer points. Except during tramming, the receiving section was kept lowered to the floor. The discharge section was kept high enough to assure that the outby bridge conveyor was elevated above the floor and reasonably level.

Typically, the operator's biggest challenge was tramming outby. During this activity, the operator had to keep one hand on each of the two tram controls, with the machine-turning being accomplished by rotating both hand-controls. To view clearances, operators needed to crawl alongside the machine while it moved outby, keeping themselves constantly aware of dolly position, ribs clearance for both conveyors and the carrier, and roof clearance of both conveyors. If necessary, the operator could leave the controls to obtain better visibility.

Cycle times were recorded at the three mines. The percentages of time spent for each function were surprisingly similar: 70.5% running coal, 9.8% tramming inby, 16.4% tramming outby, and 3.3% waiting. Thus, operators spent approximately 80% of their time facing inby and less than 20% facing outby.

Cap lamp signals provided the main form of communication between section workers. To use this system, the bridge carrier operator needed to be within the line-of-sight of the miner operator, the outby helper, and the second carrier operator (if present). Start-up or shutdown of the inby bridge conveyor by the miner operator was a signal for the bridge carrier operator to do the same with their conveyors.

MINE APPLICATIONS

Mobile bridge carriers are used primarily in low seams where shuttle-type face haulage vehicles are less effective. The model 506C-5 double bridge carrier is used predominantly for work behind the Jeffrey model 101 MC remote control continuous miner, which works in seam heights from 30 to 53 in. Therefore, the model 506C-5 is generally found only in lower-height seams. The conveying capacity of the 506C-5 is rated at 6 st/min.

Sixty-five machine delivery orders were examined to assess application requirements and the potential acceptance of a protective canopy over the operator. The seam heights at the mine site where the equipment was delivered were obtained from Jeffrey's internal data and/or coal mine directories (table 1). The bridge carriers may actually have been used at a different mine location with a different seam height.

Table 1.—Seam heights of mines using the model 506C-5 bridge carrier

Seam height, in	Number of machines	Seam height, in	Number of machines
28	2	39	6
29	3	40	2
30	2	42	5
32	6	43	9
34	3	45	1
36	10	46	6
38	8	48	2

According to these data, the mean seam height value was 38 in. Ten machines operated in 36-in seams; thus, the minimum operating height for the compartment was set at 34 in to accommodate 80% of the mine heights in the data sample.

Regardless of its canopy setting, the actual working height of a machine is dependent on mine conditions such as undulations, high spots, and roof headers. Therefore, a machine with a canopy height set at 34 in cannot operate in a working height of 34 in. Provisions have to be made for additional lowering of the canopy.

OPERATOR COMPARTMENT REQUIREMENTS AND IMPACT

After defining operator functions, the important questions remaining were location of the operator, possible postural positions, and the impact of proposed modifications on machine application. Since acceptable answers to the first two questions were difficult, they were initially considered without any constraints on changes to the machine. The following section describes the studies and considerations of these questions as related to the challenge of providing an operator compartment for a 34-in working height.

OPERATOR POSITION

Operator postural positions are constrained by compartment dimension restrictions. Obviously, an operator cannot be seated upright if the canopy height is only 30 in above the floor. Also, compartment width must not exceed 27 in or machine maneuverability will be seriously impaired.

Human factors must be considered in equipment design. In a compartment 30-in high and 24- to 27-in wide, absolute operator comfort is not possible using established principles of design. Compromises must be made on what is theoretically desirable and practically possible. Thus, the human factors challenge involves how to best meet both system design requirements and avoid undue physiological or psychological stress in the operator.

Key design criteria regarding the operator included:

1. Maximizing field of view.
2. Enabling effective use of controls.
3. Allowing postural change during operation.
4. Minimizing discomfort and fatigue.
5. Permitting rapid exit from the compartment.
6. Protection from roof falls.

In addition to meeting design criteria, compartment space requirements must be held to a minimum to insure maneuverability of the bridge carrier.

Operator comfort is achieved by minimizing static work, allowing postural changes, and providing body and limb support, especially for the head and neck during angles of severe back recline.

Field of view (fore and aft), control activation for precise tramming, and bridge height control are important factors affecting operator performance.

Safety is the keystone criterion in good compartment design. A compartment must provide for rapid operator egress, prompt emergency stop bar activation, and elimination of potential pinch points. The interior surfaces of the compartment must protect the operator from suffering additional bruises or contusions during violent motions, vibrations, roof falls or ribbing collisions.

A number of candidate operator positions were identified and evaluated jointly by a human factors consultant and the Bureau's contractor. Positions evaluated included: the prone; on the side with 45° torso rotation and elbow support; crouched and kneeling; reclined; half squatting; leaning genuflection; and the dog. Posture acceptability varied among tested individuals depending on the operator's elasticity, size, personal choice, and amount of time spent in a given position. Some positions can only be maintained for short time periods, while others (like the seat reclining posture with a proper back angle) can be maintained for hours.

The low height requirement (30 in) eliminated some postural configurations from further consideration. Positions remaining included the prone, side with 45° torso rotation and elbow support, and the reclined. These configurations all required one dimension of the compartment in the range of 5 to 7 ft.

Upon suggestion of the human factors consultant, unobstructive studies of nonmine personnel were conducted to evaluate unbiased responses to maintaining postures for 1 h within the confines of a compartment 30-in high, 24-in wide, and 70-in long. Using six college students ranging in height from 5 ft 10 in to 6 ft 3 in, a series of videotapes was collected while the subjects maintained an alert condition in the defined space. Each subject was observed for 1 h; 30 min in prone positions with buttock either turned to side or top, and 30 min reclined on a backrest. The reclined angle of the backrest permitted the subjects to sight along the inside top of the compartment while still allowing room for a mining helmet. This study confirmed anthropometric requirements and indicated more postural changes for nonreclining positions. The subjects differed in their personal preferences, but the consensus preferred the reclined position. Notable leg position changing accompanied the reclined position, probably due to the fact that stretching the legs in a 60° back angle recline results in stress of the hamstring muscles.

The striking aspect of these tests was the subjects' willingness to sit reclined at a 60° back angle for 30-min periods. This fact was later verified using test subjects within the mockup fabrication. Although subjects above the 90th percentile range would have problems with muscle discomfort over time, it appears that a compartment height of 30 in represents the lower limit for reclined seating. Below 30 in. either operator size restrictions are necessary or an entirely new concept of seating or postural placement is required, such as a prone position.

OPERATOR LOCATION

Inclusion of an operator compartment approximately 27-in wide with a 72-in base area was considered for any conceivable location on the model 506C-5 bridge carrier. The first consideration in determining compartment location was maneuverability with no regard for visibility, complexity or practicality.

Figure 5 shows four potential compartment locations that would not require significant modification to the double bridge carrier. These configurations were graphically analyzed to establish maneuver feasibility.

Entries for continuous haulage systems are typically 20-ft wide on 50-ft centers. (See figure 6.) Positions 3 and 4 were eliminated from further consideration because both bridge conveyors must be free to swing ±90° with respect to the conveyor on the carrier.

Potential modifications to the basic model 506C-5 to accommodate an operator compartment were considered singly and in combination. The potential modifications determined were—

1. Relocating the conveyor outside the crawler drive.
2. Employing single or double bends in the conveyor pan.
3. Using a swing-type discharge conveyor section.
4. Using a swing-type receiving conveyor section.
5. Increasing track width from 1 to 3 ft.
6. Providing an ingress opening through the center of the crawler drive assembly.
7. Repositioning the operator's leg space under the conveyor.

If significant machine modifications were enacted, an additional 13 potential operator compartment locations would be possible. These locations were graphically analyzed for maneuverability and are listed as follows:

Position 5. — Between crawler drive assemblies with conveyor relocated outside the crawler drive assemblies.

Position 6. — At 45° to receiving section with conveyor relocated outside crawler drive assemblies.

Position 7. — Parallel to receiving section with conveyor relocated outside crawler drive assemblies and curved inward 20°.

Position 8. — Present outboard location with swing discharge and double curve receiving conveyor sections.

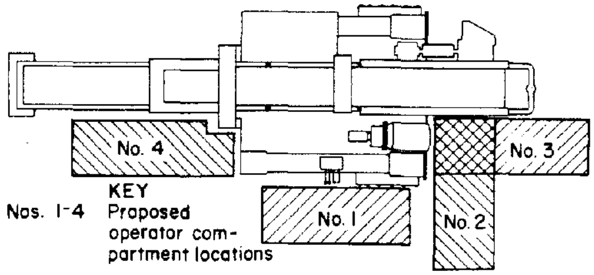

FIGURE 5.—Potential compartment locations not requiring significant modifications.

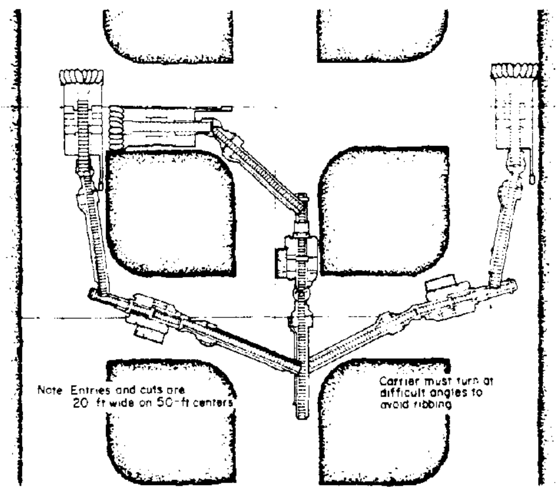

FIGURE 6.—Typical section dimensions used for continuous haulage systems.

Position 9. — Present outboard location with swing discharge section.

Position 10. — Between conveyor and crawler drive assemblies with swing discharge and swing receiving sections.

Position 11. — Crawler drive assemblies moved apart 1 ft with compartment parallel to swing discharge section.

Position 12. — Crawler drive assemblies moved apart 1 ft with compartment parallel to swing discharge section.

Position 13. — Crawler drive assemblies moved apart 1 ft with compartment parallel to discharge section.

Position 14. — Crawler drive assemblies moved apart 2½ ft with compartment between pump motor and conveyor.

Position 15. — Between conveyor and crawler drive assemblies with ingress opening through center of a crawler drive assembly.

Position 16. — Operator's legs under the discharge conveyor section.

Position 17. — Operator's legs under the conveyor center section.

Figure 7 shows the concept employing swing-type conveyors and figure 8 shows position 13, which was ultimately selected for the recommended concept.

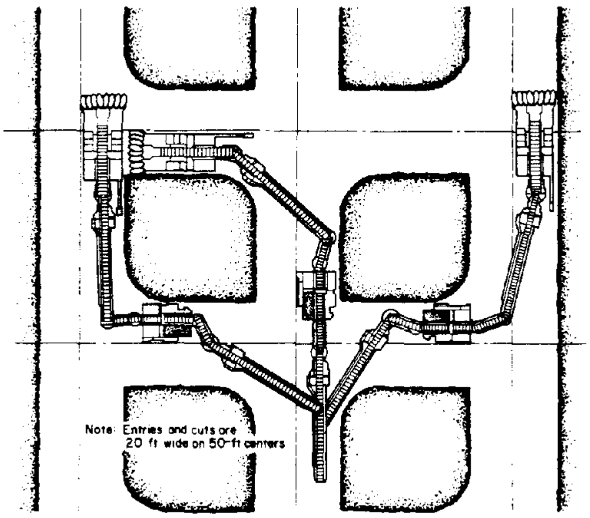

FIGURE 7.—Concept using swing-type conveyors.

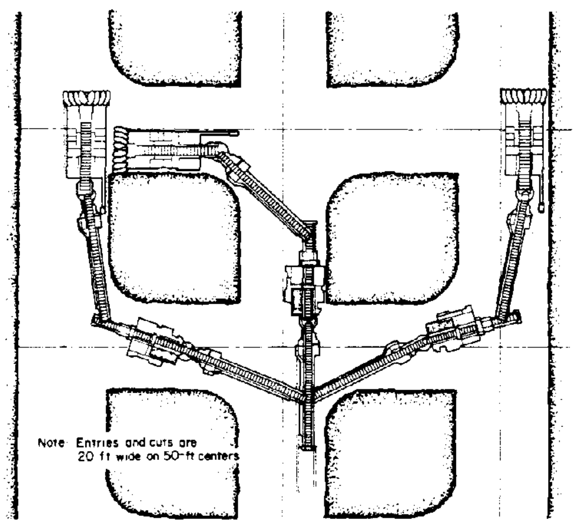

FIGURE 8.—Recommended bridge carrier concept.

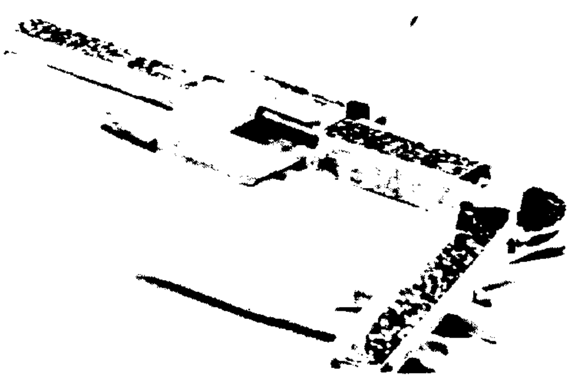

FIGURE 9.—Concept with modified operator placement.

After identification, the various potential compartment locations were rated by four evaluators using the weighted criteria in table 2. Evaluation results showed no superior concept and little difference between the highest and lowest ranked positions.

Table 2.—Criteria and weight factors for ranking potential compartment locations impact on machine and application

Criteria	Weight factors
Visibility:	
Inby (to tram)	3.5
Receiving transfer	4.25
Discharge transfer	3.5
Outby (to tram)	3.25
Sides	3.25
Maneuverability	4.5
Communication	4.0
Minimum operating seam height	3.25
Operator protection	4.5
Operator comfort	4.0
Operator emergency exit	4.0
Ingress	2.75
Control accessibility	3.5
Compatibility with personal gear	2.25
Equipment modification	3.25

A ⅛-in/ft-scale cardboard mockup was used for additional evaluation; for example, figure 9 (position 17) shows an opening between the crawler drive and the conveyor where operators with their legs folded beneath them would sit facing the conveyor. The model showed position 17 provides inadequate clearance and space for the operator.

Practical considerations further reduced the field of candidate compartment locations. Swing-type conveyors will not work over a range of ±90° without adding considerable complexity to the conveyor drive. Any increase of more than 1 ft in machine width is unacceptable when entry widths are 18 ft or less. These considerations narrowed the possible operator locations to positions 2, 13, 15, and 16.

Position 15, one of the more imaginative concepts, would have the operator ingress and/or egress through an opening in the middle of the crawler drive assembly and would locate the treads close to the roof. This concept was abandoned because it was very inefficient from a space utilization viewpoint and locations for machine components could not be readily identified. Also, the operator might suffer psychologically from being so enclosed by machinery.

The concept of placing operators facing the conveyor was explored since then they could readily see inby or outby. This would require the operator's legs to extend below the conveyor position. Unfortunately, there was not sufficient space available in the vertical direction to permit placement of the conveyor and the structure to enclose the operator's legs.

Therefore, position 13 remained the most favorable location. (See figure 10.) The compartment is 72 in by 27 in and is located parallel to the discharge conveyor.

Although the above concept appeared workable at this stage in the compartment development program, it would require considerable modification to the basic model 506C-5. The hydraulic pump and motor would need to be relocated and the crawler drive assemblies would have to spread apart by at least an additional foot. These problems ultimately led to the recommended compartment concept being incorporated into the design of a new model mobile bridge carrier.

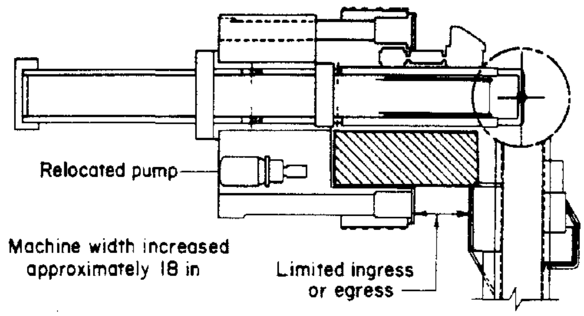

FIGURE 10.—Plan view of recommended bridge carrier concept.

All potential locations for a protected operator required some increase in machine dimensions, which would decrease machine maneuverability. The model 506C-5 is relatively maneuverable, allowing the operator to easily move out of the way when clearance is minimal. However, this maneuverability is achieved at the expence of the operator's safety. Therefore, some compromise in machine maneuverability must be made to insure operator protection.

There is no engineering guideline concerning growth of machine size. Maneuverability analysis of the model 506C-5 indicated a width change from 7 ft 11 in to approximately 9 ft could be tolerable, especially if the increased width would be located close to the machine's pivot center. If width is increased closer to the conveyor ends, maneuverability becomes more difficult.

Although any length increase would affect turning ability, a 1- to 2-ft increase over the model 506C-5's length of 22 ft 11 in should have no major impact.

As shown in figure 10, the machine with the selected operator compartment concept is wider than the present model. However, refinements to the concept (detailed in the following) hold the width increase to approximately 12 in for the crawler drives and lengthen the conveyor by approximately 18 in.

IMPACT ON MACHINE AND APPLICATION

The addition of the compartment on the machine effected significant changes in addition to length and width increases. In order to offset the change in center of gravity caused by adding to the length of the discharge conveyor, the crawler drive assemblies needed to be reversed with as much weight as possible concentrated toward the receiving conveyor end. Because the present design includes the crawler drive frames and the hydraulic tank as an integral part of the mainframe, the proposed changes require a totally new mainframe. Coupled with the additional costs of a new low-profile electrical enclosure and new parts, the required changes made a retrofit of existing machines very unattractive. However, to use the design concept for the manufacture of a new machine would add little cost increase above that associated with the addition of a new operator compartment.

In summary, the addition of a protected operator compartment to a model 506C-5 double bridge carrier requires both increased operator skills and significant machine modifications. The increased length and width caused by the addition of the compartment requires a higher skilled operator to handle the machine's reduced maneuverability. The modifications required to incorporate the operator compartment to existing 506C-5 machines are of such magnitude and cost that change is essentially precluded on a retrofit basis. However, the practicality and costs for the compartment are reasonable, provided a modified machine is built with provisions for the compartment.

PRELIMINARY DESIGN AND ANALYSIS

Having established a basic location for the operator compartment, designers began to study concepts for compartment design and its attachment to the main frame. This effort included a review of previous programs, further investigation of required modifications to the basic machine, and compartment evaluation through the use of a full-scale mockup fabrication.

The model 506C-5 bridge carrier is trammed at speeds and frequencies more like those of continuous miners than those of haulage vehicles like shuttle cars. Therefore, the operator compartment techniques employed on continuous miners seemed most useful to this project.

Previous studies had shown the advantages of a floating compartment (one which rides the floor) for use in low seams. Therefore, the floating-type design was chosen for the bridge carrier compartment.

Single pivot point design compartments have been successfully used on Jeffrey mining machines, particularly a larger-height double bridge carrier. Preliminary design of the low-seam bridge carrier compartment placed its length at approximately 6 ft, requiring that the attachment design allow freedom for the compartment to pivot in the vertical plane with respect to the main frame. While this freedom could have been provided by freeplay in a floating entrapment, a pivot joint appeared more desirable.

Consideration was given to providing for the compartment to rotate about a horizontal axis normal to the pivot axis. However, the width of the compartment did not appear to justify this added complexity.

An attachment combining both the pivot and the sliding entrapment in the vertical plane is shown in figure 11. The three views illustrate how the angle between the main frame and the compartment might change with undulations in the floor. Note that the compartment side of the pivot brackets slide vertically within the entrapments on the compartment.

Compartment attachment details were resolved and are described in a subsequent section. The basic design concept is pictured in figure 12. As shown, the entrapments are part of the two forward support posts of the canopy.

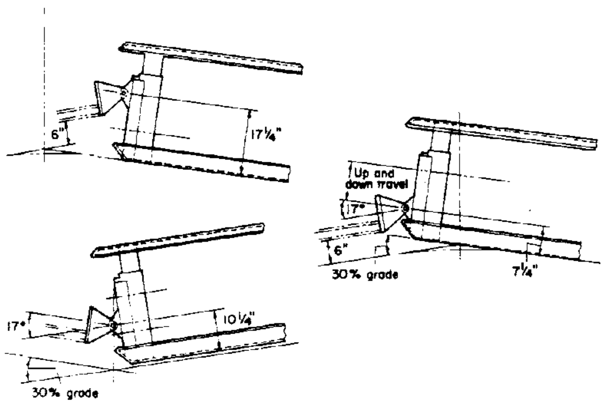

FIGURE 11.—Attachment design employing a pivot and sliding entrapment.

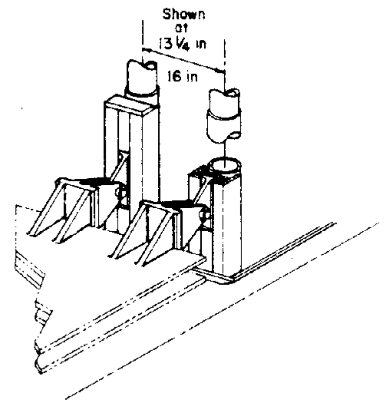

FIGURE 12.—View of compartment attachment used in final design.

COMPARTMENT DESIGN

The compartment design needed to provide the operator with adequate view of specific locations. Most of an operator's time is spent watching the receiving conveyor dolly position and responding to movements of the continuous miner. The operator must also watch the flow of material along the conveyors (including the two transfer points) and when tramming away from the face, the operator must have a clear view in the outby direction.

Experiments with a long, narrow, and low compartment indicated the operator's desire for movement. Operator's frequently rolled their bodies to obtain a view in the outby direction. By making the compartment a keystone shape, more room can be provided to roll the torso over on an arm or elbow, thus allowing a rearward head turn while minimizing the compartment width at the attachment (or foot) end. The resulting compartment shape is shown in figure 12.

In efforts to maintain a reasonable lengthening of the discharge conveyor, the compartment was designed to project forward approximately 2 ft into the area previously occupied by components on the main frame. The crawler drive assembly was moved out an additional 1 ft from the conveyor. By moving the gear drive for the crawlers to the inby end, more clearance was provided for the compartment; this also helped to keep the center of gravity forward.

Although only three canopy support posts were originally considered, a fourth post was added to maximize ease of operator ingress and/or egress, to improve operator protection, and to provide better support of the canopy. Mockup evaluation of the four-post structure showed no measurable degradation in operator ease of ingress or obscuration of visibility.

The operator compartment seat was positioned approximately 19° away from parallel to the conveyor (figure 13) for the following reasons: the operator faces directly at the dolly position, the major task concern; easier ingress and/or egress; more space for controls and an armrest; and the operator can now see outby without having to make a 180° head turn. At the widest point of this configuration, the compartment does not exceed the width of the outer edge of the crawler drive.

The compartment floor was dished upward around the edges to prevent digging into the mine floor as the carrier moves. This is especially important in the area behind the operator; otherwise, significant material could be plowed loose during rearward motion, resulting in a buildup that would push the compartment upward. The goal of height selection of the dished sides was to minimize the accumulation of coal within the compartment.

Figure 14 shows a side view of the double bridge carrier with the compartment in place. A solid or closed-top canopy was employed. In very low seams, the clearance between the canopy and roof is so small that there is no need for the operator to see the roof overhead. Therefore, a solid canopy does not obstruct operator visibility.

The canopy was designed with adjustable height pin supports, adequate for most mine applications. This design is simpler and less expensive than hydraulically adjustable posts. Where mine conditions require frequent resetting of canopy height, hydraulic adjustment can be provided. Hydraulic lines routed to actuators behind the operator could be placed in the compartment floor lip area, adjacent to the conveyor. If necessary, a shield could protect these lines.

Various split or semi-split canopies were evaluated (fig. 15). The reduced canopy area allowed a smaller height clearance between the canopy and the roof. However, investigation showed that operator visibility was impaired in important directions by the canopy and the protective grid.

A two-piece, split canopy would have to be over 5 ft long because it must extend from behind the heads of reclining operators to below their knees. The lower half of the canopy could only extend over the operator's feet and shins without being too high to obstruct line-of-sight to the receiving conveyor. Even if the top canopy were partly

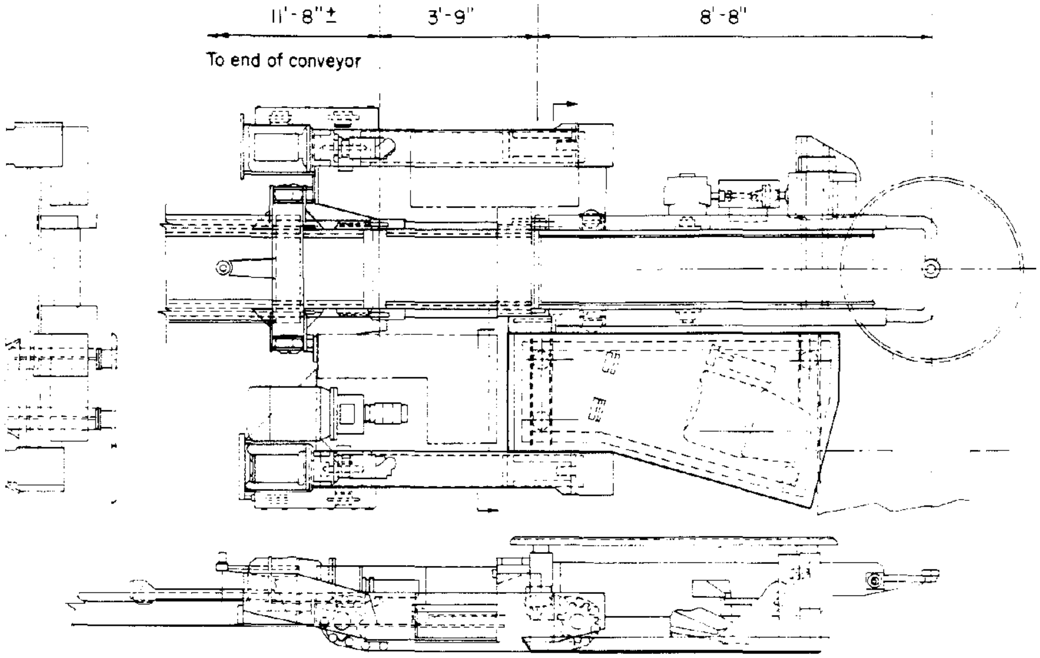

FIGURE 13.—View of compartment shape.

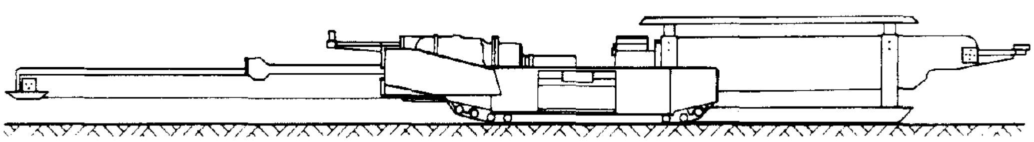

FIGURE 14.—Side view of bridge carrier with compartment in place.

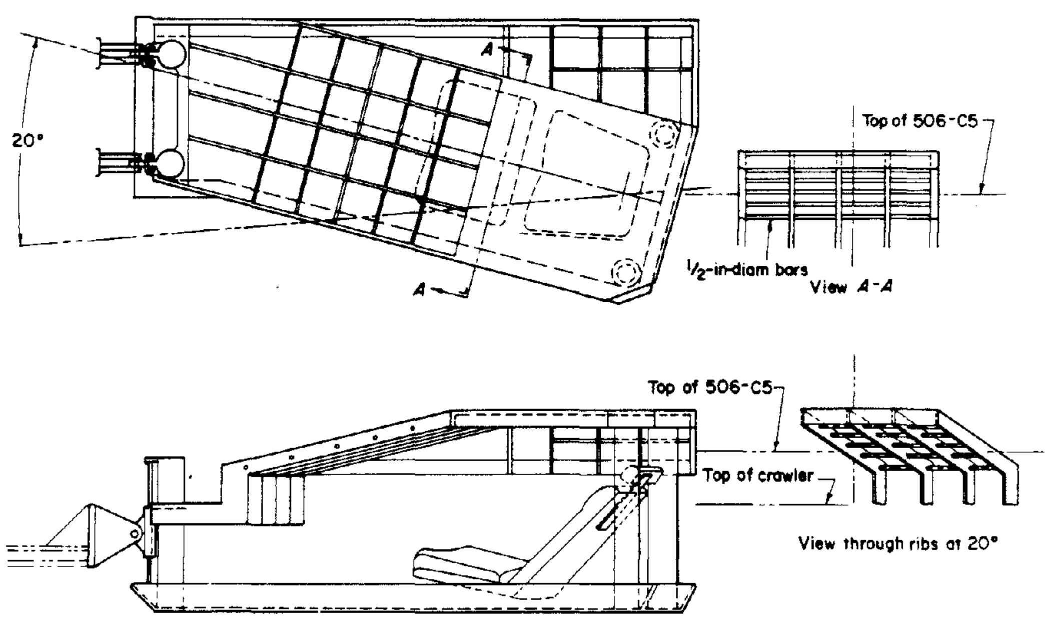

FIGURE 15.—Compartment concept using split canopies.

open grid, it would be difficult to support almost 5 ft of overhang. Also, 5 ft versus 6 ft is not enough difference in the top area to justify that approach.

SEAT AND CONTROLS

Operator space within the compartment is approximately 5½ ft long by 30 in high at the lowest usable setting. These dimensions require a 60° from vertical back angle to accommodate a 95th percentile male. These were approximately the same dimensions used in the videotape studies.

Given the above space dimensions and the static test results, the best choice for postural configuration was the reclining operator supported by a back recline angle of 60° from vertical. The seat design must include lumbar support and have an adjustable back tilt to permit smaller operators to sit in a more upright position. The seat pad length should be no greater than 17 in to avoid cutting off circulation in the legs of smaller operators. Footrests permit postural leg changes to deter stretching out the legs, which in time, stretches the hamstring muscles and puts pressure in the back of the thighs, producing blood circulation problems.

A perforated fiberglass seat cushion that permits coal dust to filter through was selected as the best choice of fabric. An adjustable style back and seat tilt were also chosen. The most critical aspect of good seat design is a good head and neck support device. It should be adjustable in length and rotation to accommodate different sized operators and to hold the operator's head upright during machine operation. The head and neck supporter should also allow for head recline during rest periods. An elliptical design with eccentric operation might accomplish this purpose. The side view of such a head support is sketched in figure 16.

A seat similar to one used in another low-seam haulage vehicle was selected for the mockup evaluation. This seat has fore and back adjustments, adjustable back tilt, and swing-away adjustable armrests. The seat pad was 2-in thick and had a vinyl fabric cover. Head support was obtained from a preshaped neck pad which adjusted vertically with respect to the seat back. After some modifications, this seat design proved satisfactory for the new operator compartment. The subsequent design included a new head or neck support, a more durable mechanism for the back tilt, and a more rugged set of armrests. The armrest on the controls side could have been made adjustable instead of swing-away.

Only four controls are frequently used by the bridge carrier operator; the two (left and right) tram controls and the two (receiving and discharge) conveyor elevation controls. With the operator compartment in the location shown, these controls are spring centered (off) as on the base 506C-5 bridge carrier. Ability to operate both tram controls in the same or opposite directions, with only one hand, was maintained. To reverse direction, operators must rotate their forearms and hands on the controls; therefore, the tram controls are located at the end of the armrest and move up and/or down in a near vertical plane with a backward tilt of approximately 15° to 20°. The bridge elevation controls are mounted adjacent to the tram controls and move up and down in the same plane of motion as the conveyors. Placement and handle styles provide the operator with tactile feedback as to which control is being operated.

Bridge elevation controls are accessible to both hands. They are not used as frequently as the tram controls and the operator's left arm need not be supported during their operation. As noted during the underground mine visits, the operator often keeps both hands on the tram ocntrols for extended periods of time. Consequently, a good arm support was designed to facilitate this operating position. One concept for these controls is shown in figure 17. Some adjustability for the controls and armrest position were required.

For easy access and to keep hydraulic hoses out of the operator compartment, the hydraulic valves were mounted on the machine main frame. Rods were used between the controls and the new operator levers. These rods were carried through the attachment that allows compartment up and/or down and pivot motion. Special provisions were made for the control rods to pass through the attachment point.

Figure 18 shows the design concept for the control rods that transmit the operator's movement of the hydraulic controls. Although some small translation of the rods occurs as a function of the compartment's vertical position with respect to the machine main frame, the proper choice of dimensions in the detailed design keeps

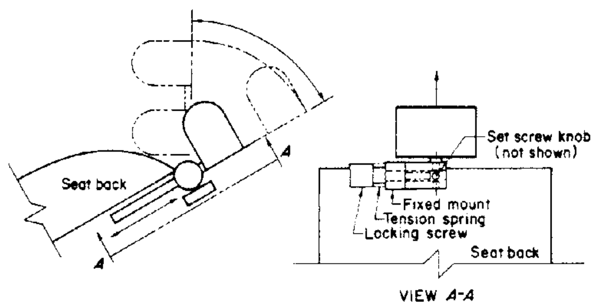

FIGURE 16.—Side view of head support concept.

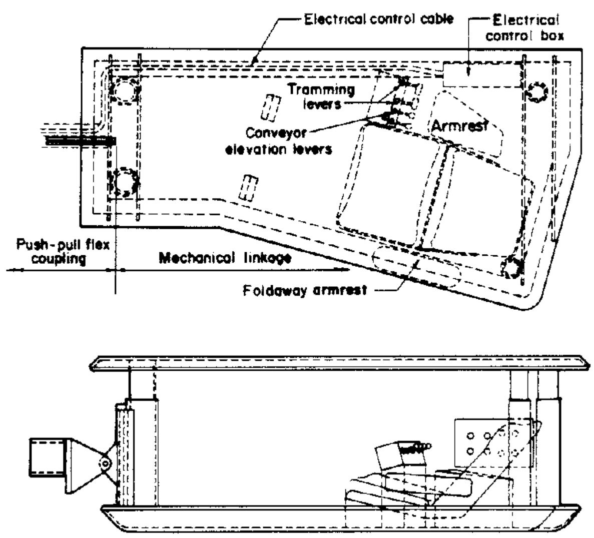

FIGURE 17.—View of concept for operator controls.

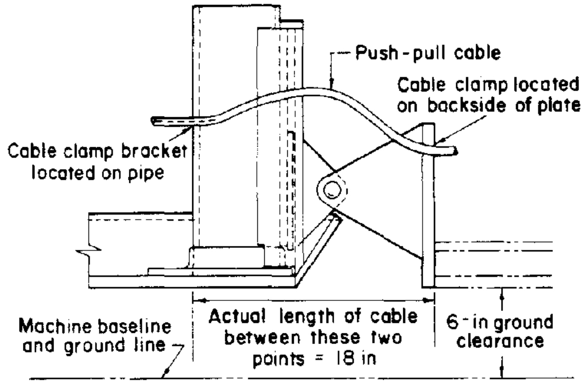

FIGURE 18.—Detailed view of control rods.

this movement to an insignificant value. The rods slide through bushings on the compartment side of the pivot and the rods are pivoted on the main frame side of these bushings.

Because the electrical controls are infrequently used, pushbutton controls were employed. These are the same type of controls used in the larger model Jeffrey 524 double bridge carrier. The electrical controls are mounted as shown in figure 17. An emergency stop bar (not shown in the figure) is mechanically linked to these controls and can be easily activated by the operator's arm or leg.

FIGURE 19.—View of full-scale mockup.

MOCKUP EVALUATION

The mockup evaluation was performed in two steps. First, a simple wooden compartment was fabricated so that various operator positions within a compartment could be studied. One objective of the initial mockup was to establish overall compartment dimension requirements. As mentioned in the operator position section, a variety of body positions were considered along with such factors as whether a seat should be provided, whether a simple movable bodyrest would be better, and whether the compartment should have hinged floor boards that can be raised at either end to serve as a tilted backrest. This compartment was used in conjunction with simple corrugated cardboard shapes simulating the mobile bridge carrier.

After the evaluation established the importance of a reclining seat and determined the operator position to be most beneficial at an angle with respect to the conveyor, a new shape for the compartment was defined. A new wooden compartment shell with three pin-adjustable posts supporting the canopy was fabricated. Initial results from the cardboard shapes mockup were favorable, alleviating the need to make a complex machine wooden mockup. Additional portions of the machine were represented by vinyl fabric-covered cardboard shapes. The full mockup used in the detailed evaluation is shown in figure 19.

The receiving conveyor dolly was represented by the shape on top of the conveyor in the center foreground of figure 19. This is the area watched most often by the operator. Figure 20 is the view toward the simulated dolly from the operator's eye location. The vertical scale seen beyond the dolly shows the distance above the floor. This scale was repositioned for measurements during the visibility study. Note that only key shapes affecting visibility and/or compartment clearance were included in the mockup of the double bridge carrier.

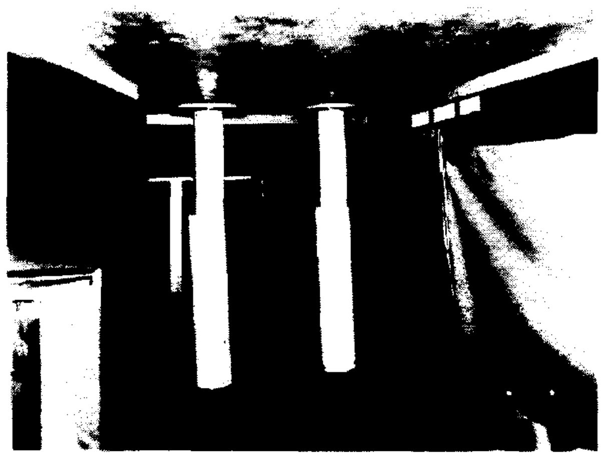

FIGURE 20.—Operator's view toward simulated dolly.

Figures 21 and 22 show how the operators can turn or roll their bodies to see outby. In these pictures, the operator is under a 36-in-high canopy setting with his right hand on the tram controls. Note that the final control orientation is shown in figure 17 rather than as shown here.

FIGURE 21.—View of operator looking outby.

FIGURE 22.—Second view of operator looking outby.

Figure 21 shows how an operator's left hand can reach across to operate the infrequently used conveyor elevation controls. The additional compartment width in the head and shoulders area is necessary to provide room for the torso to adequately twist and roll. Sturdy, properly placed armrests are important factors affecting operator comfort during these movements.

The mockup served as the tool for conducting studies of the operator's visibility. The model 506C-5 operators have considerable freedom of motion to aid their sight in any direction, and if necessary, they can move essentially around the crawler drive assembly.

Figure 23 is a plan view showing four reference points used in the evaluation; position 2 is the inby transfer point and dolly, and position 4 is the outby transfer point. Positions 1 and 3 are locations on opposite sides of the machine and are sometimes in the line-of-sight of the continuous mining machine operator.

The visibility study was conducted using operators from the 5th, 50th, and 95th percentile male standards. The subjects were seated in the compartment with the seat back adjusted to its maximum angle. Evaluations were conducted at canopy height settings of 30, 32, 34, and 36 in. Results of the study are given in table 3.

Eye level values were calculated by first measuring the distance from the operator's eyes to the bottom surface of the canopy, then subtracting this value from the known distance from the floor to the canopy. For a given operator, eye level values and seat angle varied as a function of head tilt. As the operator's head laid back, the distance

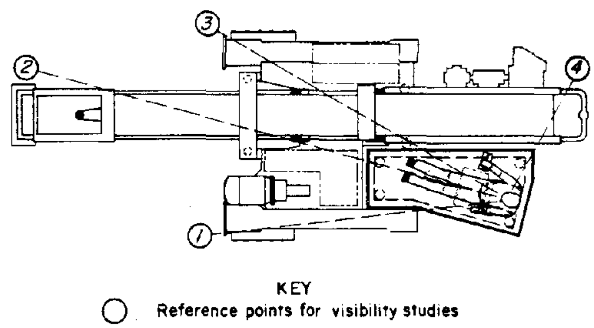

FIGURE 23.—Reference points used in visibility evaluation.

Table 3.—Mockup evaluation results with different sized operators

Canopy height, in	Seat back angle from vertical, °	Eye level, in	Visibility at noted location (above floor), in				Compartment length required, in	
			No. 1	No. 2	No. 3	No. 4	Legs bent	Straight
OPERATOR SIZE, 5%								
30	65	22	17-48	25-47	35-42	26-49	63	Nap
32	60	25	17-46	25-47	32-42	25-47	52	60
34	55	27	17-48	25-49	28-45	25-40	48	58
36	50	30	17-50	25-52	24-45	26-43	44	54
OPERATOR SIZE, 50%								
30	65	25	18-42	25-42	33-41	26-43	72	Nap
32	60	26	17-42	25-41	30-39	26-41	54	69
34	55	27	17-43	25-43	26-41	26-38	56	69
36	50	30	17-46	25-47	24-45	26-43	51	65
OPERATOR SIZE, 95%[1]								
32	60	23	17-47	25-44	32-42	26-47	58	72
34	55	25	17-46	25-44	27-43	26-47	58	72
36	50	29	17-48	25-48	25-46	25-42	58	74

[1]Operator unable to adapt to a 30-in canopy height at this operator size.

above the floor actually increased to a peak until continued movement caused a decrease. The degree of operator head tilt was determined by operator comfort and the severity of the angle at which the cap lamp was aimed forward.

During the study, some suggested that the operators not wear the cap while under the canopy to increase their comfort. This suggestion was disregarded because cap light signals are a primary means of communication between the bridge carrier operator and other section workers. Cap lamp communication is especially important during times when the operator has both hands on the controls and wants to signal.

Visibility data are given in table 3, which notes the lowest and highest visible readings on the various scales. As expected, operator field of view improved with increased canopy height. The operator had no apparent problem seeing the roof in the area above the dolly (position 2).

The operator must judge the distance of the receiving conveyor above the floor by visually comparing the clearance between the dolly and the roof. Additionally, the operator is not able to directly see spillage at the inby transfer point. Although overall visibility toward the dolly is good, the viewing angle is along the conveyor and some operators may find it difficult to judge the dolly position. If necessary, the problem can be eased by the addition of a position indicator.

Rearward field of view is operator dependent as it relies on their agility in turning and rolling their bodies. The compartment caused no restriction to operator view in the outby direction.

As part of the study, each operator configuration was photographed. (See figures 24 through 28.) As shown, the 50th percentile operator was comfortable with the canopy set at 30 in, but the hard hat and lamp had to be tipped forward for the light to be useful. An adapting bracket might be added to the hat to help aim the lamp downward. Figure 25 is a view across the dolly toward a 5th percentile operator under a 32-in canopy. In all cases, the cap lamp and the operator's eyes were visible from this position.

The 30-in canopy setting could not accommodate the 95th percentile operator; figures 27 and 28 show the tight fit with the canopy set at 32 in. In figure 27, note the proximity of the operator's knees to the canopy, thus precluding further consideration of the previously discussed split canopy.

Figures 24 through 28 also show the compartment's openings for ingress and egress and the relative ease with which an operator could roll into or out of the compartment. If a rib or other obstruction blocked the normal route of egress, the operator could also exist by lowering the seat back.

The mockup was evaluated for improving the following human factors:

1. Side and rear protection for the operator should be increased.
2. Footrest strips, 3- to 4-in high, should be provided across the floor of the compartment for postural relief.
3. Provisions should be made for operators with bifocal glasses who would have difficulty operating with their heads laid back and their eyes sighted across their noses. (The need for better head and neck support was discussed earlier.)
4. The seat's lumbar support should be increased between the pad and the back cushion during large back recline angles. Also, a seat pad tilt would be desirable.
5. Operator activity should be increased to prevent potential operator alertness problems.
6. Egress should be simplified or the operator might be less inclined to leave the compartment to perform other chores like cleanup or unclogging.

In addition to the first three items above, several points were considered in the detail design phase; for example, seat selection. This decision involved choosing a seat design that still allowed clearance of the cap lamp battery and self rescuer. Other points included: avoiding sharp corners, providing handholds to facilitate ingress and/or egress, and movable or fixed controls (to compensate for seat-operator positions).

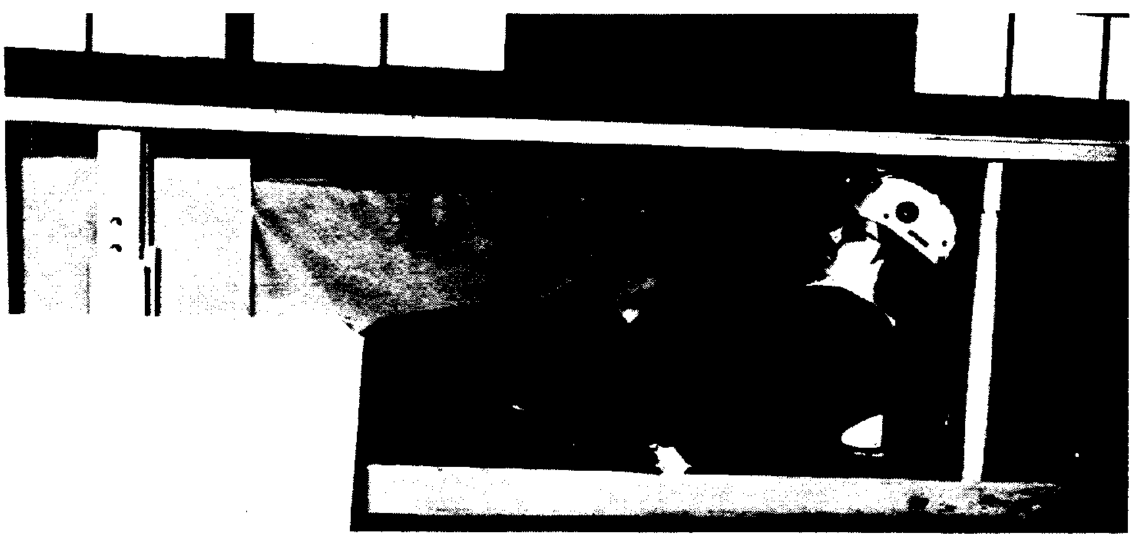

FIGURE 24.—View of mockup compartment with 50th percentile operator under a 30-in canopy.

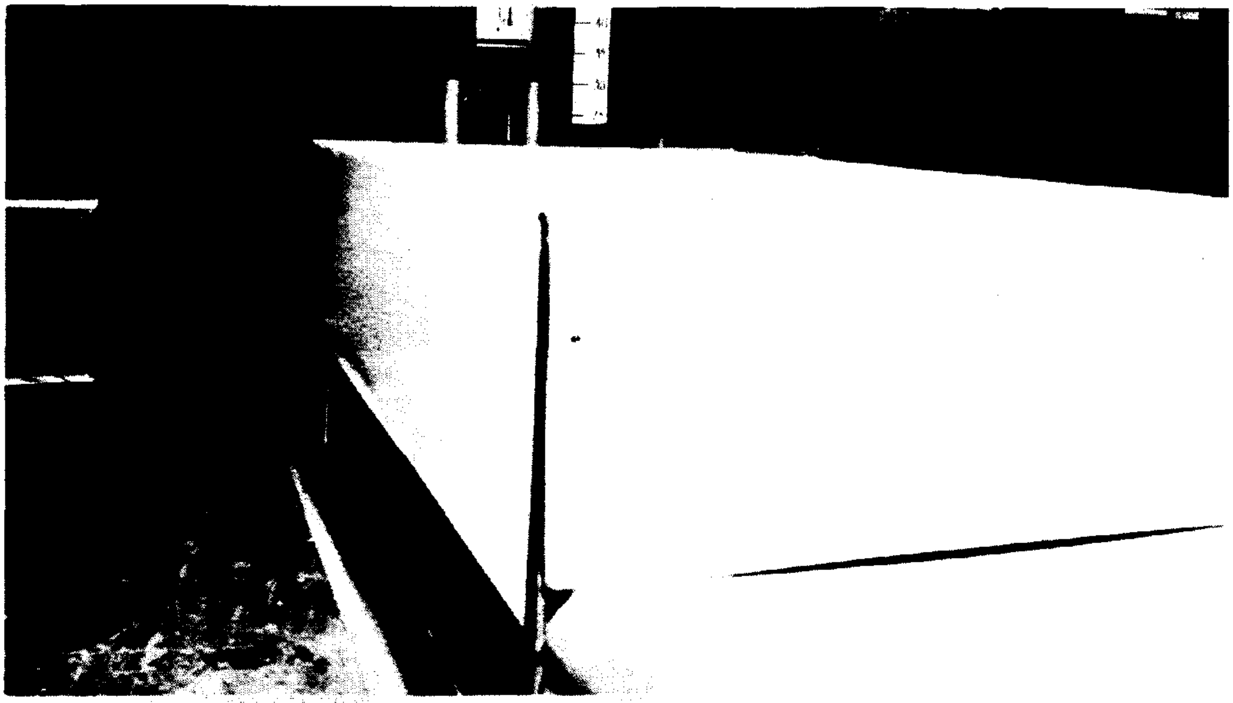

FIGURE 25.—View across dolly toward a 5th percentile operator under a 32-in canopy.

FIGURE 26.—View of mockup compartment with 50th percentile operator under a 36-in canopy.

FIGURE 27.—View of mockup compartment with 95th percentile operator and 32-in canopy.

FIGURE 28.—Second view of mockup compartment with 95th percentile operator and 32-in canopy.

DETAILED DESIGN OF THE OPERATOR COMPARTMENT

At this point, efforts were abandoned to develop a protected operator compartment, installable on a retrofit basis, for a model 506C-5 mobile bridge carrier. As previously detailed, the required pysical changes to the base machine to allow for installation of a protected operator compartment were of such magnitude, complexity, and cost that such an installation was essentially precluded. However, Jeffrey Mining Machinery was concurrently involved in the design of a new mobile bridge carrier with greater conveying capacity than the model 506C-5. Jeffrey agreed to allow for inclusion of the newly developed operation compartment on its new machine, eventually marketed as the model 5010.

Considerable effort went into the detailed design of the operator compartment and its attachment to the bridge carrier. The original concept was changed by moving the operator controls from the left to the right side of the machine. The idea was to keep the bridge carrier operator on the same side of the entry as the operator of the Jeffrey model 101 continuous miner; a unit commonly employed with the Jeffrey line of bridge carriers. (See figure 29.)

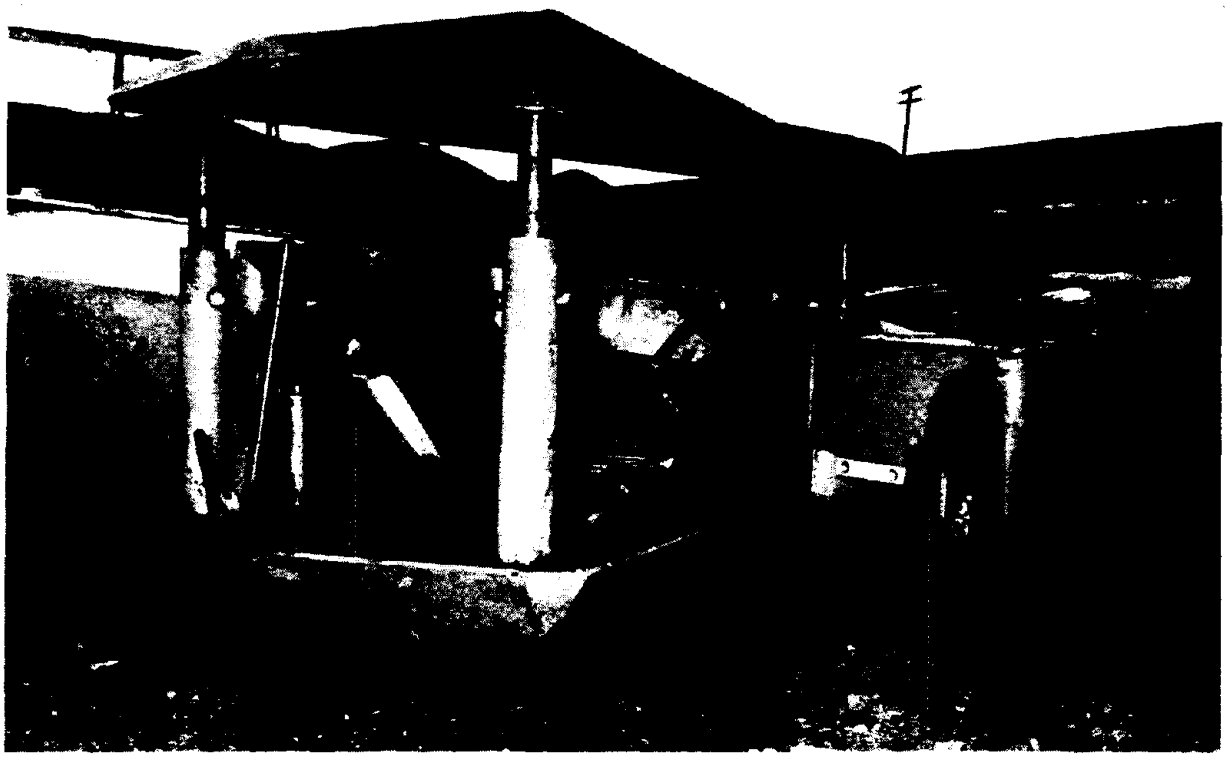

FIGURE 29.—View of compartment on right side of bridge carrier.

The operator compartment was designed to attach to the mainframe through pivots and slides. Figure 30 shows a close-up view of the attachment during mobility testing. Note that the compartment is inboard of the track (under the oil tank on the left) at the attachment points. To accommodate the compartment, the new bridge carrier was made 9-in longer and almost 4-ft wider than the model 506C-5 bridge carrier. The new bridge carrier design also required longer crawler tracks.

The compartment was attached to the mainframe by two pivots with horizontal axes. The compartment side of the pivots consists of steel collars that slide vertically along the two front canopy support posts. The slide travel was limited to 8 in by support members at the bottom and fixed collars at the top. Angular movement of the compartment with respect to the discharge conveyor was limited in the upward direction by a stop on the conveyor and in the downward direction by a link chain.

The slides and pivots were tested at the manufacturing facility. The range of motions allowed by the attachment are (fig. 31) rear tilt upward, (fig. 32) slides up with rear tilt downwards, and (fig. 33) compartment level at the top of the slides.

Selection of an operator seat for the compartment was limited by availability. In this case, the seat selected had a backrest separate from the seat unit. A new adjustable seat mount was designed using data from the functional mockup evaluation. A single lever on the seat back retracts dual pins that engage in holes in the seat mount. This provides reclining vertical positions of 25°, 34°, 43°, 51°, or 60°. A similar arrangement allows for adjustment of the seat cushion at horizontal angles of 10°, 20°, or 30°.

FIGURE 30.—Close-up of compartment attachment hardware.

FIGURE 31.—View of compartment with rear tilted up.

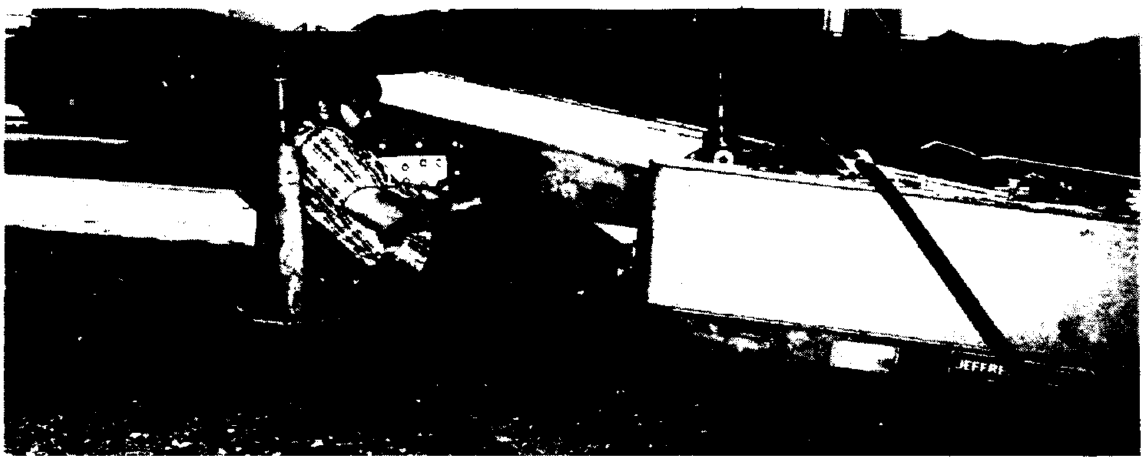

FIGURE 32.—View of compartment with slides up and rear tilted down.

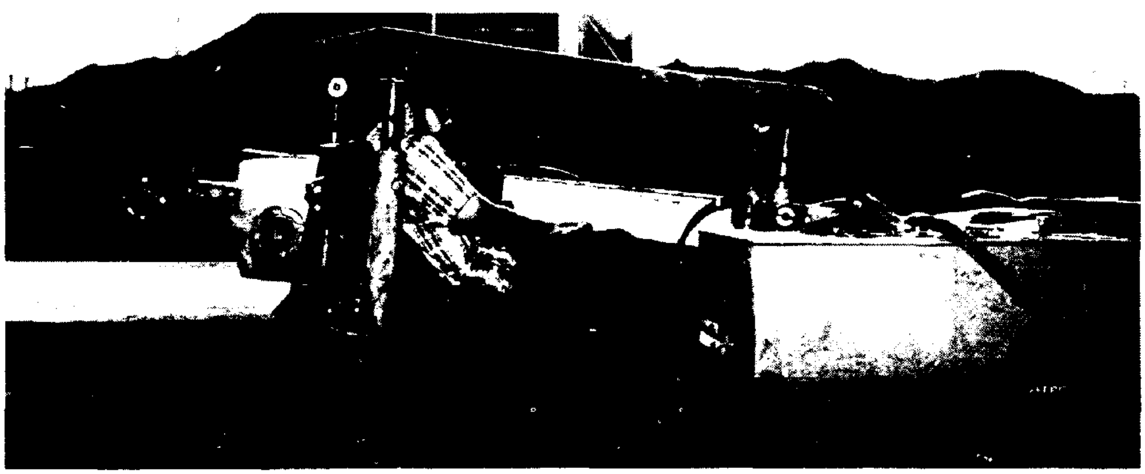

FIGURE 33.—View with compartment level and at top of slides.

The adjustment holes are shown in figure 34. A clevis pin through holes in the seat mount allows for nine fore-aft position selections in 1-in increments.

Armrests that tilt back for ingress and/or egress were originally provided; however, the left armrest was removed because it interfered with arm movement and other compartment activities.

During operation of a model 506C-5 bridge carrier, the operator kneels on the floor facing the machine and needs only a 90° head turn to see both inby and outby operations. (See figure 3.)

Unfortunately, in the newly designed Jeffrey 5010 machine, there was not enough room to place a compartment with the operator facing the machine as is the case in the model 506C-5. The new design compromised by placing the operator at a small angle (19°) with respect to the longitudinal axis of the machine. This angle helps operators considerably when turning their heads to see the outby transfer point. However, most operators sitting in the reclining position still must roll their bodies slightly off the seat to turn to see outby.

Four posts were required to support the canopy because of its large size and the weight of the loads it must support. The posts are telescopic and each is pin adjustable in 2½-in increments for canopy heights from 30 to 42½ in. The adjustment increments used in the final design differed from the 2-in adjustment increments used in the mockup studies.

During the compartment design phase, the Solar Fuel Co. (SFC) showed an interest in this program and agreed to an in-mine evaluation of the machine at its No. 9 mine. Because the seam height at this mine has considerable variation and undulations, SFC desired a method to change canopy height without using extra equipment such as jacks. Two hydraulic-lift cylinders were added to the compartment; one at the left rear (fig. 35) and the other at the opposite corner.

A small pump with an oil reservoir and a reversing valve comprised the rest of the canopy raise system. The pump was operated by stroking the handle with flow direction set by the valve. The first step in adjusting the canopy height was to pump-up the circuit, lifting the weight of the canopy off the four pins for removal. The four adjustment pins must then be replaced in the desired height setting before the operator enters the compartment. Figure 36 shows, left to right; the hydraulic pump, the flow direction valve, the raise cylinder, and the support post. Both the electrical and hydraulic controls were located to the left of the operator so as not to impede ingress and/or egress.

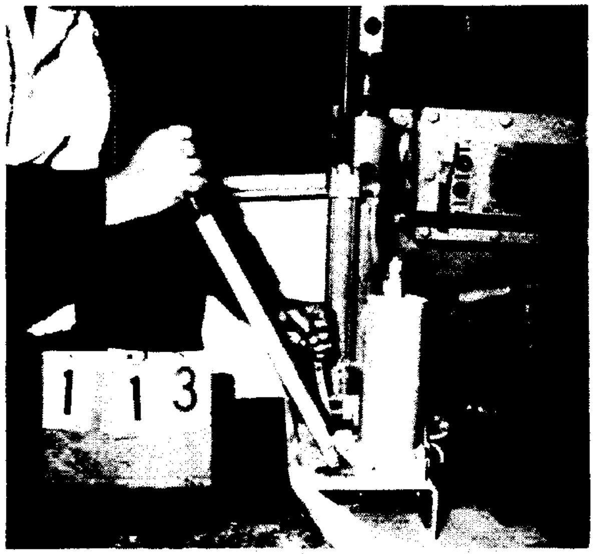

FIGURE 35.—View of canopy hydraulic lift cylinders.

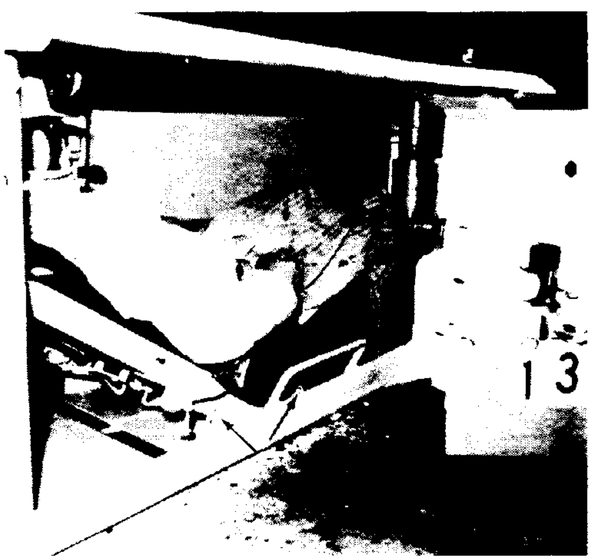

FIGURE 34.—View of seat adjustment holes.

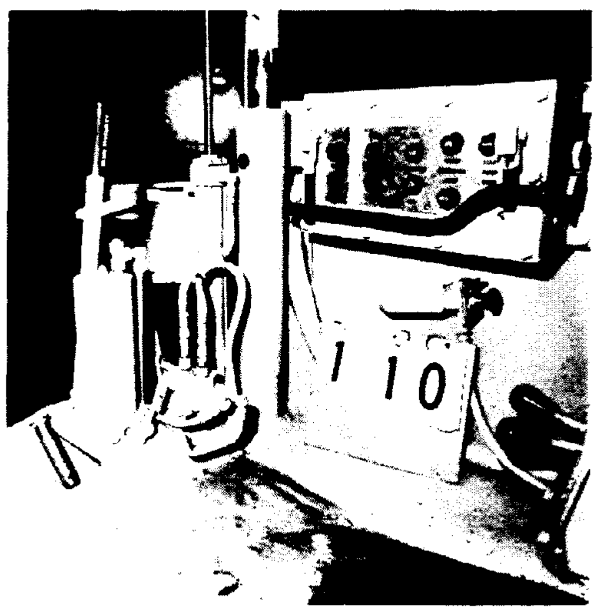

FIGURE 36.—View of support post raise cylinder, flow-direction valve, and hydraulic pump.

EVALUATION PRIOR TO SHIPMENT

Visibility measurements for the actual machine with compartment were repeated prior to shipment to the test mine. As previously noted, the compartment was located on the right, rather than the left, side of the bridge carrier. This was the only difference in the procedures used for the two tests.

A camera was positioned in the operator eye location and pictures were recorded at each of the marker locations. With the canopy set at 30 in above the floor, operator field of view was very limited. As shown in figure 37, operator field of view was limited to 43 to 47 in. When the canopy was raised to 35 in (fig. 38), operator field of view values improved to 23 to 56 in. At a canopy height of 40 in (fig. 39), excellent values of 22 to 75 in were measured.

When observing the bridge carrier outby transfer point, the operator's field of view angles are limited. However, this poses no real problem as the operator does not have to see over a large vertical angle; vision of only coal flowing across the transfer point is acceptable. Operator field of view for this situation was judged to be adequate for all canopy height and operator size combinations.

Another consideration was visibility toward the general outby direction when the machine was tramming outby. In this situation, the operator usually turns in the opposite direction, as when observing the outby conveyor transfer. Although there was very little field of view obscuration in this direction, the operator (fig. 40) had to strain to see, even with a canopy setting of 35 in.

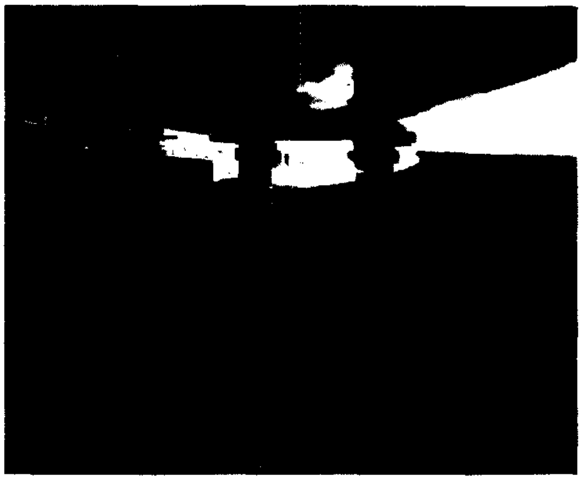

FIGURE 37.—View of visibility limits with canopy set at 30 in.

FIGURE 38.—View of visibility limits with canopy set at 35 in.

FIGURE 39.—View of visibility limits with canopy set at 40 in.

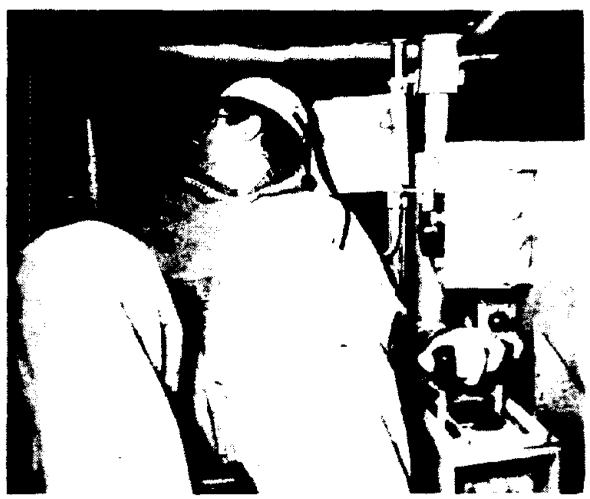

FIGURE 40.—View of operator position to see in general outby direction.

The visibility was reasonable at most canopy heights except for 30 in. If operator size is not much over the 50th percentile and mine conditions are good, then operation with the canopy at 30 in is possible. Table 4 summarizes the visibility data collected using subjects in the machine before it was shipped to the mine.

Canopy heights of 35 in or more are reasonable on this particular mobile bridge carrier as the viewing window is large enough for good visibility angles. A perspective on the window may be obtained from figure 41, which is a photograph looking at the 5th percentile operator in the compartment with the canopy set at 35 in.

Table 4.—Summary of collected visibility data

Canopy height, in	Seat back angle from vertical, °	Seat cushion angle from horizontal, °	Visibility[1] at noted location (above floor), in				Seat cushion to bottom edge of foot rest in distance, in
			No. 1	No. 2	No. 3	No. 4	
			OPERATOR SIZE, 5%				
30	43	30	NM	34-47	NM	NM	15.5
32.5	34	30	NM	25-46	NM	NM	15.5
35	34	30	NM	NM	NM	NM	18.5
40	25	30	NM	NM	NM	NM	18.5
			OPERATOR SIZE, 50%				
30	60	30	30-41	28-38	26-34	14-34	18.5
35	51	30	NM	23-56	NM	NM	21.5
40	34	30	24-56	22-75	24-75	16-56	23.5
			OPERATOR SIZE, 95%				
30	60	20	NM	27-35	NM	NM	18.5
32.5	60	20	NM	22-42	NM	NM	18.5
35	51	20	NM	21-50	NM	NM	19.5
40	34	10	NM	16-64	NM	NM	23.5

NM No measurement.
[1]Paired numbers indicate the height range, in inches above the mine floor, visible to the operator at each location.

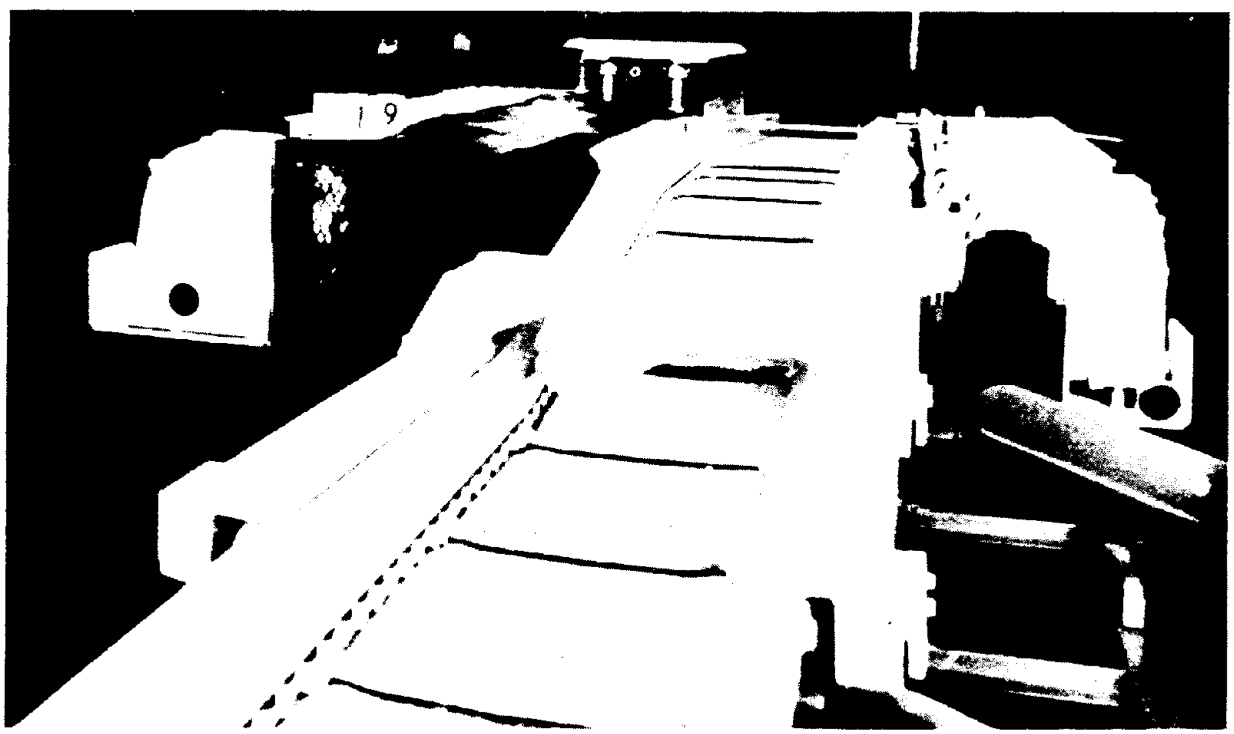

FIGURE 41.—View into operator compartment with canopy set at 35 in.

As shown in figure 42, the 5th percentile operator fits well within the confines of the compartment. In this case, the canopy was set at 35 in. This operator set the seat back angle at 34° from vertical and the seat bottom at 30° from horizontal.

When a 50th percentile operator was under the 35-in canopy (fig. 43), his head position was farther back, though still within the canopy confines. This operator positioned the backrest at 51° from vertical and moved the seat back 3 in more than the smaller operator. As a result, the upper limit of visibility was somewhat reduced.

The large operator found the compartment a tight fit (fig. 44). In this picture, the canopy height is at 35 in and the backrest angle is 51° from vertical.

Each operator had a different preference for leg positions. The 5th percentile operator preferred placing both feet flat on the floor. This seemed normal since his legs, being smaller, were less apt to be in his line-of-sight. Also, his legs were too short to comfortably reach the slanted footrest when the seat fore-aft position was reasonable for reaching the controls.

The 50th percentile operator preferred the slanted footrest (fig. 45). Two of the hydraulic actuator control cables (as shown) were too short, causing them to touch the operator's left foot. The design data were corrected to call for longer cables, which would be out of the way, as the other two hidden control cables.

FIGURE 42.—View of 5th percentile operator with canopy set at 35 in.

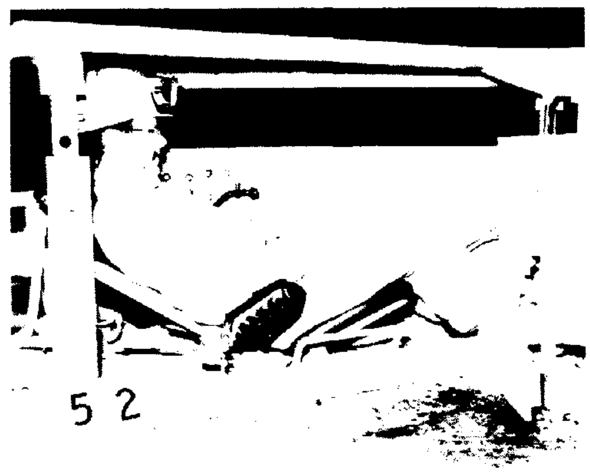

FIGURE 43.—View of 50th percentile operator with canopy set at 35 in.

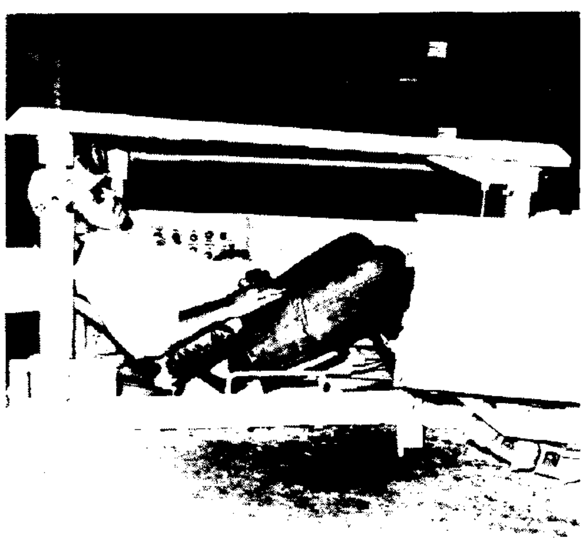

FIGURE 44.—View of 95th percentile operator with canopy set at 35 in.

FIGURE 45.—View of leg position for 50th percentile operator.

The favorite position for the 95th percentile operator was with legs crossed and on the floor (fig. 46). In this photograph, the canopy height is 40 in and the backrest angle is 34° from vertical. Another view of this operator position is shown in figure 47. Note that this operator used the headrest to support his shoulders instead of his head.

Control operation is primarily accomplished by using the left hand. As shown in figure 48, there are *four* levers located in a console on the floor of the compartment to the left of the operator. Through cables, the levers activate hydraulic controls located on the mainframe. The two upper levers are for the left and right tram. Pushing them forward moves the machine inby, while pushing them rearward reverses the tram. Figure 49 shows both upper levers being pulled simultaneously.

FIGURE 46.—View of leg position for 95th percentile operator.

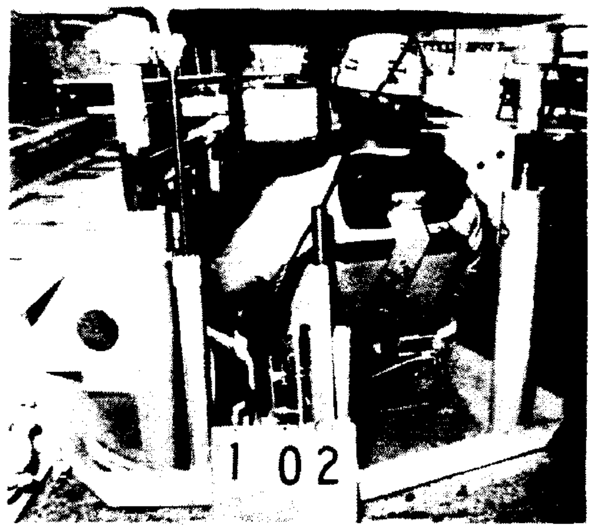

FIGURE 47.—View of 95th percentile operator with canopy set at 40 in.

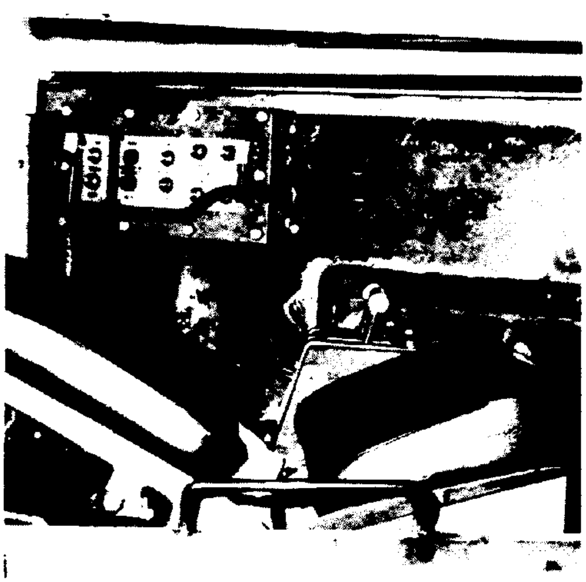

FIGURE 48.—View of lever controls located in console.

FIGURE 49.—View of operator activating both tram controls.

Two controls located on the console work the receiving and the discharge conveyor booms. When it is pushed upward, the left control raises the discharge conveyor, and lowers it when it is pushed down. The receiving conveyor works similarly with the right control lever. Figure 50 shows the operator's left hand (though not pictured) working the discharge conveyor raise-lower and the right hand working both tram controls.

All electrical controls were located within the enclosure mounted high on the left wall of the operator compartment. This was an existing control box, which had already been approved by MSHA for use on another machine. Figure 51 shows the details of the electrical controls. The fire extingusiher is located below the electrical control case, and the actuator knob is visible just above the backrest in figure 51.

Figure 52 shows the typical reach to start the pump motors. Although the electrical control buttons may be actuated with the left hand, it is more natural to use the right hand. The far left control is the hardest to reach (fig. 53). This is seldom used and will shut down the continuous mining machine as well as the haulage system. Note that the panic bar may be operated either with the left shoulder or a hand.

If desired, the operator can work both the electrical and hydraulic controls at the same time (fig. 54). Note that this view is with the 50th percentile operator and canopy setting of 30 in.

Figure 55 shows the large operator working the hydraulic controls while looking back in the outby direction. The canopy in this picture is set at 35 in.

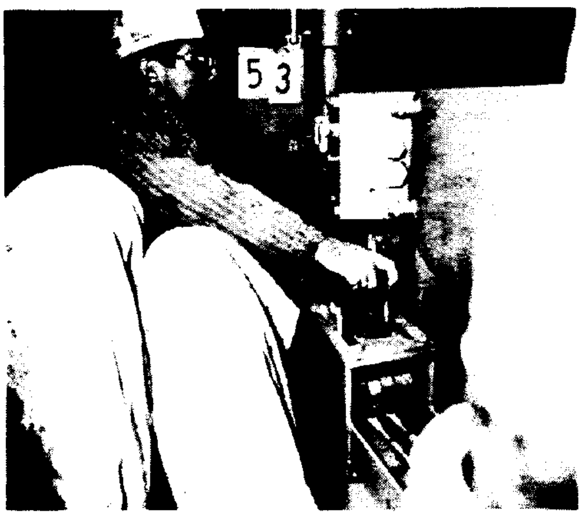

FIGURE 50.—View of operator working discharge conveyor raise-lower and tram controls.

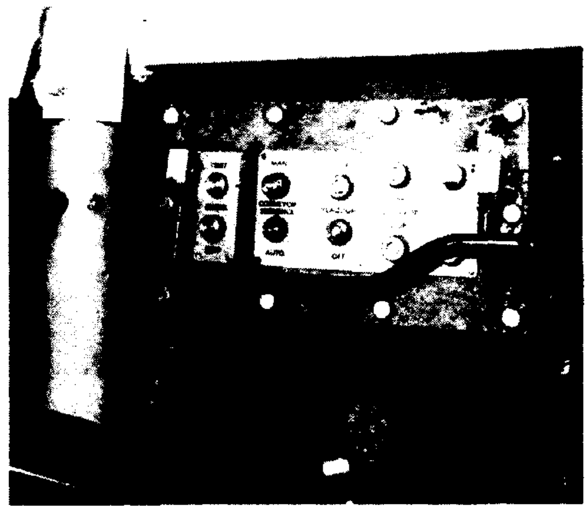

FIGURE 51.—Detailed view of electrical controls.

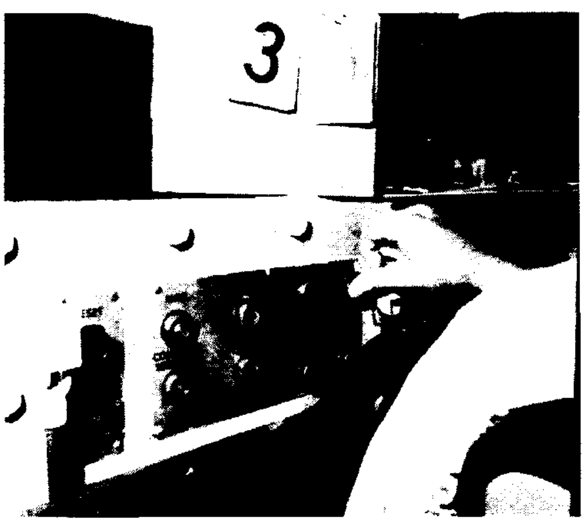

FIGURE 52.—View of operator reach required to start pump motors.

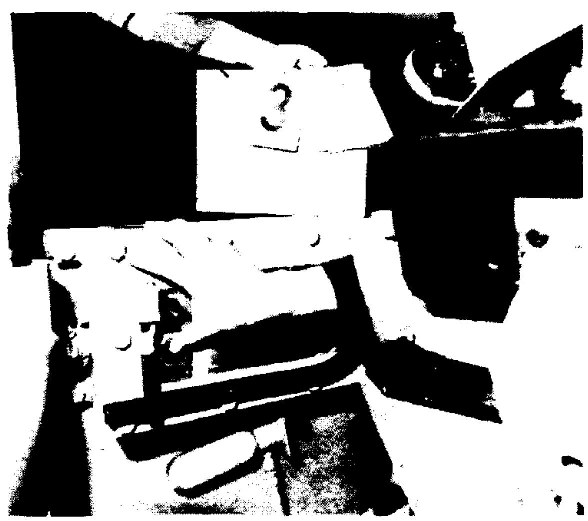

FIGURE 53.—View of operator reach required to use leftmost pump control.

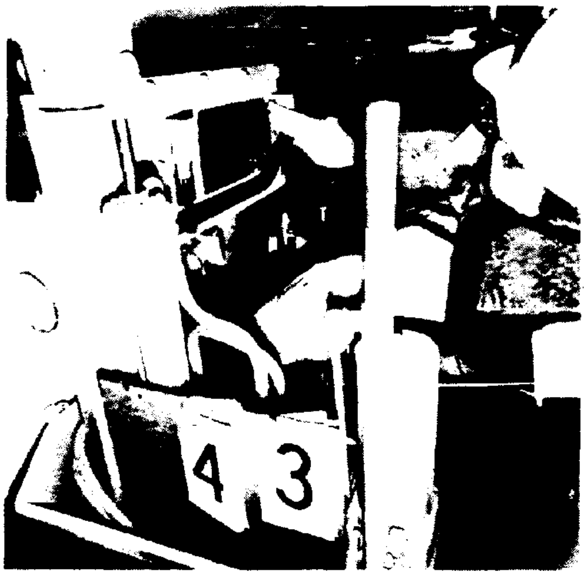

FIGURE 54.—View of operator working both electrical and hydraulic controls.

FIGURE 55.—View of 95th percentile operator working hydraulic controls while looking outby.

UNDERGROUND EVALUATION

An in-mine evaluation was conducted through the cooperation of the SFC at its No. 9 mine, located near Somerset, PA. Seam height at this mine generally varied from 40 to 46 in, but frequently pinched down much lower. Entries and crosscuts were 20-ft wide. Overall moisture, roof, and floor conditions were fair.

The new bridge carrier (Jeffrey model 5010) with operator compartment was substituted on an operating section for a Jeffrey model 506C-5 bridge carrier. Machine installation occurred in October 1981, with a 3-month evaluation planned. The evaluation period was extended to 10 months for a variety of reasons that included interruptions to the mining operation, unrelated to the new bridge carrier. The bridge carrier with operator compartment was removed from the mine in October 1982, and was delivered to the Bureau's facilities at Bruceton, PA.

The new bridge carrier was trammed into the mine from the highwall entrance. In order to clear the roof, the canopy height was set at 30 in. Coal, mud, and water filled the compartment floor because of several low areas with accumulated water. The edges of the compartment were angled around the periphery in order to make the compartment ride over, rather than dig into, the floor during tramming (fig. 56). This feature also caused the floor to retain water when the drain holes became blocked. The water accumulation was cleaned out when the machine was installed on the section; subsequently, reoccurrence of buildup required only infrequent cleaning.

At the working section, the mine operator tried the 35-in canopy setting, but settled on the 37.5-in and 40-in settings soon thereafter. Some places in the section had little clearance between the canopy and the roof with the canopy set at 40 in (fig. 57). During the in-mine operation, the compartment floated well along the floor because of the slides and pivots. As a result, the canopy to roof clearance measured as much as 6 in at certain locations.

Operator field of view was fairly good with the canopy set at 40 in. Figure 58 is a view looking back toward the compartment.

The mine added a protective metal mesh, angled inward, onto the top of the compartment wall before bringing the machine into the section. The mesh was intended to curtail the possibility of the operator being pinched by relative movements between the compartment and the discharge conveyor. The mesh did not significantly block the operator's view toward the opposite side of the machine.

The discharge conveyor may be raised several inches from the horizontal position. Figure 59 is a view from the left front of the machine with the conveyor raised close to the roof. While the conveyor obscures vision directly across the machine, it does not otherwise affect operation. The conveyor is lower when tramming the machine, which allows the operator to see through the mesh and across the machine.

Four different operators of the double bridge carrier were observed during the in-mine evaluation: one 50th percentile male, two 40th percentile males and one 60th percentile female. Figure 60 shows that a 50th percentile operator fits well within the compartment with a canopy height of 40 in. This view was taken while running coal. Note the operator's right hand is resting on his right leg with no support from the back armrest. This posture was a matter of individual preference because the operator believed that he was comfortable enough without having to move the armrest for egress and or ingress. Also, note that the operator's knees are raised with both feet still on the slanted footrest.

Figure 61 is a close-up of a smaller operator with his left hand on the tram controls and the canopy set at 37½ in. He preferred to use the armrest and placed his hand on his lap.

Operator indoctrination occurred quickly once the operator got over the restless reaction resulting from confinement within the compartment. Inability to directly see the inby conveyor carriage posed the greatest problem. Using the new machine, movement between stops is limited to only 5 ft, which means the operator must be skillful in moving the bridge carrier to avoid banging the carriage against the stops as a result of continuous miner movement. When seated in the compartment, the operator can see only the top of this carriage.

Each operator preferred different working positions within the compartment, with frequent repositioning to retain reasonable comfort. Because the operators had little to do within the compartment, they tended to become inattentive. In efforts to alleviate boredom, operators were encouraged to get out of the compartment frequently to do spillage cleanup and machine inspection.

The operators were skillful in tramming the bridge carrier inby and outby. When the panline was on the left side, the operators attempted to maintain 3 ft of clearance between the compartment and the right rib. When the panline was on the right side, it was easier to see.

After 1 to 2 months of operating the machine, two operators complained of backache. It was not determinable whether these complaints really resulted from operating the double bridge carrier or were injuries from some unrelated cause. Later operators of the machine never expressed any backache complaints. If the backache complaints are justified, a better seat should be designed that would still be economically acceptable.

Difficult mining conditions, due to incursions of stone into the coal seam, precluded a good measure of the effect that adding an operator compartment onto the double bridge carrier would have on coal production. From the data collected, it appeared that the production rate remained unchanged from that of the section when using the model 506C-5 bridge carrier.

FIGURE 56.—View of rear of operator compartment showing dished sides.

FIGURE 57.—View of roof clearance with canopy set at 40 in.

FIGURE 58.—View into the operator compartment.

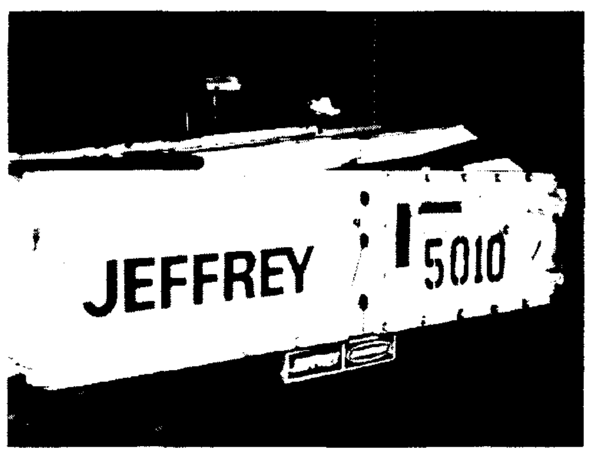

FIGURE 59.—View of conveyor when raised close to roof.

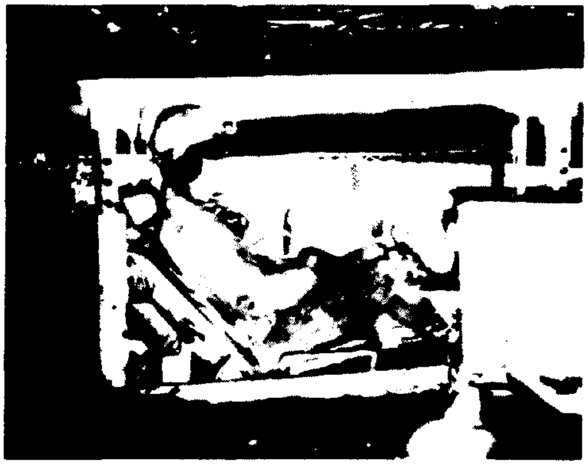

FIGURE 60.—View of operator working within compartment.

FIGURE 61.—View of second operator working within compartment.

SUMMARY

The project objective to develop a protective operator compartment for a low-seam mobile bridge carrier was achieved. Significant benefits of the project to the coal mining industry include: the compartment is available as a standard order item from a major equipment manufacturer and is successfully being employed in several thin-seam mines; and workable, protective operator compartments can be achieved in working seams less than the present 42-in Federal requirement.

Significant findings of the project include:

1. A protective operator compartment for a thin-seam mobile bridge carrier was found feasible for use in coal seams as low as 40 in.
2. The addition of the operator compartment did not appear to have any adverse effects on production rates.
3. The general design philosophy of the bridge carrier compartment should be useful in designing protected operator compartments for other types of thin-seam mining equipment.

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