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GUIDELINES FOR AUTOMATIC COUPLERS

VOLUME I TECHNICAL REPORT

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UNITED STATES DEPARTMENT OF THE INTERIOR
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by

ENSCO, INC.
Transportation and Instrumentation Sciences Division
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ENSCO, INC.

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Guidelines for Automatic Couplers

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In this report, the results of the studies and investigations of automatic couplers presently in use are presented. This includes an analysis of accident data for 1972-76; a discussion of the ability of existing couplers to withstand operational conditions in the mines; and a reliability study to estimate the durability, safety, and maintenance requirements of the various couplers. In addition, the reliability and safety of various uncoupling mechanisms were examined to identify which uncoupling mechanisms are safe to operate, rugged in design, and not easily susceptible to damage. An analysis was also conducted to investigate the hazards involved in the various steps of coupling and uncoupling to identify those that are potentially the most hazardous.

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FOREWORD

This report was prepared by ENSCO, Inc., Transportation and Instrumentation Sciences Division, 5408A Port Royal Road, Springfield, Virginia 22151, under USBM Contract No. J0366010. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of PM&SRC with Mr. George Susko acting as the Technical Project Officer. Mr. Alan Bolton was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period June 1976 to August 1977. It was submitted by the authors on 15 December 1977.

We would like to thank Mr. Edward Cunney and Mr. Steven Hawkins of the ENSCO staff for their help during the course of this study and the consulting firm of Management Engineers Incorporated, of Reston, Virginia for their technical assistance relating to the mining environment. We also thank the various coupler manufacturers and coal mine operators for their interest and cooperation. The suggestions received from Mr. Joseph Tortorea of the Mining Enforcement and Safety Administration are also appreciated.

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1. INTRODUCTION

Automatic couplers are presently used in most coal mines so that coupling and uncoupling can be achieved without personnel going between cars. However, due to inadequate design, lack of maintenance, component wear, and other factors, couplers do not always function properly and personnel go between mine cars to couple and uncouple the cars. As a result, severe accidents, including fatalities, still persist in the coupling and uncoupling of mine cars.

While the present Coal Mine Health and Safety (CMH&S) Regulations stipulate that all haulage equipment which is normally coupled and uncoupled has to be equipped with automatic couplers, these statutory provisions do not provide specific performance requirements for the couplers. In order to improve the performance of the couplers and to decrease accidents associated with coupling and uncoupling, a detailed set of guidelines for design, inspection, and maintenance of automatic couplers is required. The objective of the present study is to obtain necessary data and information and to analyze these data for establishing guidelines for the design, inspection, maintenance and safe operation of automatic couplers.

In June 1976, ENSCO, Inc., in conjunction with the consulting firm of Management Engineers Incorporated (MEI), was awarded a contract (J0366010) to evaluate performance of automatic couplers and to develop guidelines for their safe operation. Volume I of this report summarizes the studies and investigations carried out for the development of guidelines for design, inspection and maintenance of automatic couplers. (The details of these guidelines are given in Volume II--Design, Inspection and Maintenance Manual.)

In this report, the results of the studies and investigations of automatic couplers presently in use are presented. This includes an analysis of accident data for the years 1972-76; a discussion of the ability of existing couplers to withstand operational conditions in the mines; and a reliability study to estimate the durability, safety and maintenance requirements of the various couplers. In addition, the reliability and safety of various uncoupling mechanisms were examined to identify which uncoupling mechanisms are safe to operate, rugged in design and not easily susceptible to damage. An analysis was also conducted to investigate the hazards involved in the various steps of coupling and uncoupling in order to identify which ones are potentially the most hazardous.

The effect of environmental factors, such as coal dust, rock dust, and mine water on automatic coupler performance, was also investigated to ascertain what protection (if any) the couplers need in order to withstand the mine environment over a long period of time.

The results indicate that, in general, automatic couplers are quite adequate to withstand the loading and environmental conditions encountered in the mines. However, certain aspects of design, poor maintenance of uncoupling mechanisms, and general inadequacy of inspection and maintenance procedures used in the mines, are still problem areas.

The design, inspection and maintenance guidelines developed in this study, presented in Volume II of this report, should have a significant effect in reducing these problems. The design guidelines define the essential features of a safe, reliable automatic coupler; the inspection and maintenance guidelines are intended to insure that these safe and reliable features are retained throughout the effective lifetime of the coupler.

2. COUPLER NOMENCLATURE

In order to eliminate any ambiguities which may arise in the discussion of operation and performance analysis of automatic couplers, the various automatic coupler components and associated terms are defined in the following.

CENTERING SPRING--The spring which maintains the coupler in line with the center line of the car and perpendicular to the car face.

CLEVIS OR PIVOT PIN--The pin about which the coupler head pivots.

COUPLER HEAD--The main body (usually a casting) of the coupler.

DRAFT GEAR--The device which absorbs shocks that are applied to the coupler. [Note: A coupler which is bolted directly on the car bumper is said to have no draft gear.] The draft gear may include a draft spring, or rubber buffing and pulling pads for absorbing the shocks.

FOLLOWER PLATE--A plate in the draft gear which moves with the coupler and serves to spread the loads.

HORIZONTAL GATHERING RANGE--This is the maximum horizontal offset of the coupler head at which the coupler will couple automatically (see Figure 1).

HORIZONTAL SWING ANGLE--This is the maximum horizontal angle, measured from the coupler center line, through which coupler head is free to move horizontally (see Figure 2).

LOCK--That component which prevents uncoupling unless activated by an outside force.

LOCK LEVER--That lever which is connected to the lock mechanism for releasing the lock prior to uncoupling. [Note: In the Ohio-Brass and Mayo couplers, the lock (coupling cam) and the lock lever are a single cast unit.]

LOCK PIVOT PIN--The pin about which a pivotal lock swivels when moving from the locked position to the unlocked position or vice versa (used on Ohio-Brass, Mayo and American couplers.)

STOPS--Devices that are placed on the coupler housing to limit horizontal swing of the coupler to within 30°-45° from the center line.

UNCOUPLING LEVER--The lever which is used by an operator to bring the lock into its unlocked position prior to uncoupling.

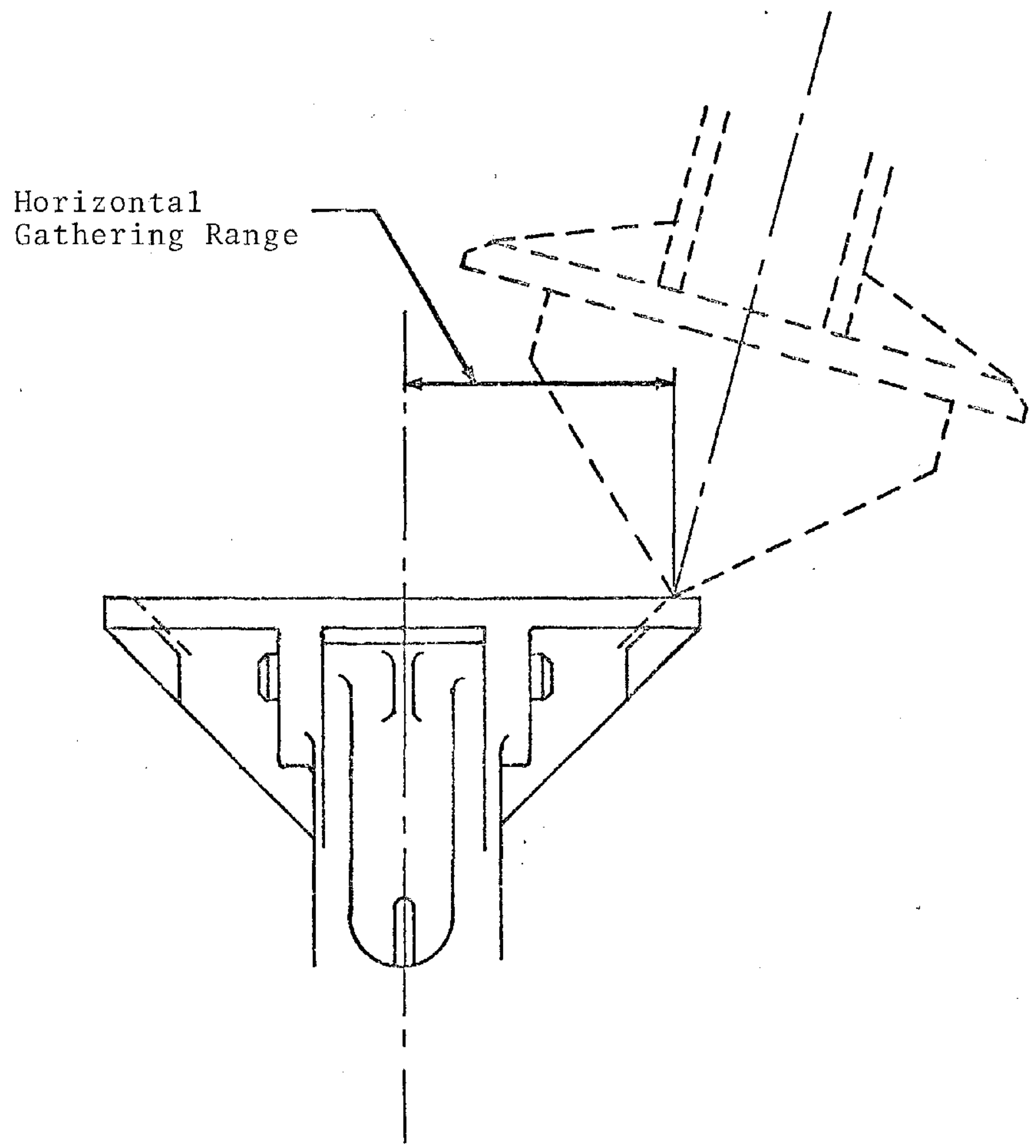


Figure 1. Horizontal Gathering Range of Automatic Coupler

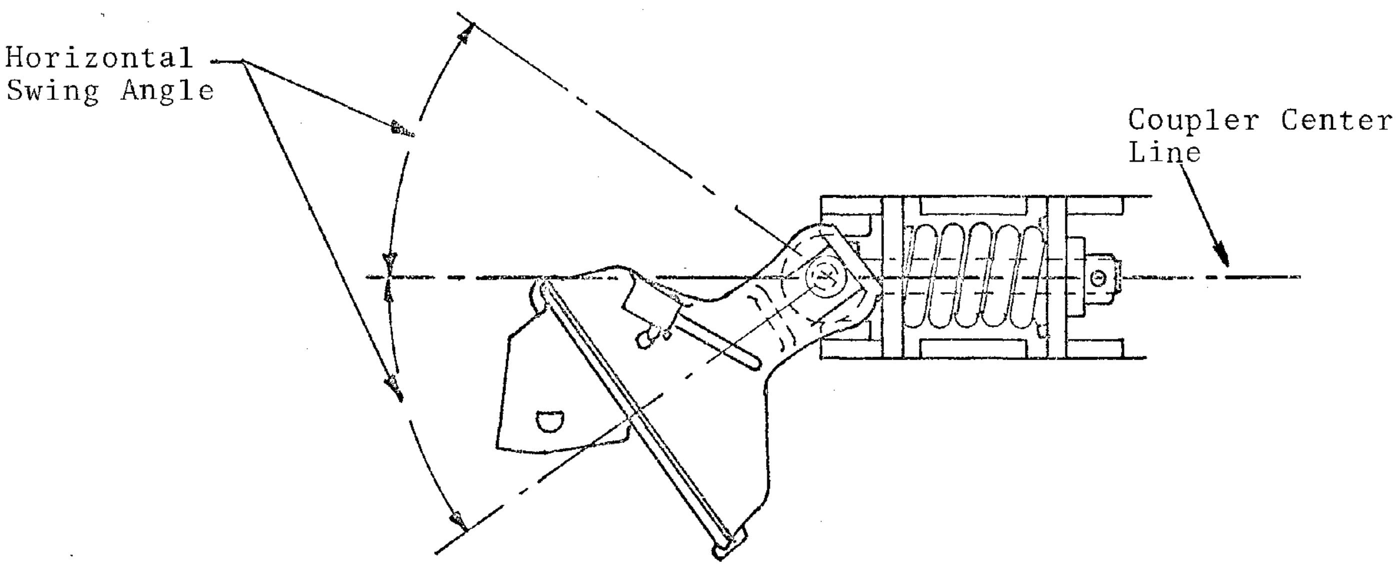


Figure 2. Horizontal Swing Angle

UNCOUPLING LINKAGES--Linkages used to transmit forces from the uncoupling lever to the lock lever.

UNCOUPLING MECHANISM--The uncoupling lever and the uncoupling linkages.

VERTICAL GATHERING RANGE--This is the maximum vertical offset of the coupler head up to which the coupler will couple automatically (see Figure 3).

VERTICAL SWING ANGLE--This is the maximum vertical angle, measured from the coupler center line, through which the coupler head is free to move vertically (see Figure 4).

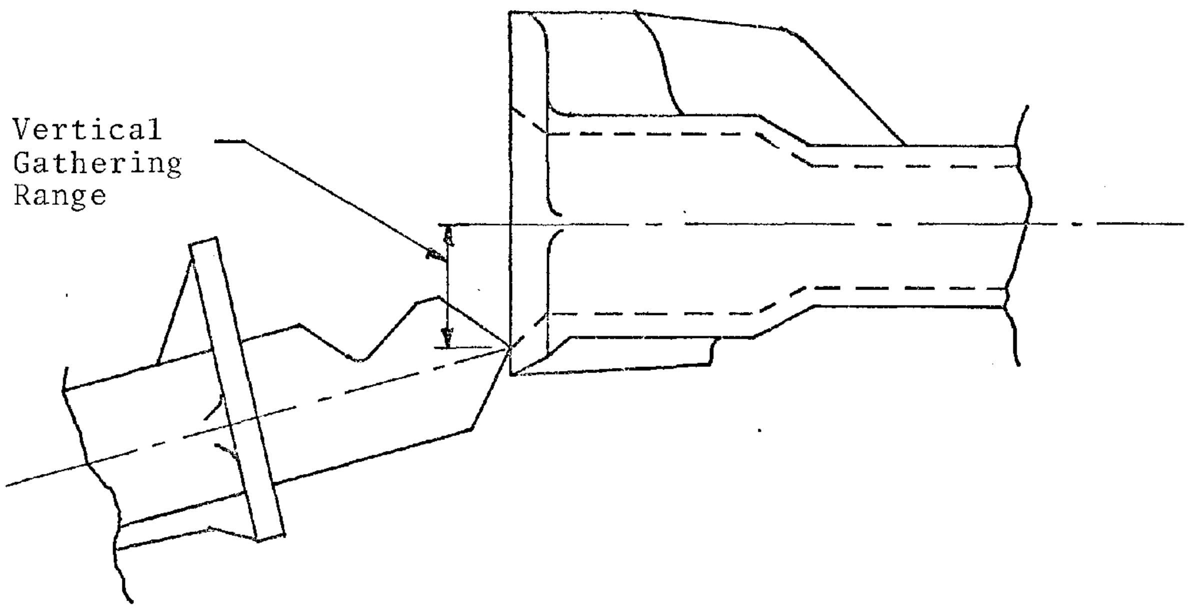
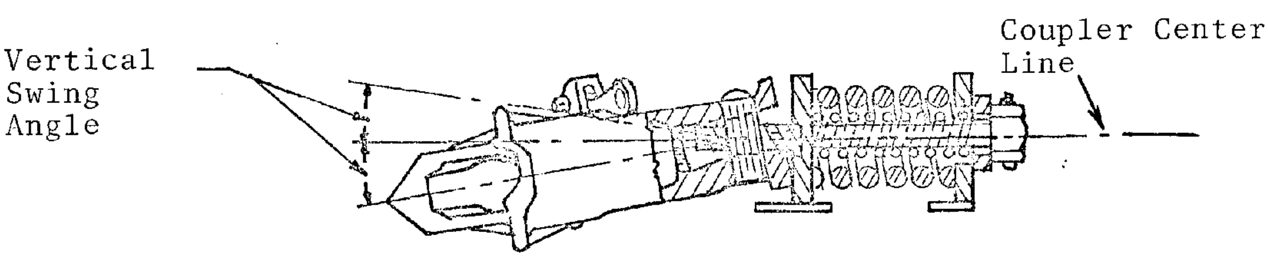


Figure 3. Vertical Gathering Range for Automatic Coupler



Figurc 4. · Vertical Swing Angle

3. AUTOMATIC COUPLERS PRESENTLY IN USE

3.1 TYPES AND PERFORMANCE DATA

Through a survey of mine operators and coupler manufacturers, it was determined that most mines use one of four basic automatic coupler types--American, Mayo, Ohio-Brass and Willison. This information was gathered from a survey of mines throughout the Eastern United States and the Midwest, and the manufacturers of automatic couplers.

The data on couplers presently in use was collected through technical data forms and by actual visits to the mines and coupler manufacturers by ENSCO and MEI personnel. The various features for the four major automatic coupler designs are summarized in Table 1. Important aspects of the coupler design are the ultimate strength, the rated drawbar pull, the horizontal and vertical gathering ranges, whether it has a self-centering device, whether it can be used with rotary dumps, etc. In addition, information associated with the draft gear is also included in this table as failure of this can adversely affect the coupler performance.

The four coupler designs, mentioned above, are briefly described in the following together with engineering drawings of their basic configurations.

The American coupler is a reversible male and female type where each coupler end contains both the male and female fittings. This coupler provides a positive interlock and both the heads are completely enclosed when coupled. In this coupler, the unlocking arm can be on the side or on the top of the coupler body. The special lock-set feature of this coupler allows coupling and uncoupling to be accomplished by one worker. This coupler is shown in Figure 5. The performance features of this coupler are given in Table 1.

The Mayo coupler is very simple in design and is based on the link-and-pin coupler concept. It is a nonreversible coupler with a male and female end and provides a positive interlock when coupled. The coupler is shown in Figure 6. The performance features of the coupler are given in Table 1.

The Ohio-Brass coupler is a nonreversible male and female type. The male and female ends provide a positive interlock when coupled and the coupler provides a very large horizontal gathering range (7.5 inches). This coupler is shown in Figure 7. The performance features of this coupler are given in Table 1.

The Willison coupler is a reversible type. Most Willison couplers are manufactured without a hood but some designs include a

Table 1. Summary Data of Automatic Couplers

Coupler Type and Model	Manufacturer	Yield Strength (Klbs.)	Ultimate Strength (Klbs.)	Rated Draw Bar Pull (DBP)(Klbs.)	Horizontal Gathering Range (inch)	Vertical Gathering Range (inch)	Horizontal Swing Angle (°)	Vertical Swing Angle (°)	Self-Centering	Rotary Dump Capability	Reversible	Coupler Body Material	Failure Area in Ultimate Failure Tests	Lock Set Device	Draft Gear Information	Remarks
American 1. X-2 2. X-8 3. X-9	American Steel Foundries	200	310	Not Available	5	$2\frac{7}{8}$	35	9	Yes	Yes	Yes. Each coupler contains male and femal fittings.	Cast steel Spec. AAR M201 Grade B	Coupler nose, around the locking pin	Yes	AAR D2 Coil spring. Working load 14,000 lbs at 1" travel	X-2 for locomotives; X-8 non-rotating; X-9 rotating. All will intercouple
Mayo 1. Standard 2. Jumbo	Elgood-Mayo Corporation	Not Available	77 106	30 50	3 $4\frac{1}{4}$	$1\frac{1}{2}$ $2\frac{1}{4}$	30	15	Yes	Yes	No. Link & pin automatic coupler	Cast steel	Coupler pin	None	Standard draft gear for rotating coupler only	Standard & jumbo sizes are not interchangeable.
Ohio Brass (OB) 1. Form 8 2. Form 8A	Ohio Brass Company	Not Available	125 165	45 80	$7\frac{1}{2}$	$2\frac{1}{2}$	45	6	Yes	Yes	No. Male & female type	3060 cast steel 1045 cast steel	Bottom sill of female coupler	None	Rubber buffing pad. Buffing forces of 100,000 lbs at $1\frac{1}{4}$" compression. Pulling forces of 25,000 lbs. at $\frac{1}{2}$" comp.	Forms 8 and 8A are interchangeable
Willison 1. Reduced 2. Industrial 3. Heavy-duty	National Castings, Midland-Ross Corp.	200 300 460	330 470 800	Not Avail-	5 5	5 6 (coupler with hood $3\frac{3}{4}$)	45	Variable up to 10	Option available but not used in most Willison couplers	Yes	Yes	High-tensile cast steel	Coupler Shank	Design Available	E.A. Multi-pad rubber cushioning devices	Industrial size mostly used in mines. Industrial & heavy-duty are inter-changeable.

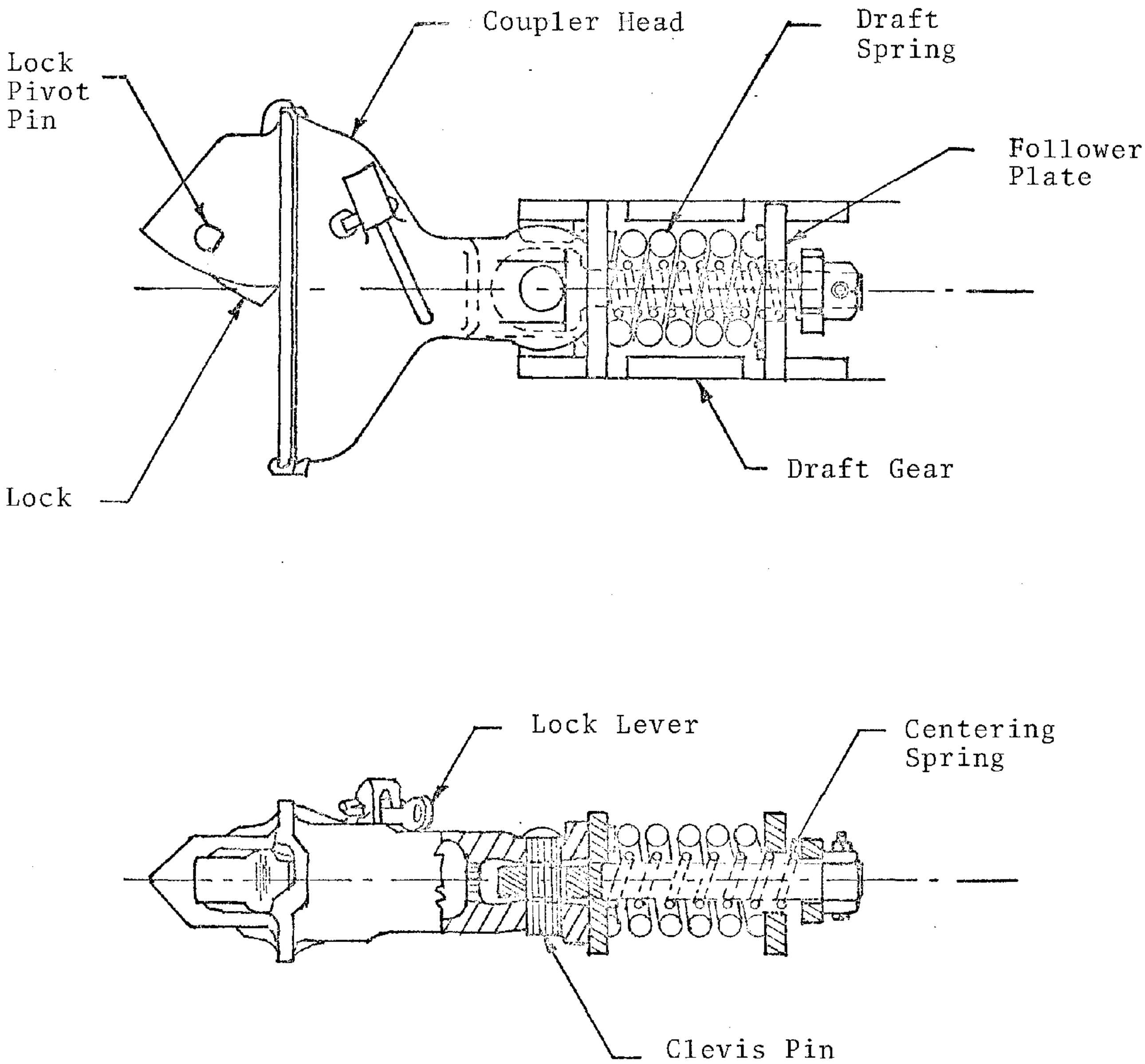
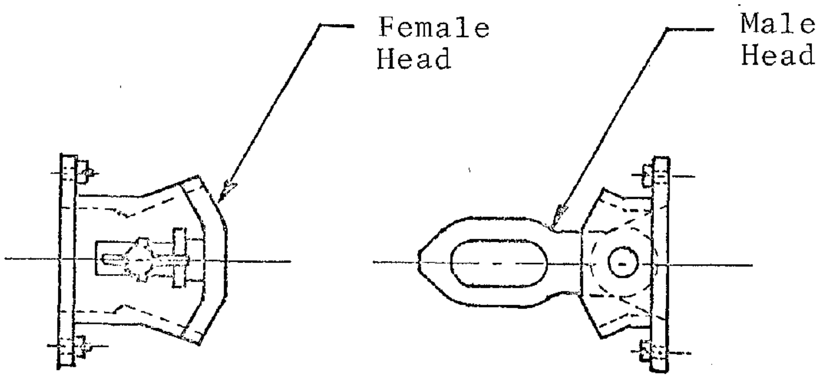
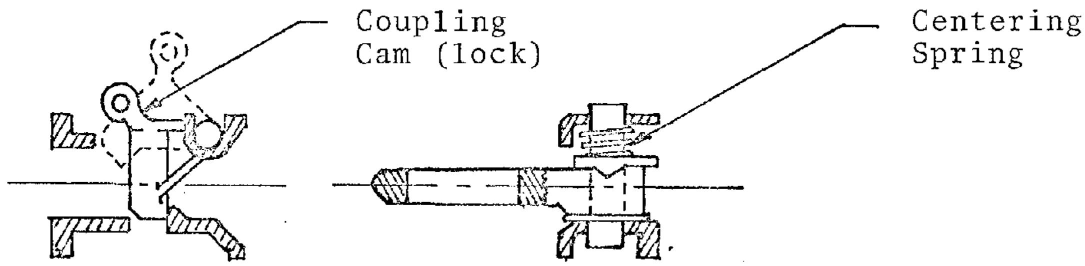


Figure 5. American Coupler (Courtesy American Steel Foundries)



Top view



Section through female and male heads

Figure 6. Mayo Coupler (Courtesy Elgood-Mayo Corporation)

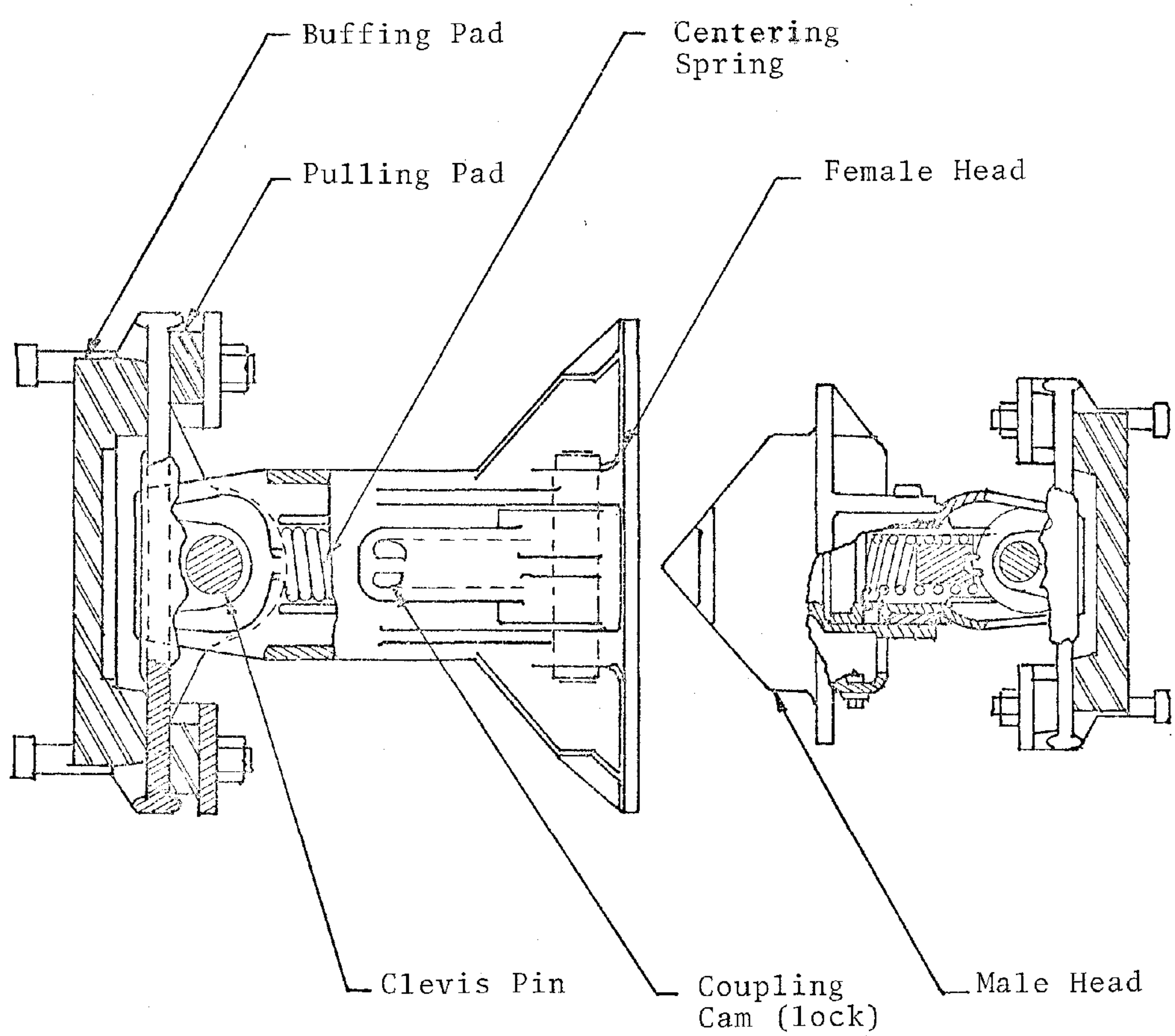


Figure 7. Ohio-Brass Coupler (Courtesy Ohio-Brass Company)

small hood to prevent vertical separation. The coupler is shown in Figure 8. The performance features of the coupler are given in Table 1.

The data collected on automatic couplers during the visits to various mines are summarized in Table 2a-c. Besides determining the type of coupler used in the mine, information concerning the years of service of the coupler, the type of car used, the condition of the track and other data relevant to the performance of the coupler were all collected.

3.2 ANALYSIS OF COUPLER ACCIDENT DATA

Section 314(f) of Public Law 91-173 requires that track haulage equipment that is regularly coupled and uncoupled shall be equipped with automatic couplers. In accordance with this public law, statutory provisions regarding automatic couplers are provided. Specifically, the law states:

> §75.1405 Automatic Couplers.
>
> [STATUTORY PROVISIONS]
>
> "All haulage equipment acquired by an operator of a coal mine on or after March 30, 1971, shall be equipped with automatic couplers which couple by impact and uncouple without the necessity of persons going between the ends of such equipment. All haulage equipment without automatic couplers in use in a mine on March 30, 1970, shall also be so equipped within 4 years after March 30, 1970."
>
> §75.1405-1 Automatic Couplers, Haulage Equipment.
>
> "The requirement of §75.1405 with respect to automatic couplers applies only to track haulage cars which are regularly coupled and uncoupled."

While it was determined that all the four types of automatic couplers commonly in use meet the classification of automatic couplers as per this law, accidents still occur with automatic couplers. This is because when the automatic couplers do not function properly, workers resort to unsafe practices, such as going between the cars.

To understand more fully what kinds of accidents occur, an analysis of available accident data was undertaken. First, an analysis was conducted to identify causes of automatic coupler accidents. Then, the accident data for both link-and-pin and automatic couplers were examined to assess the impact of the 1969 CMH&S Act on coupler accidents for the periods before and after 1974.

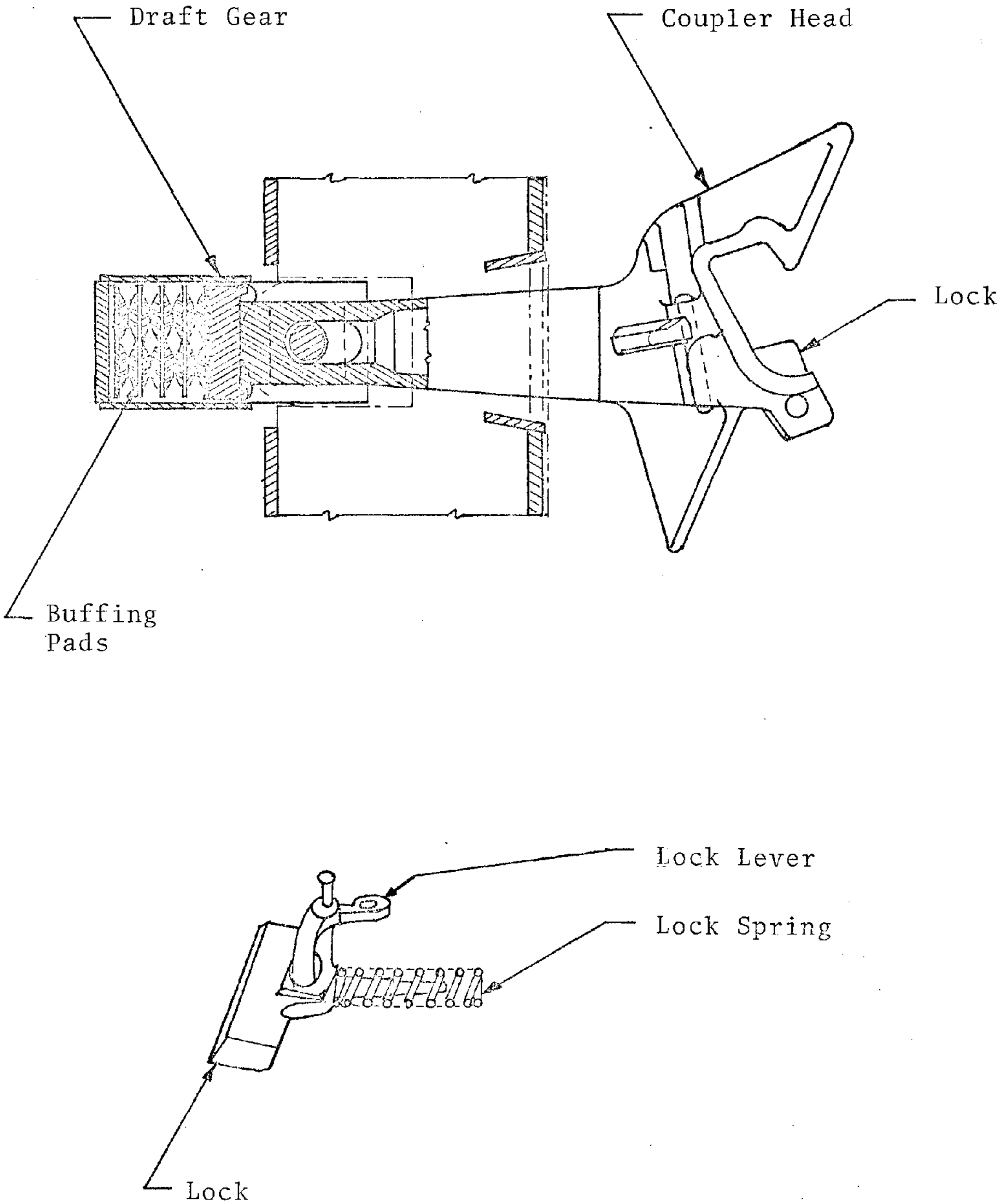


Figure 8. Willison Coupler (Courtesy Midland-Ross Corporation)

Table 2-a. Summary of Mine-Coupler Survey Data

PARAMETER \ MINE NUMBER	1	2	3	4
Type and model of coupler	Willison	Willison hooded	Willison	Modified link and pin with hand-held link aligner
Rotating (Yes/No)	Yes	Yes	Yes	Yes
Draft Gear (Yes/No)	Yes	Yes	Yes	No
Years of service for mine cars	6	28 (8-wheel) 16 (4-wheel)	10	28 (old cars) 3 (new cars)
Car capacity (tons)	10	7	25	5
Number of wheels on car	8	8 4	8	4
Mainline locomotive size (tons)	37	27	62.5	18
Average number of cars per loaded trip	12 (CM sec.) 23 (at longwl)	16-18	30	39
Maximum grade mainline/secondary	<± 1% ± 7%	6% against load	± 2% ± 5%	3.8% with load
General condition of track	Good	Good	Good	Good
Tightest curve radius (feet) mainline/secondary	75 37	120 --	-- 35	260 30

Table 2-b. Summary of Mine-Coupler Survey Data

PARAMETER \ MINE NUMBER	5	6	7	8
Type and model of coupler	American	Elgood Mayo Standard	Willison Hooded	Willison Hooded Self-centering
Rotating (Yes/No)	Yes	No, supply cars	Yes	Yes
Draft Gear (Yes/No)	Yes	No	Yes	Yes
Years of service for mine cars	28	10 (3 yrs with Elgood Mayo cplr.	26	16
Car capacity (tons)	8	2	10	15
Number of wheels on car	8	4	4	8
Mainline locomotive size (tons)	13 (2 tandem)	10	20	50
Average number of cars per loaded trip	30	2	40	18
Maximum grade Mainline/Secondary	4% against load	± 3%	3.5% against load	1.2% against load ±.8%
General condition of track	Fair	Good	Poor	Fair
Tightest curve radius (feet) mainline/secondary	200 --	-- 43	120 --	250 75

Table 2-c. Summary of Mine-Coupler Survey Data

PARAMETER / MINE NUMBER	9	10	11	12	13
Type and model of coupler	Ohio Brass Forms 6,8,9,8A	Ohio Brass Forms 8,8A	Link and pin	Willison	Willison
Rotating (yes/no)	Yes	No, drop bottom	Yes	Yes	Yes
Draft gear (yes/no)	Yes	Yes	No	Yes	Yes
Years of service for mine cars	28	27 (old cars) 3 (new cars)	25	20	30
Car capacity (tons)	6.5	30	5	19	12
Number of wheels on car	8	8	4	8	8
Mainline locomotive size (tons)	20 (2 tandem)	62.5	15 (3 tandem)	50	15 (2 tandem)
Average number of cars per loaded trip	40	18	22	20	24
Maximum grade Mainline/Secondary	1% with load	2% with load ±9%	3.5% against load	0.5% against load	3% against load
General condition of track	Fair	Good	Poor	Good	Fair
Tightest curve radius (feet) Mainline/Secondary	280 --	-- 35	400 --	45 45	-- --

3.2.1 CAUSES OF AUTOMATIC COUPLER ACCIDENTS

Accident data obtained from the Mining Enforcement and Safety Administration (MESA) for the years 1972-1976 were reviewed and those accidents relating to automatic couplers were identified. These accidents were then analyzed to identify specific causes. The breakdown of the accidents in terms of the action leading to the injury or resulting injury is shown in Table 3.

As can be seen from Table 3, poor operating procedures and equipment failures were the major causes of injuries. It is felt that these injuries can be reduced to a great extent by the use of effective self-centering devices on the automatic couplers and through better design and maintenance of uncoupling mechanisms.

Table 3. Accident Data for Automatic Couplers
(Source: MESA, years 1972 through 1976)

Action Leading to Injury or Resulting Injury		Number	Percent
Caught hand or finger in coupler, or between coupler and car		14	(25%)
Uncontrolled movement of car		2	(3.5%)
Caught between cars		3	(5%)
Caught foot in coupler while attempting to align coupler		11	(19%)
Failed parts		4	(7%)
Caught hand or fingers in uncoupling mechanism		18	(31.5%)
Caught between cars due to passed couplers		1	(2%)
Slipped and fell while coupling		1	(2%)
Car ran over foot while coupling		3	(5%)
	TOTAL	57	(100%)

3.2.2 IMPACT OF THE 1969 COAL MINE HEALTH & SAFETY ACT

The time period of 1972 through 1976 encompasses a significant period with respect to the CMH&S law since the mandatory installation of automatic couplers was required as of March 30, 1974. Thus, the objective of the present analysis was to assess the impact of the 1969 CMH&S Act on coupler accidents for the periods before and after 1974 in order to give insight into the potential effectiveness of the guidelines developed under the present study. In reality, several contradictory factors made such a comparison less than conclusive. First, many mines had installed automatic couplers 20 or more years prior to the effective date of the CMH&S Act. Thus the accident data prior to 1974 was not solely related to link-and-pin couplers because a substantial number of automatic couplers were already in use. Second, the period after 1974 does not represent a period when all mines were equipped with automatic couplers. This is due to certain equipment which is not "regularly coupled and uncoupled" being exempt from the law. In addition, certain mines including some surveyed during the study had obtained "releases" from the law because of the imminent closure of the mine. Consequently, non-automatic couplers are still included in accident statistics after 1974.

Two types of analyses were conducted. First, the total accident statistics were analyzed to evaluate the general impact of the law. Second, accident causes were investigated to identify what particular aspects of the coupling/uncoupling operation were causing the accidents.

3.2.2.1 Analysis of Total Accident Data

Statistics of coupler-related accidents were obtained from MESA and reviewed. The breakdown of these accidents in terms of coupler types is given in the following chart.

	Number of Accidents				
Coupler Type	1972	1973	1974	1975	1976
Link-and-pin	95	79	66	45	57
Automatic	7	8	12	15	25
Subtotal	102	87	78	60	82
Unknown	119	136	75	70	56
Total	221	223	153	130	138

This data shows a significant downward trend in coupler-related accidents during the years 1972 to 1976. However, several factors should be considered when drawing conclusions from this data in terms of relating the reduction in accidents solely to automatic couplers. First, there has been a slight downward trend in the use of rail equipment for haulage during these years which means there are proportionately less mine cars and couplers in use. Secondly, accident reporting can be erratic so that it is not always clear whether changes in accident levels occur because of improved equipment such as automatic couplers or because of less precise accident reporting. For example in the chart below the total number of injuries (excluding disasters) for underground mines for the years 1972 through 1973 is reported as follows:

	Year			
	1972	1973	1974	1975
Total Injuries	18,614	17,215	9,783	12,117

It will be noted that there is a large drop in injuries for the year 1974 and it is felt that this may be due to less precise accident reporting rather than an actual reduction in injuries. Nevertheless the statistics do show the injuries have decreased during the period 1972 to 1976 and with the two provisos noted above this decrease can be linked to the increased use of automatic couplers as a result of the CHM&S Act.

3.2.2.2 Analysis of Causes of Coupler Accidents

The next step in the analysis was to review each of the accident reports to identify specific causes of coupler accidents. In particular the years 1972, 1975 and 1976 were analyzed. The breakdown of these accidents in terms of the action leading to the injury or resulting injury is shown in Table 4.

It may be noted from Table 4 that the two most common actions leading to an injury were associated with part of the worker's body being caught in the coupler and the worker being hit by the pin, in the case of link-and-pin couplers. These two causes were investigated in more detail as described below in an attempt to identify any common trends. The analysis was broken up into three parts. First of all the type of operation, whether it be coupling or uncoupling, was investigated. Secondly, the type of coupler involved was analyzed, and thirdly, the type of equipment to which the coupler was attached was analyzed.

Analysis of injuries relating to worker catching part of body in the coupler, or being caught between the car and its coupler.

	Type of Operation			
	Couple	Uncouple	Unknown	Total
1972	30	4	1	35
1975	14	7	1	22
1976	24	17	0	41

Table 4. Accident Data for Couplers*

Action Leading to Injury or Resulting Injury	1972	1975	1976
Caught part of body in coupler or between car and coupler	35	22	41
Hit by pin	53	32	37
Struck due to uncontrolled movement of cars	0	4	0
Caught between cars	3	7	2
Dropped coupler bar on foot	4	3	4
Caught foot in coupler while aligning	3	5	7
Caught hand in uncoupler mechanism	2	5	6
Caught between cars (passed couplers)	0	1	0
Car ran over foot while coupling	1	5	6
Lifting drooping coupler	0	2	7
Miscellaneous including malfunctions, caught between car and rib slips, hit by parts, etc.	12	3	5
TOTAL	113	89	115

*In this table, the numbers include some accidents where the type of coupler could not be identified. Thus, the totals here are higher than corresponding subtotals for automatic and link-and-pin couplers given in Section 3.2.2.1. On the other hand they are lower than the corresponding totals in Section 3.2.2.1 since in some instances injuries could not be categorized into the classifications used in the above table.

Analysis of injuries relating to worker catching part of body in the coupler, or being caught between the car and its coupler. (cont')

Type of Coupler

	Automatic	Link and Pin	Unknown	Total
1972	2	26	7	35
1975	5	6	11	22
1976	5	11	25	41

Type of Equipment*

	Car	Motor	Supply	Unknown	Total
1972	10	14	7	4	35
1975	9	9	3	1	22
1976	17	16	5	3	41

Investigation of the above chart reveals the following trends. For this particular cause of injury, more injuries result from the coupling operation than the uncoupling operation. However, the ratio between the two is decreasing with time. This is due to the increasing use of automatic couplers in the total population of couplers which are generally more safe in coupling than uncoupling. An important finding is that the proportion of accidents associated with coupling and uncoupling of exempt equipment (i.e., equipment that is not "regularly coupled and uncoupled") is considerable.

Analysis of injury caused by part of workers being hit by pin. (These accidents are associated with link-and-pin couplers only.)

Type of Operation

	Couple	Uncouple	Unknown	Total
1972	36	15	2	53
1975	13	19	0	32
1976	19	18	0	37

*In this chart, couplers used between mine cars are classified under car; couplers used between mine car and motor, motor and motor, and supply car and motor are classified under motor; and couplers used between supply cars and between supply car and tractor-trailer are classified under supply.

Analysis of injury caused by part of workers being hit by pin. (These accidents are associated with link-and-pin couplers only.) (Con't)

	Type of Coupler		
	Link and Pin	Unknown	Total
1972	51	2	53
1975	32	0	32
1976	34	3	37

	Type of Equipment				
	Car	Motor	Supply	Unknown	Total
1972	19	14	13	7	53
1975	10	6	8	8	32
1976	7	17	12	1	37

These results show that there has been a substantial decrease in the number of injuries associated with link-and-pin couplers, which coincides with the findings of Section 3.2.2, and is largely due to the replacement of these couplers with automatic couplers.

An important finding is that although the number of injuries associated with mine cars is decreasing, the injuries involving motors, supply cars and other types of on-track vehicles is not decreasing. It appears that the law is not being applied to this type of equipment in the same way that it is to the mine cars. Since this is equipment that is regularly coupled and uncoupled, some considerations should be given to requiring automatic couplers on this equipment, since it accounts for such a large number of injuries.

4. PERFORMANCE OF COUPLERS IN MINES

As stated earlier, although the various automatic couplers used in the mines satisfy the classification of the CMH&S 1969 Act, they do not always operate satisfactorily under all mining conditions. An important aspect of the present study was to investigate how the automatic couplers presently in use stand up to the mining conditions in terms of adequacy of construction and general ability to withstand the environmental conditions of the mine. Also, what maintenance is presently given to the couplers (if any) to keep them operating. The importance of this work is that it defines the performance requirements for the couplers, which forms the basis of the guidelines for design, inspection and maintenance of automatic couplers.

4.1 CAPABILITY OF COUPLERS TO WITHSTAND MINING CONDITIONS

4.1.1 LOADING ENVIRONMENT

In day-to-day operation in the mine, the couplers are subjected to a complex loading environment. These loads consist of tensile forces in the coupler due to pulling the mine cars, forces induced on the coupler due to negotiating curves and forces due to derailments, if they occur. In addition, forces induced on the draft gear, due to car-mover action, are quite substantial.

The tensile forces experienced by couplers which are associated with draw-bar pull are dependent upon several factors including: rolling resistance, axle load, track condition, air resistance, speed and grade. The maximum tensile force that can be induced on the couplers is essentially determined by the available traction from the locomotive. The maximum tensile force is found by multiplying the locomotive weight and the coefficient of friction between the locomotive and the rails. For a 62.5-ton locomotive, which is the heaviest used in most mines, this force is 32,250 lb_f (assuming the friction coefficient to be 0.25). It was found that all of the automatic couplers surveyed were capable of withstanding these force levels.

In general, the lateral forces that are generated due to the mine car negotiating curves are not high because all the couplers are allowed to pivot laterally. Higher lateral forces can be placed on couplers if the couplers hit the stops (stops are devices, added to coupler housing, to limit horizontal swing of the coupler to within 30°-45° from the center line). However, these forces cannot be large enough to deform the coupler since before such a large force can be developed, the stops would deform. The only other case where lateral forces would be placed on a coupler during normal turns would be if the coupler had somehow frozen (rusted, etc.) into position and could no longer pivot. Then, while negotiating a curve, high lateral forces would be exerted on the coupler shank. Again, before such a force can develop to a sufficient level either the shank will be freed from the frozen condition or the cars will be derailed. Therefore, it is highly improbable that the coupler will experience high enough lateral forces to cause failure.

During derailments, forces can greatly exceed those occurring under normal circumstances. These forces depend on the size of the trip, the speed at derailment, the number of derailed cars, the manner in which the derailed cars stopped the rest of the trip, etc. In the available accident and survey data, no breakage due to derailment was reported so that it may be assumed couplers are capable of withstanding these forces due to derailment.

Forces on the draft gear are generated during coupling and uncoupling operations, by the car mover (used with the rotary dump), and during acceleration and deceleration of the trip. Our analysis shows that forces due to coupling and uncoupling operations are not very high but that the forces exerted by the car mover can be quite severe. For example, in one mine these forces were estimated to be as high as 18,500 lb_f. In this particular mine, the American coupler was being used for which the draft gear is supposedly designed for 15,000 lb_f. Consequently, it was not surprising to find that the draft gear springs, the draft gear front and rear follower plates, had a high rate of failure in this mine.

4.1.2 HORIZONTAL GATHERING RANGE

The horizontal gathering range of an automatic coupler is basically determined by the width of its face. The requirements for horizontal gathering range for automatic couplers are dependent upon the car design (i.e., the number of wheels, the wheel base, the amount of overhang), and the types of curves in the mine. The extreme requirement in horizontal gathering capabilities of automatic couplers occurs when attempting to couple a car situated on a curve and one on a tangent track. This is particularly severe when the cars are four-wheel types with a large overhang (see Figure 18 in Appendix C). Theoretically, with a 25-foot curve (radius of the center line of track) and a particular four-wheel car, this can require a gathering range as high as 19 inches, which none of the couplers surveyed could meet. (The methods for obtaining extreme requirements in horizontal gathering range is given in Appendix C of this report). However, this is an extreme condition and most mine operations would not require coupling under such severe geometries.

4.1.3 VERTICAL GATHERING RANGE

The vertical gathering range of an automatic coupler is basically determined by the depth of its coupling face. The requirements for vertical gathering ranges for automatic couplers are dependent on the car construction and the extreme vertical track conditions. The extreme vertical gathering range is imposed when attempting to couple one car on a sharp vertical curve to a car on level track (see Figure 19 in Appendix C). For example, with a 50-foot radius vertical curve and a four-wheel car with a wheel base of 7 feet, approximately 9 inches of vertical gathering range is required. (The methods for determining the extreme requirements in vertical gathering ranges are discussed in Appendix C.) Of the couplers surveyed, none could meet this requirement. However this is an extreme case and mines would not need to couple under these conditions.

4.1.4 SELF-CENTERING DEVICES

There are differences of opinion as to the importance of the self-centering feature for automatic couplers. Self-centering is advantageous for coupling operations on tangent track. On the other hand, when given the option, some mine operators select a coupler that is not self-centering as under the condition of coupling on tight curves, it is advantageous to have a coupler that can be set at an angle with the track line.* Also, a coupler with a self-centering device has more parts and therefore has a higher chance of failure.

Nevertheless, when it becomes necessary to use the hands and feet in aligning a coupler, the merit of the automatic couplers without self-centering is questionable. Indeed, an analysis of the accident statistics associated with automatic couplers (Table 3, Section 3.2.1) showed that personnel frequently had their feet crushed while attempting to align couplers. It seems that properly maintained self-centering devices are an essential feature for reducing accidents with automatic couplers.

4.1.5 UNCOUPLING UNDER TENSION

If tension exists between cars, the uncoupling operation is impeded. We found it a general practice in the mine for mine personnel to release this pressure by buffing up before uncoupling.

4.1.6 COUPLER REVERSIBILITY

Most mine haulage systems are designed so that mine cars do not have to be reversed. Therefore, coupler reversibility is not an essential feature. Manufacturers of reversible couplers claim that since the cars can be turned around, the wear on various components will be even. Therefore, the mine operators would only have to worry about one type of coupler head instead of both male and female heads. In reality, however, cars are seldom turned around in the mine. Therefore, the need for interchangeability is not critical in our estimation.

4.1.7 ROTARY DUMP CAPABILITY

Rotary dump capability is required in a coupler when the mine cars are emptied utilizing a rotary dump device. All of the automatic couplers surveyed provide this feature as an option. In

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*Ilsley, L. C., and Gleim, E. J., "Some Information on Automatic Coupling of Mine Cars," U.S. Department of the Interior, Bureau of Mines, Information Circular No. 7245, 1943.

order to evaluate the reliability of the rotary dump mechanism in automatic couplers, the mine operators were questioned whether they encountered any problems with the mechanism. Also, during our visit to the mines, rotary dumping operations were observed. At one mine where Willison couplers were used, problems occurred with the coupler body separating. This was eventually determined to be caused by a missing component in the draft gear. At a second mine using Willison couplers, problems occurred with the fixed, nonrotating part trying to rotate. This was believed to be caused by jamming of the rotating part due to poor lubrication of the parts of the coupler. Both these problems were attributed to poor installation or maintenance and not design features. Our survey indicates that, in general, rotary dump capability is not a problem area for safe operation of automatic couplers.

4.1.8 LOCK-SET DEVICE

Another design consideration that affects the safety and reliability of automatic couplers is the lock-set device. The provision of a lock-set device in an automatic coupler allows the coupler to be set in a locked-open position whereby it automatically releases as the coupler heads pull apart. This feature allows coupling and uncoupling to be accomplished by one worker. It saves manpower and reduces accidents that can occur due to poor coordination between the locomotive driver and the coupler operator. Currently, only the side-operated American coupler is designed with such a feature. In addition, Midland-Ross Corporation has a lock-set design available but Willison couplers have not been manufactured with such devices. In the one mine surveyed where the American coupler was in use, the workers were not even aware of this special feature of the American coupler! We feel mine operators should be made aware of the advantages of such devices.

4.2 RELIABILITY AND SAFETY OF COUPLERS

A reliability investigation was performed on the automatic couplers currently in use to determine the durability, ruggedness, and maintenance requirements of the couplers. Since uncoupling mechanisms have already been identified as a general problem area for the effective performance of automatic couplers, a special investigation of these mechanisms was also made. In addition, a hazard analysis was conducted to evaluate coupling and uncoupling operations and to ascertain the relative safety of the various types of couplers. While the data base is not very large, the results do form an important background for the design, inspection and maintenance guidelines.

4.2.1 RELIABILITY ANALYSIS

Several factors were identified as being important for determining the reliability of couplers. These were:

- Years of service--This is based on the number of years of service of the mine cars to which the couplers are attached.

- Couple-uncouple (C-UC) cycles--This is based on the actual operations which move loaded mine cars from the loading point to the dump and return them.

- Miles traveled--This is based on the total miles traveled by the mine car.

- Tons hauled--This is based on the total tons hauled by the mine car.

- Car size--This is the loaded weight of the mine car.

- Drawbar pull--This is the drawbar pull exerted by the largest locomotive in the mine.

- Rated capacity of coupler--This is the capacity of the coupler as established by the manufacturer.

- Car mover action--This relates to the operation of the car mover at the rotary dump.

- Track condition--This is an estimation of the track conditions based on visual inspection. The condition of the track is rated from good to poor.

- Replacement rate--This is based on the number of couplers replaced per 100 mine cars per year.

Table 5 shows the results of the reliability investigation for those mines for which data was available. Although the data is somewhat limited, some qualitative evaluation of couplers was possible.

Evaluation of American Coupler

The American coupler was observed at one mine. This mine reported numerous component failures associated with the draft gear. However, they had few problems with the coupler itself. Actually, the mine had a harsh-acting car mover which exerted extremely large forces on the springs of the draft gear which is believed to be the cause of the problems. Common failures reported included:

- Lock springs

- Draft gear springs

- Draft gear spring retaining plates

Though data in Table 5 was not available on the replacement rate for this coupler, the mine reported satisfactory performance of

Table 5. Reliability Data of Automatic Couplers

Mine No.	Type of Coupler	Years of Service	C-UC Cycles	Miles Traveled	Tons Hauled	Car Size (tons)	Drawbar Pull (tons)	Track Condition	Recommended Capacity of Coupler (tons)	Draft Gear	Car Mover Action	Replacement rate per 100 cars/yr
1	Willison	6	216	8K	13K	10	9.25	Good	N/A	Good	Smooth	1.0
2*	Willison	28	2814	70K	81K	7	13.5	Good	N/A	Good	Smooth	0.6
2+	Willison	16	1536	40K	47K	7	13.5	Good	N/A	Good	Smooth	0.6
7	Willison	26	975	91K	65K	10	12.0	Good	8.0	Poor	Harsh	6.1
8	Willison	16	720	62K	56K	15	12.5	Fair	N/A	Fair	Smooth	0.7
12	Willison	20	500	75K	96K	19	N/A	Good	40	Fair	Smooth	--
13	Willison	30	690	50K	75K	12	7.5	Fair	N/A	Fair	Smooth	N/A
3	Willison	10	N/A	N/A	N/A	25	15.5	Good	N/A	Good	Smooth	N/A
9	Ohio Brass (6&9)	28	232	43K	23K	6.5	12.5	Fair	12.5	--	Harsh	3.8
10	Ohio Brass (8&8A)	27	1266	130K	189K	30	15	Good	22.5 & 40	--	Smooth	N/A
5	American	28	590	204K	45K	8	10	Fair	N/A	Poor	Harsh	N/A

N/A = not available
* = eight-wheel cars
\+ = four-wheel cars

the coupler. The major problems seemed to be associated with the particular draft gear selected for the mine cars.

Evaluation of Mayo Coupler

The Mayo coupler is normally used in tunneling operations, not in coal mines. However, some mines do use Mayo couplers and this coupler (standard model) was observed at one mine. This coupler was in a light-duty application hauling supplies. The couplers had been in service for only a short period of time and the mine personnel were generally dissatisfied with the coupler's performance. (It was difficult to determine if this was their dissatisfaction with the CMH&S Act requirement or dissatisfaction due to failure rates.) Failures occurred primarily due to broken links which were probably due to the improper installation of the coupler. The recommended installation procedure is to rigidly attach the coupler with four bolts on the bumper of the car. However, in this mine, the couplers were mounted on a pivot arm which, in turn, was mounted by a pin to the car. This gave four pivot points in the connection between the cars and the coupler and it is this that would lead to excessive slack and eventual breakage. Besides broken links, failure of the self-centering springs was also reported for this mine.

From design and strength considerations, the standard Mayo couplers which are generally installed without draft gear, can only be considered adequate for light-duty application. For heavy-duty applications (e.g., for locomotives above 10 tons), the couplers should be installed with draft gear.

Evaluation of the Ohio-Brass Coupler

The Ohio-Brass (OB) automatic coupler was observed at two mines. Information was also obtained from two other mines where the OB was used on supply cars. At one location, the Model 6 was utilized on locomotives and Model 9 on mine cars. The Model 9 was built especially for this mine and differed from the Model 6 by the presence of a special flange for an air brake connection hose. Both the Model 6 and Model 9 experienced high failure rates basically due to the inadequate capacity of the couplers to handle the loads imposed on them. These failures included:

- Belling and cracking of the lower lip of the female coupler.
- Worn tip on the male coupler.
- Broken shanks.
- Cracks around the pivot pin hole.
- Defective lock springs (this was later overcome by using stainless steel springs).

The deficiencies of the Models 6 and 9 were recognized by the manufacturer and new, improved models were developed. (Models 6 and 9 are no longer manufactured). The Model 8 now replaces the Model 6 and a Model 8A is available for heavy-duty applications.

From the data in Table 5, it is apparent that the Models 8 and 8A in mine No. 10 were subjected to much greater usage than Models 6 and 9 in mine No. 9. Though replacement rate data was not available for the Models 8 and 8A, the mine operators expressed their satisfaction with these couplers and no problems were reported.

Evaluation of Willison Coupler

The Willison coupler was observed in seven mines. The models observed included rotating and nonrotating models, couplers with and without self-centering, and couplers with and without hoods. The couplers were in excellent condition in most mines with replacement rates being less than one coupler per 100 cars per year on the average. There was only one instance of an unusually high replacement rate and this was attributed to the use of the wrong capacity coupler, and to the large acceleration forces of the car mover.

As far as maintenance is concerned, most mines limited maintenance to those instances when a coupler was sent to the shop because of defects. (Only one mine reported any routine maintenance.) The common defects were associated with the:

- Lock spring
- Rounding of shank on nonrotating coupler
- Pivot pin
- Bushing
- Uncoupling levers

In general, the Willison coupler performs well in the field. Its maintenance requirements are low, and its average life exceeds that of the mine cars on which it is installed. However, the unhooded version of the coupler is susceptible to unintentional uncoupling under severe track conditions which can lead to a runaway trip. Furthermore, all Willison couplers should be equipped with self-centering devices since this greatly improves safety by removing the need to reach between the cars to center the coupler.

4.2.2 RELIABILITY AND SAFETY OF UNCOUPLING MECHANISMS

The influence of uncoupling mechanisms on the safe operation of automatic couplers cannot be overemphasized. A review of injuries associated with coupler operations shows significant numbers of injuries are directly attributable to the uncoupling mechanism. An investigation of the uncoupling mechanisms was performed to see the various design considerations that constitute a safe and reliable uncoupling mechanism. (The details of the various uncoupling mechanisms are given in Appendix A.) The general conclusions were that the uncoupling mechanism design should be rugged, not easily susceptible to damage, together with the following features:

- Uncoupling action--The nature of the uncoupling action plays an important role in the safe operation of the mechanism. An action which requires motion of the worker toward the car is obviously unsafe since it could cause a man to fall between the cars. A lifting motion is also unsafe, since the man could be thrown off balance by any car movement. A downward motion is generally acceptable, but the most favorable action is an outward motion away from the cars.

- Design of the hand-hold--The design of the hand-hold should be such that the chance of a worker's hand getting caught between the cars and the lever is remote. Most levers are designed to allow the worker to grasp the lever with his hand. In such cases, a hand can easily become wedged between the car and lever. (A large number of accidents with automatic couplers involved catching the hand in the uncoupling mechanism.) A well-known cause of accidents is the catching of a ring on the edge of the lever. A round handle prevents this from occurring. Another excellent alternative is to design the lever in such a manner that it is activated by pushing with the palm of the hand and so that it cannot be grasped by the hand.

- Location of the operating levers--The operating levers should be located at the end of the car and be designed so as not to protrude beyond the end of the car. They should be at a height that permits easy, convenient movement by the worker and should be designed to be easily accessible and operable from both sides. This eliminates the need for workers to cross between cars.

- Protection from impact damage--The uncoupling mechanism should be protected to withstand impact damage and preferably be of flexible construction.

Table 6 shows the results of analyzing the various uncoupling mechanisms that were surveyed in the contract. These mechanisms

Table 6. Survey of Various Uncoupling Mechanisms

No.	Description*	Design Complexity	Handle	Action	Location	Reliability	Resistance to Damage	Other Features	Improvements Required
1	Cable with handle	Simple	Round (safe)	Away (safe)	End of car (safe)	High	Excellent	--	--
2	Cable with lever and lock	Moderate	"	"	"	Moderate	Poor	Locking device	Protect pulley with angle iron
3	Lever with pivot and chain	Simple	Rect. (unsafe)	Down (safe)	"	High	Fair	Independent action from both sides	Redesign handle to make it round
4	Foot lever and pivot	Simple	Foot pad (unsafe)	Down & in (unsafe)	Between cars (unsafe)	High	Excellent	--	Foot levers are unacceptable
5	Lever, bell crank and chain	Complex	Round (safe)	Away (safe)	End of car (safe)	Low	Poor	Spring return	Needs protection against damage at pivot points
6	Rotating lever and chain	Simple	"	Parallel to trk. (unsafe)	End of car (safe)	High	Poor	--	Welded angle iron over rod would protect it against damage; redesign action
7	Rotating lever and chain with lock	Moderate	"	"	"	Moderate	Poor	Locking device with release	Welded angle iron over rod would protect it against damage; redesign action
8	Rotating lever with outside handle and lock	Simple	Flat (safe)	Down (safe)	Side of car (safe)	High	Poor	Locking device	Welded angle iron over rod would protect it against damage.

* See Appendix A for details.

were either developed by the coupler manufacturer or the mine operators themselves. It was concluded that the "cable with handle" design is a very safe and efficient uncoupling mechanism for automatic couplers.

4.2.3 HAZARD ANALYSIS FOR COUPLER OPERATIONS

A hazard analysis of the couplers was conducted to investigate safety of coupling and uncoupling operations. (The details of this analysis are given in Appendix B.) For the purpose of this analysis, couplers were grouped as: automatic coupler without self-centering; automatic coupler with self-centering; and automatic coupler with self-centering and lock-set device.

For analyzing the hazards associated with coupling operations, the coupling operation was broken up into twelve steps. The analysis involved rating each step in the coupling operation according to the hazard involved (low, medium, high, and very high) for the various groups. This analysis showed that the automatic coupler equipped with a self-centering device substantially eliminates the hazards associated with the coupling operation. Without self-centering, however, significant hazards still exist.

For analyzing the hazards associated with the uncoupling operations, the uncoupling operation was again divided up into several steps. This analysis showed that automatic couplers (and modified link-and-pin couplers) were very effective in eliminating the hazards associated with uncoupling operations. The automatic coupler equipped for one-man operation (i.e., use of lock-set device) virtually eliminates all hazards by removing all personnel from the immediate area of the cars.

4.3 EFFECT OF ENVIRONMENTAL CONDITIONS ON AUTOMATIC COUPLER PERFORMANCE

The effect of mine moisture, mine water, coal dust, etc., on couplers was investigated to see how the coupler withstands the mine environment over long periods. As it was not possible to quantitatively determine the long-term effects of the mine environment on the coupler performance within the time span of the present contract, most of the information had to be primarily obtained from discussions with the coupler manufacturers and mine operators. Nevertheless, during visits to the mines, ENSCO personnel took the opportunity whenever possible to examine the various environmental factors and their effects on the couplers. The major findings were as follows.

4.3.1 MINE WATER

Mine water arises from seepage through the roof and from spraying operations carried out during mining. Some of the chemical elements of the coal dissolve in water and produce acidic compounds which can affect the coupler material if the coupler is subjected to them over a sufficiently long period. The couplers generally have a massive cross section, and corrosion (either due to rusting or acid attack) needs considerable time before the cross section will be reduced to a point where the coupler fails structurally. It certainly does not take place within the 20-30 year working life of the coupler. Some corrosion of small components, particularly springs, was noted and some mines had changed to stainless steel for these components.

4.3.2 COAL AND ROCK DUST

Coal dust is too soft to cause significant abrasion and wearing of the mating parts of the coupler. In fact, small quantities of coal dust around moving parts can act as a mild lubricant. The rock dust encountered in the coal mines is usually of the limestone variety which is sprayed on to neutralize the explosive coal dust air mixture and is very soft and unabrasive.

4.3.3 BUILD-UP OF COAL AND ROCK PARTICLES ON COUPLERS

The build-up of dirt on the coupler mating surfaces and clogging of the clevis pin or other spring components can inhibit coupler performance. Again, our investigation shows that contamination of coupler components is not a serious problem. The parts that mate are usually clean and well-polished due to the constant coupling and uncoupling operations and due to the scuffing that occurs during transit of the cars. While the coupling operation can also be impeded due to the accumulation of fallen debris on the coupling surfaces, this debris can easily be removed and again this is not a problem. In any case, the high forces applied during coupling operations are sufficient to crush or dislodge any debris which might accumulate on the coupler face.

The mating surfaces of both Ohio-Brass and American couplers are completely enclosed when in a coupled position and therefore dirt cannot get into them at all. In the case of the Willison and Mayo couplers, there is a remote possibility of jamming of couplings in the coupled position due to debris getting into the coupler. Again, in our survey, not a single occurrence was reported so that this cannot be considered as a problem for these couplers either.

4.4 EXISTING MAINTENANCE PRACTICES FOR AUTOMATIC COUPLERS

Data collected on automatic couplers was examined to identify existing maintenance practices and techniques. The manufacturers' recommended maintenance practices for automatic couplers and the actual practices of the various mines surveyed are described below.

4.4.1 MANUFACTURERS' RECOMMENDED MAINTENANCE PRACTICES

All of the manufacturers recommend that certain inspections and maintenance practices be carried out on their couplers. National Castings (Willison) has just developed a comprehensive maintenance plan. American and Ohio-Brass had previously published such documents. Elgood-Mayo, upon request, furnished a letter outlining specific inspection and maintenance requirements.

All of the plans suggest a periodic examination for cracks, loose parts or broken components. They each cite specific components to be checked in order to ensure adequate performance. Willison and American have gauges of the go/no-go variety to check critical components to insure their dimension is within acceptable limits. Ohio-Brass has a gage to be used in rebuilding the coupler, and to check whether the coupler head has reached its wear limits.

Lubrication of the coupler seemed to be a point of contention. Although many mines reported that they carried out lubrication, manufacturers differed in their recommendations. Willison and American stated none was required citing the susceptibility of the lubricant to attract and hold dirt and debris. On the other hand, Ohio-Brass suggested use of graphite-based dry lubricants.

4.4.2 MAINTENANCE PRACTICES OF MINES

In general, maintenance practices vary widely within coal mines and those concerning maintenance of automatic couplers are no different. The majority of mines treated couplers as a component which is run until failure. The basic simplicity of design of the coupler causes mine operators to concern themselves with supposedly more crucial problems and ignore the couplers.

Among those who did maintain the couplers, we found that couplers were usually visually inspected as the cars progressed through the rotary dump. As a result, cars with defective couplers were identified and sent to the shop for repair. In another case, couplers which caused problems, either in coupling or uncoupling, were identified by the motormen and marked for the shop. Also, any car sent to the shop for other reasons (bad wheels, bolsters, etc.) was thoroughly inspected and the coupler repaired if faulty. Lubrication was performed concurrently with car wheel bearings. This was generally twice a year. Lubrication included all components where surfaces rubbed together. These surfaces were usually brushed with an oil or grease solution.

One mine had a sophisticated system for controlling car inspection and maintenance whereby a computerized output identified cars requiring service. On periodic intervals (every four or six months), each car was passed over a pit where a complete inspection took place. Mines with these programs had very low coupler replacement rates.

5. PERFORMANCE OBJECTIVES AND GUIDELINES

In developing guidelines for design, inspection and maintenance, it is first necessary to define the in-mine performance objectives for the automatic couplers. Based on these performance objectives, design guidelines can be developed, so that the couplers perform adequately when they are new. The inspection and maintenance guidelines can be developed to ensure the couplers perform properly throughout their expected life of 20-30 years, which is the normal useful life of the mine cars to which they are attached.

5.1 PERFORMANCE OBJECTIVES

The general performance objectives for an automatic coupler are that it couple on impact and that it can be coupled and uncoupled without mine personnel going between the cars. In order to meet these general objectives, the couplers have to satisfy various performance specifications. These performance specifications have to be determined by detailed and comprehensive investigations of the mine environment under which the couplers must operate. This was accomplished in the work described in the previous Chapter 4. From this survey, the set of specific requirements for automatic coupler performance has been derived as outlined in the following sections.

5.1.1 LOAD CAPABILITY

The strength of the coupler should be adequate to prevent permanent deformation of the coupler components by forces encountered in normal operation in the given mine. The maximum force expected to be applied is associated with the locomotive drawbar pull.

5.1.2 HORIZONTAL COUPLING CAPABILITY

The coupler should have the ability to automatically couple in all horizontal track configurations where coupler mating operations can be performed in a mine. The maximum gathering range required is determined by the track configuration where the tightest curve meets a tangent track.

5.1.3 VERTICAL COUPLING CAPABILITY

The coupler should have the ability to automatically couple in all vertical track configurations where coupling operations can be performed in a mine. The maximum vertical gathering range required is determined by the track configuration where the tightest curve meets a tangent track.

5.1.4 CURVE NEGOTIABILITY

The coupler swing angle and installation geometry should be designed so that the cars can negotiate the tightest curve which exists in the given mine without being forced off the track.

5.1.5 VERTICAL SEPARATION

The coupler should be designed so that when the cars are in the coupled condition there is enough free vertical travel between the cars so that when profile undulations are encountered in the mine they do not cause one of the wheels of one of the cars to be lifted off the track. On the other hand, the vertical movement capability should not be so great as to allow the cars to separate due to unintentional release of the couplers.

5.1.6 SELF-CENTERING

The coupler should be so designed that when not engaged, the coupler head automatically aligns with the center line of the car and perpendicular to the car face.

5.1.7 UNCOUPLING LEVERS

All uncoupling levers should be designed so that uncoupling operations can be performed without personnel going between cars. In particular, they should be designed so that the operation of uncoupling with the lever is inherently safe, i.e., the worker is always positioned in a stable physical stance, or if he does happen to fall due to uncoupling exertion, he will fall away from the hazardous area of the mine cars.

5.1.8 ROTARY DUMP CAPABILITY

In mine operations where rotary dumps are used for emptying the mine cars, the couplers must allow free rotation when in the coupled condition.

5.1.9 MOUNTING DEVICE

The couplers should be mounted on the mine cars through a device which reduces shocks during starting, hauling, stopping, shunting, and during coupling and uncoupling operations. The mounting supports and draft gear used in installing the couplers should be structurally adequate to prevent permanent deformation of the supporting structure induced by forces encountered in normal operations.

5.1.10 CORROSION RESISTANCE

The material used in the coupler and mounting device construction should be able to withstand any corrosive acid encountered in the mine or should be designed with sufficient excess metal to render any corrosion damage over a 20-year period to be ineffective in decreasing the structural integrity of the components.

5.2 DESIGN GUIDELINES

The design guidelines for automatic couplers have been developed based on the data collected during the survey of coal mines and manufacturers as described earlier in this report. Based on the engineering investigation of these data, performance specifications for automatic couplers were first established (see Section 5.1). The development of the design guidelines has been specifically geared to these performance specifications.

The design guidelines define basic features of automatic couplers that should be taken into account by coupler manufacturers when designing their couplers. These design guidelines will also be helpful for mine operators in deciding what features automatic couplers should have for their particular mine requirements. It is expected that design guidelines will also provide a good foundation from which the government may derive suitable standards for regulating automatic coupler design. The various features of these guidelines include: strength and material; self-centering device; horizontal and vertical coupling capability; curve negotiability; limitation of vertical movement; uncoupling mechanism; lock-set device; rotary dump capability; and mounting device and draft gear.

The details of these guidelines and examples of their use are given in Volume II of this report, "Design, Inspection and Maintenance Manual." The details of various geometric calculations, viz., calculation of coupler gathering ranges, calculation of minimum distance between cars, and calculation of coupler swing angles are given in Appendices C through E of this report.

5.3 INSPECTION AND MAINTENANCE GUIDELINES

The inspection and maintenance guidelines for automatic couplers have been developed for insuring proper operation in the mine. These guidelines are based on recommendations obtained from the coupler manufacturers, the best practices observed in the mines and the engineering investigations carried out in the present study. These guidelines are for use by the mine inspection and maintenance personnel. They provide details on standards and allowable tolerances, method of measurements to determine if couplers are in safe condition, and methods for maintaining them in safe condition. It is expected the inspection and maintenance guidelines will also provide a good foundation from which the government may derive suitable standards for regulating automatic coupler performance. These guidelines are given in detail in Volume II of this report for the four commonly occurring couplers, viz.: American Industrial coupler, Mayo coupler (standard and jumbo models), Ohio-Brass coupler (Form 8 and Form 8A), and National Castings Industrial Size Willison coupler.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Important features of the investigation and the conclusions from this study are summarized in the following:

- Analysis of coupler-related accident data shows that automatic couplers have made an important contribution in reducing general coupler accidents.

- Poor operating procedures and inadequate maintenance of automatic couplers are the major causes of injuries with these couplers. Better design and proper maintenance of uncoupling mechanisms and the use of self-centering devices would have significant effect in reducing these coupler accidents.

- Automatic coupler designs are quite adequate to withstand the loading and environmental conditions encountered in the mine.

- Uncoupling mechanisms used with automatic couplers are generally not properly designed and are also kept in a poor state of repair. Significant reduction in accident occurrences could be achieved through adequate design and proper maintenance of uncoupling mechanisms.

- The design guidelines developed in this study define basic features of automatic couplers that should be taken into account by coupler manufacturers when designing their couplers. The design guidelines will also be helpful for mine operators in deciding what features automatic couplers should have for the particular requirements of their mine.

- The inspection and maintenance guidelines developed in this study are for use of mine inspection and maintenance personnel. They provide details on standards and allowable tolerances, methods of measurement for determining if couplers are in safe condition, and methods for maintaining them in safe condition.

- The guidelines developed in this study would provide a good foundation from which the government may derive suitable standards for regulating automatic coupler design and performance.

6.2 RECOMMENDATIONS FOR FUTURE STUDY

6.2.1 DEVELOPMENT OF COUPLER INSPECTION DEVICES

Some coupler manufacturers have already developed procedures for the inspection of couplers and special gages for the measurement of the effects of corrosion, distortion and wear. The various coupler inspection items and the tools required for performing them are given in Table 7.

As can be seen from Table 7, tools and devices are available for the inspection of couplers with the following two exceptions:

- Determination of the distance from the car center line to the position to which a self-centering coupler returns.
- Measurement of the slack due to wear in the coupler draft gear.

Therefore, a study is recommended to develop tools to inspect these two exceptions. In addition, existing automatic coupler gages should be examined and refined if necessary. This study would involve the following:

- Procure and study gages and tools recommended by the manufacturers for the measurement of corrosion, wear, and distortion of couplers. Procure two used couplers of each type and use available coupler inspection gages to measure coupler wear and determine the adequacy of inspection gages. If necessary, refine existing coupler inspection gages.
- Design a tool or device that will provide a projection of the center line of a car across the top of the coupler pin to the coupler face.
- Design a device to apply pulling force and buffing force against a coupler. Investigate the force requirements to move couplers for measurement wear of draft gear.
- Build two prototype devices, one in accordance with each design and check out these devices.

Table 7. Inspection Items and Tools Required

INSPECTION ITEMS	TOOLS REQUIRED
1. General visual inspection	None
2. Uncoupling mechanism	Ruler
3. Self-centering mechanism	Centering device (to be developed), ruler
4. Lock, lock pin and lock lever	Caliper
5. Mounting and draft gear	Device for applying force to draft gear (to be developed), ruler
6. Shank wear and distortion	Ruler
7. Coupler butt wear	Ruler
8. Coupler pivot pin and pivot pin holes	Caliper
9. Coupler contour and lock wear	Coupler contour gages (available from manufacturers), ruler, caliper
10. Coupler sag	Ruler

6.2.2 INVESTIGATION OF AUTOMATIC COUPLERS FOR OFF-TRACK HAULAGE

The movement of supplies to and from the operating face has long been a problem in underground coal mines. The use of standard rail cars for movement of supplies has the disadvantage of requiring unloading of cars, temporary storage of the supplies and reloading into the shuttle car for movement to the working face. This constant rehandling of supplies has led to an increasingly wide acceptance of rubber/rail equipment. Now the rail car can be loaded once, moved to the vicinity of the section by rail where the rubber wheels are lowered and the car is towed by battery-powered tractor to a convenient location at the rear of the section. Where the size of the job merits it, the car can be moved directly to the work place and material unloaded as it is required. This greatly minimizes the amount of handling and rehandling associated with the section supplies.

The 1969 CMH&S Act provisions do not apply to rubber/rail cars, when they are off the track, though they are coupled and uncoupled regularly; the rubber/rail car coupler acts like that of any other car coupler on rail. However, once on rubber wheels, the conditions are quite different. The severe bumps and jolts, undulations and handling cause dramatically different dynamics under which the coupler must function. Couplers must now have positive interaction or be equipped with hoods to prevent uncoupling over the severe undulations. Mountings must be capable of vertical and horizontal ranges greatly in excess of those required for cars used just on rail operations. Provisions must be made to allow coupling and uncoupling under conditions where alignment problems are dramatic. Uncoupling levers and mechanisms must be properly designed to withstand rough handling conditions.

An indication of the difficulties associated with the operation and maintenance of such couplers was demonstrated in the survey of automatic couplers at a large Eastern coal mine, where, out of 400 mine cars equipped with automatic couplers, a total of 20 (5%) had been replaced. On the other hand, with the same couplers on 31 rubber/rail cars, 16 couplers (50%) had been replaced over the same period. Observation of these rubber/rail cars also showed 25 had defective or inoperative uncoupling levers.

The need for automatic couplers for rubber/rail cars has clearly been identified by MESA in recent studies. However, problems do exist in the design, operation and maintenance of these couplers. A comprehensive study is required of these couplers in their various forms and a detailed report of their adequacies and inadequacies prepared with specific recommendations as to needed improvements.

7. SUBJECT INVENTIONS

There were no subject inventions in this investigation.

APPENDIX A

ANALYSIS OF VARIOUS UNCOUPLING MECHANISMS

The various uncoupling mechanisms surveyed in this study are discussed in the following.

1. CABLE WITH LEVER AND LOCK

The design consists of a cable channeled over a pulley and connected to a lever mounted on the side of the car (Figure 9). The pulley and the action of the lever lead to a low force requirement to activate the lock lever. The locking device allows the coupler latch to be held in an open position, a feature which enables one man to couple and uncouple cars. (This particular locking device does not have a self-release feature.) The handle is round, thus unlikely to catch rings on the workman's hand. The action is away from the car, which is a desirable feature. The reliability is moderate due to the complexity of two handles and locks and its exposure to damage is quite high. Bumping of cars is likely to render the mechanism inoperative.

2. FOOT LEVER WITH PIVOT

This simple design is used on flatcars and other supply equipment. The design consists of a lever with a skid pad for foot activation (Figure 10). The lever is mounted directly on the uncoupling latch and pivots on the base of the coupler. The foot pad is located in a very hazardous position between the cars. The action is down and in, which is extremely hazardous. Using the foot to operate the lever places the man in an unbalanced position. He must partially balance himself by grasping the car. Any movement will knock him off balance. The design is simple, thus likely to be reliable. This design is very poor from a safety standpoint and should not be allowed.

3. LEVER WITH PIVOT AND CHAIN

This simple design is quite common in the mining industry. The design consists of a lever with a pivot (Figure 11). One end of the lever is attached by a chain to the uncoupling latch. The lever follows the contour of the car. The handle is rectangular, it is rigidly mounted, and there is a small gap between the handle and the car body making it possible for a person to catch rings or fingers when unexpected car movements occur. The action is down, which is acceptable. The lever is susceptible to damage, but could sustain minor impact. The mechanism has the advantage that it can be operated independently from either side of the car.

4. CABLE WITH HANDLE

This design consists of a cable attached to the lever on the

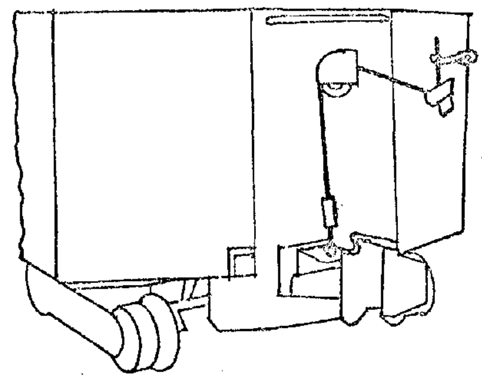

Figure 9. Uncoupling Mechanism--Cable with Lever and Lock

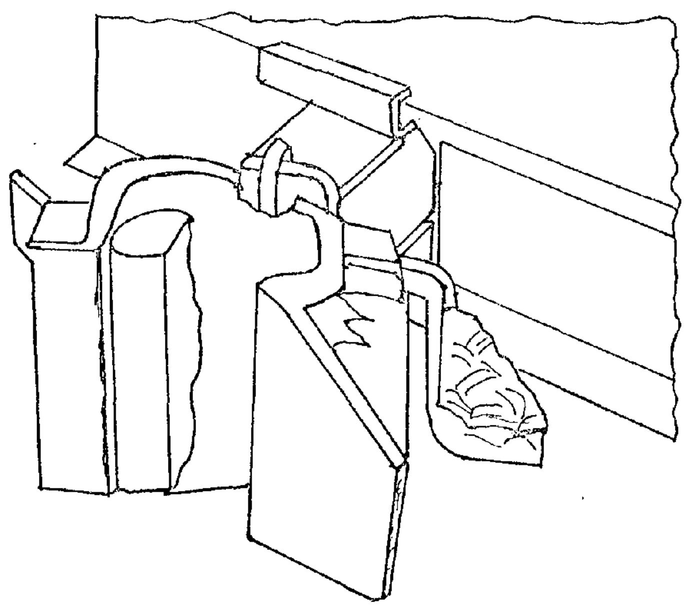

Figure 10. Uncoupling Mechanism--Foot Lever with Pivot

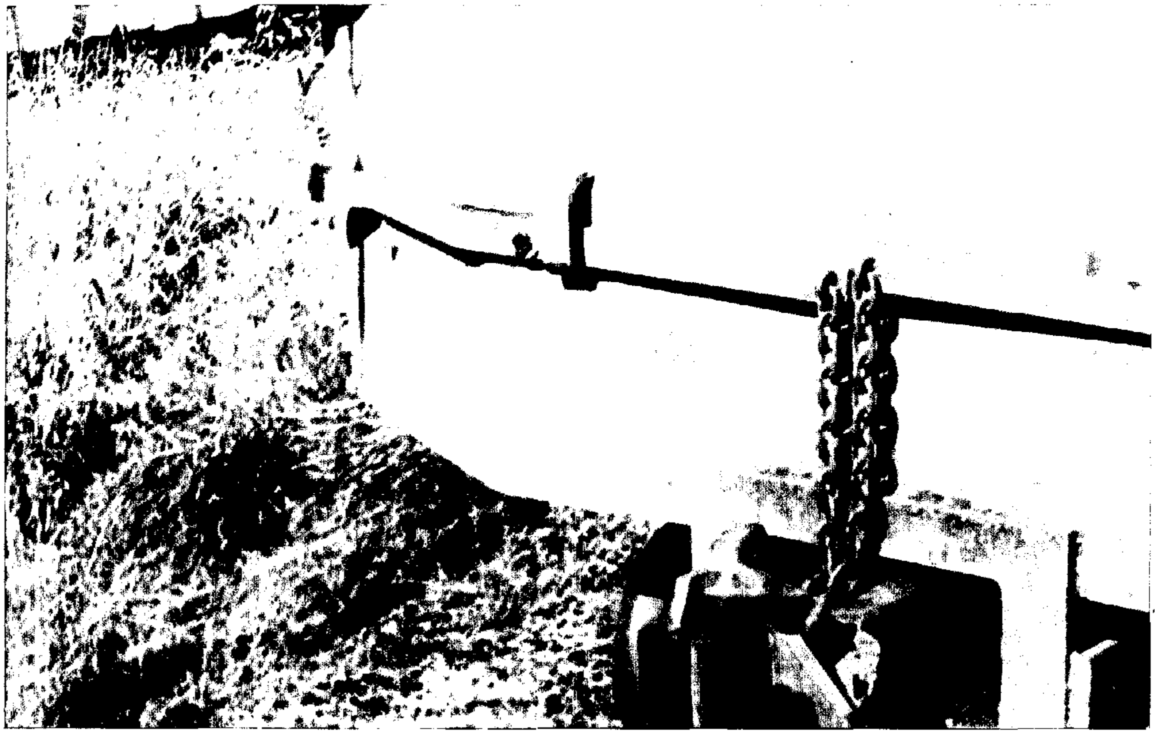

Figure 11. Lever with Pivot and Chain

Figure 12. Cable with Handle

coupler and channeled-through eye hooks to a location on the end of the car (Figure 12). The handle is round in design and is unlikely to catch a worker's hand or finger, particularly since it is not rigidly mounted on the car. The action is away from the car, again, a desirable feature. The design is simple, thus reliable. It can tolerate impacts except perhaps directly on the eye hooks.

5. LEVER WITH BELL CRANK AND CHAIN

The design consists of rods anchored together by a pin (Figure 13). At one end, the rod is connected by a pin to a bell crank. A pulling action rotates the crank which is linked by a chain to the uncoupling latch. At the other end of the rod assembly is a round handle. A spring assembly acts against the pulling action to return the mechanism to a released position. The round handle makes it unlikely to catch a workman's hand or rings. Although the handle is attached to the end of the car, sufficient gaps have been allowed to avoid catching of a workman's hand. As before, the action is away from the car, but the design is extremely complex and thus judged somewhat unreliable. It is not designed to sustain impacts between cars.

6. ROTATING LEVER WITH CHAIN

This simple design is quite common in the mining industry. The design consists of a rod which is mounted to the end of the car by a pair of brackets (Figure 14). On one end, a lever extending outward from the rod is connected by a chain to the uncoupling latch. At the other end, the rod is bent 90° to serve as a handle. The handle is round in design, and it is unlikely to catch a workman's fingers or rings. The location of the handle is at the end of the car. The action is parallel to the track, thus posing a potential hazard in operation. The design is simple, thus reliable.

7. ROTATING LEVER WITH CHAIN AND LOCK

This design is basically the same as the rotating lever and chain, except it incorporates a locking device to set the coupler in an uncoupled position (Figure 15). The locking device is a latch mounted on the handle. When the handle is pulled to open the coupler, the latch can be set on the ratchet mounted on the car body. This holds the coupler in an open position. The chain hanging from the adjacent car is attached to the latch. As the cars separate, the slack in the chain is taken up until the chain trips the latch. This allows the rotating lever to return to the normal position and close the coupler. The rod itself has a round handle and is unlikely to catch a workman's hand. Actually, the lock device eliminates the need for a man to hold the lever during uncoupling (unless buffing is required). The location of the handle is at the end of the car. The action is parallel to the track, thus unsafe. The design is somewhat complex, thus perhaps unreliable.

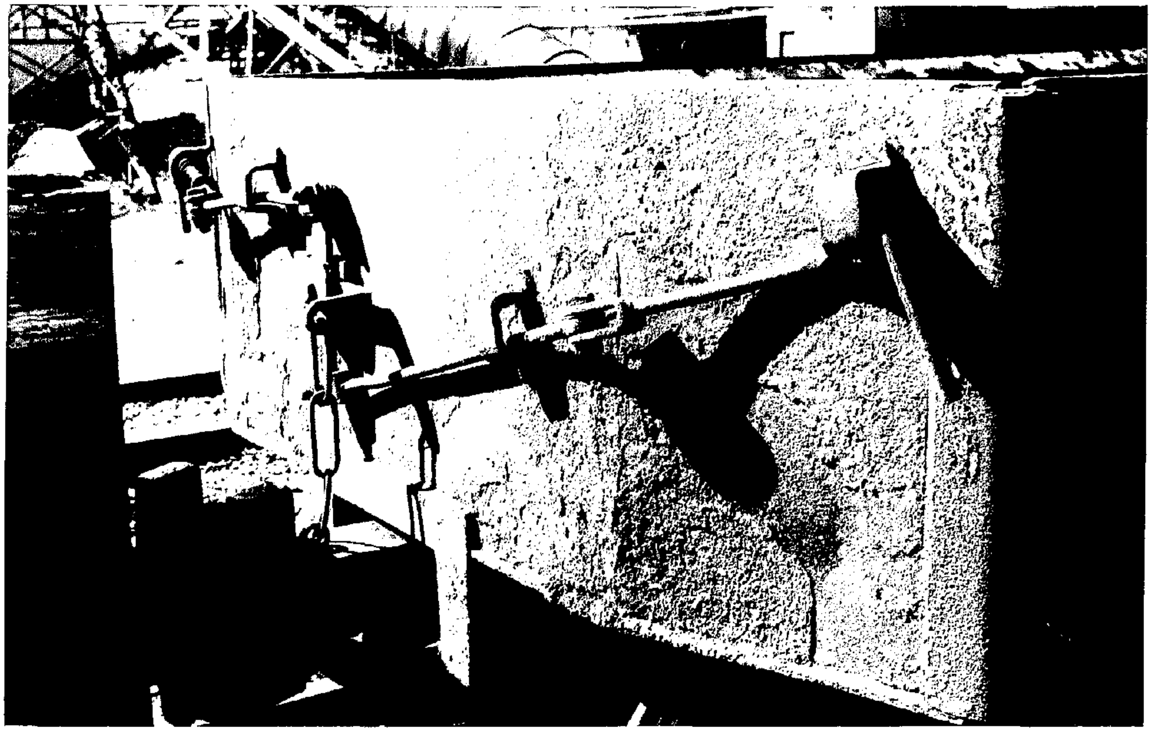

Figure 13. Lever with Bell Crank and Chain

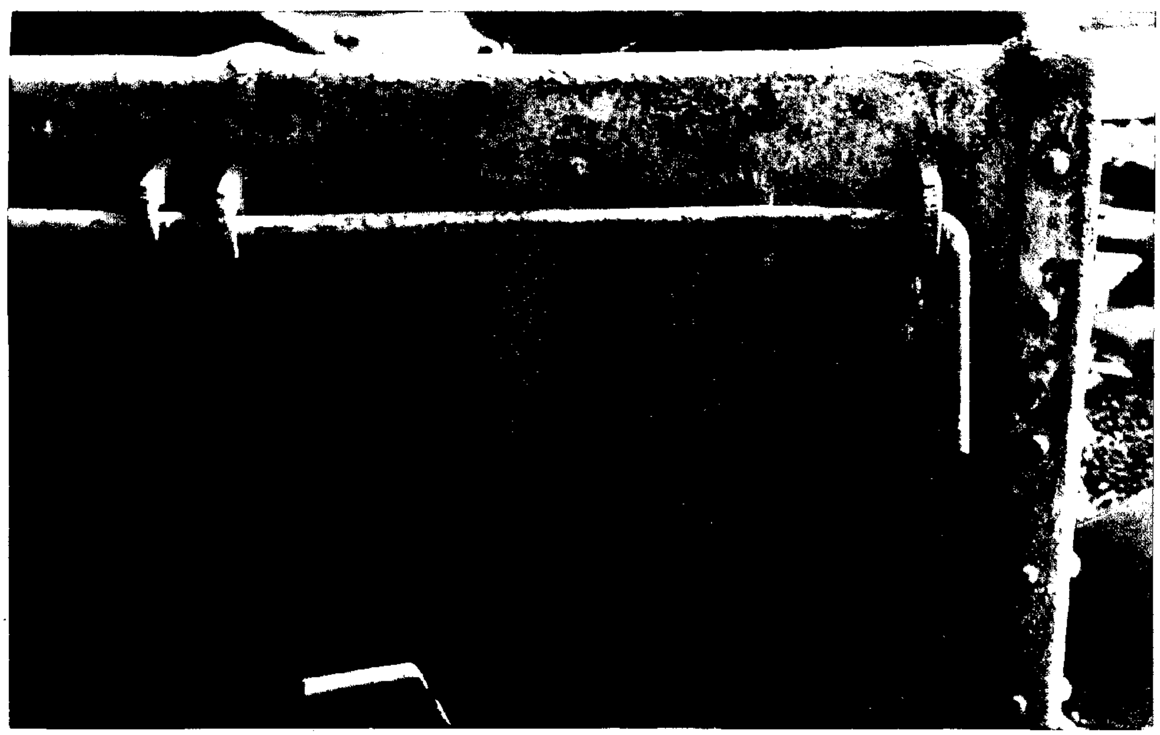

Figure 14. Rotating Lever and Chain

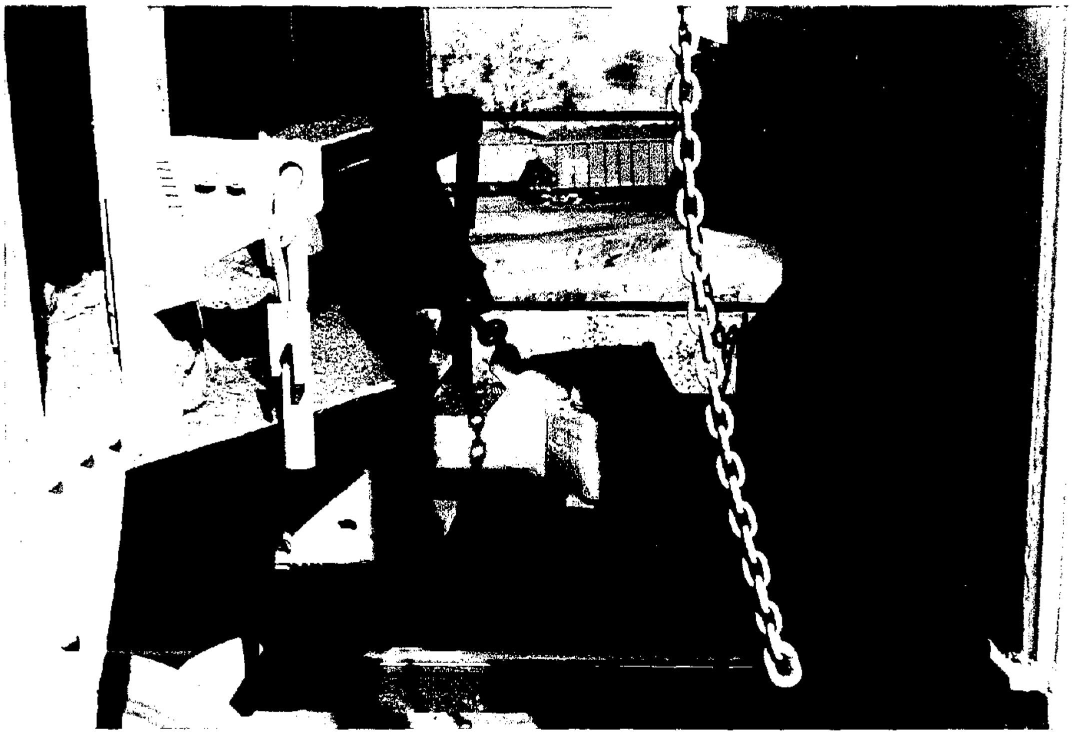

Figure 15. Rotating Lever with Chain and Lock

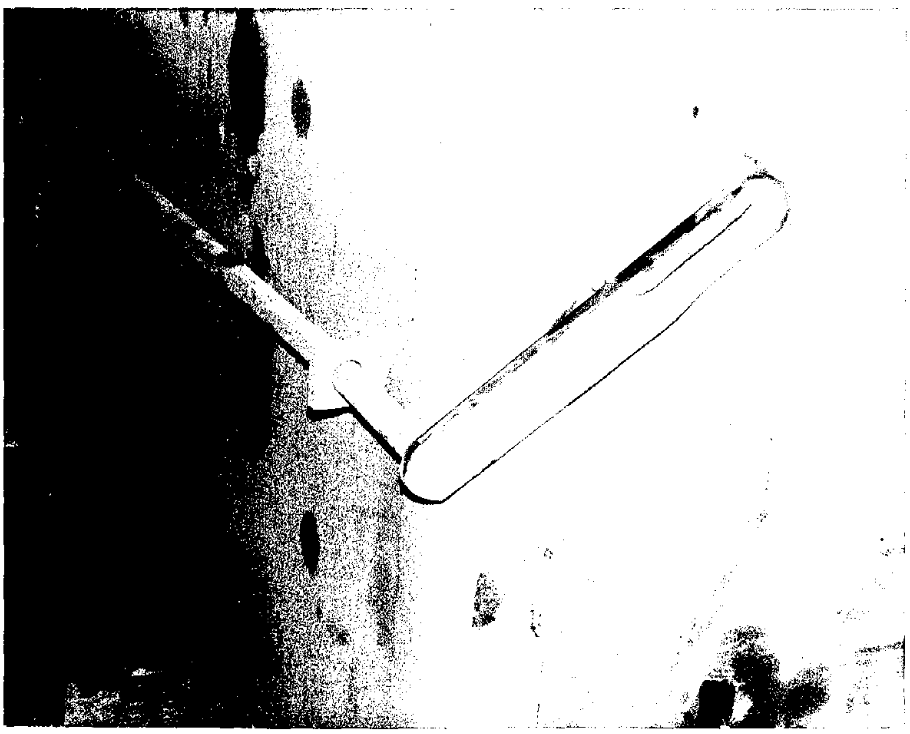

Figure 16. Rotating Lever with Outside Handle and Lock

8. ROTATING LEVER WITH OUTSIDE HANDLE AND LOCK

This simple design is similar to the other rotating lever designs, however, the handle has been moved to the outside of the mine car (Figure 16). The handle consists of a lever mounted on the end of the rod fitting tight against the body of the car. A ledge extends outward from the car. The lever is activated by pushing with the heel of the hand. It is impossible to grasp the handle, thus impossible to catch the hand, an excellent feature. A lock lever is provided to hold the handle in the open position. The location of the handle is excellent. The design is simple. The mechanism is susceptible to damage.

APPENDIX B

HAZARD ANALYSIS OF COUPLER OPERATIONS

The purpose of this analysis is to identify the hazards associated with coupler operations and to determine which coupler types can be coupled and uncoupled safely. In this analysis, coupling and uncoupling operations are divided into several steps and hazards associated with each step are examined. This is done for the basic types of coupling devices observed.

The various coupler types analyzed include:

- Link-and-pin--a single or swivel link anchored to the car by a pin and hand-held link aligner.
- Modified link-and-pin with hand-held link aligner--a single or swivel link with a positive or gravity action pin inserter and lever and hand-held link aligner.
- Modified link-and-pin--a single or swivel link with a link aligner attached to the car and a positive or gravity action pin inserter and lever.
- Automatic coupler with no self-centering--an automatic coupler complying with the CMH&S Act.
- Automatic coupler with self-centering--a fully automatic coupler complying with the CMH&S Act which is also self-centering.
- Automatic coupler with self-centering and uncoupling-set lever--a fully automatic coupler complying with the CMH&S Act which is self-centering, and which has a device to hold the coupler in a released position for one-man uncoupling.

The analysis involves rating of each step in the coupling and uncoupling operation in terms of its inherent hazards. The susceptibility to injury is classified as low, medium, high, and very high. These classifications are applied as follows:

- Low--This is an operation in which there exists a degree of risk, but one in which, under normal conditions and when following stated procedures, there is little chance of injury.

- Medium--This is an operation in which the chance of injury is relatively high, due to the proximity of a dangerous location.

- High--This is an operation which is performed in a dangerous location and in which any unusual condition or slight variation from an established safe procedure will result in injury.

- Very High--This is an operation which is performed from an extremely hazardous position, in which no safe procedure exists, and for which a high probability of injury can be expected.

HAZARD ANALYSIS OF COUPLING OPERATIONS

In analyzing the coupling operation, the coupling procedure is divided into twelve steps and inherent hazards for the various couplers in performing each step are examined. This is discussed in the following.

Step 1--Select Cars to be Coupled

In this step, there are no apparent hazards which can be attributed to the coupler.

Step 2--Place Skid under Wheel of Non-moving Car

In this step, the man performing the coupling operation must set a skid or other device under the wheel of the stationary car. This is required for all types of couplers since the impact of the moving car could cause the non-moving cars to start moving. Any grade would cause a runaway car. There is always some element of hazard when inserting a skid. Although long handles are provided, the worker must bend down and insert the skid. He is in a vulnerable position. With automatic couplers, some resistance of the car to movement is required to achieve coupling. If a skid is not present, the speed of the moving car must be increased. Even then, it is possible that the cars will not couple.

Step 3--Prepare Coupler

In this step, the man performing the coupling operation must prepare the coupler on the moving car. For the link-and-pin coupler, he must go to the end of the car, grasp the pin, and pull it from the hole. He is susceptible to injury from unexpected movement of the car. This hazard is substantially reduced for modified link-and-pin couplers with a pin inserter. The worker can now remove the pin while standing at the side of the car without exposing himself between the cars. The hazard still exists, however, due to the chance of unexpected movement of the car. Automatic couplers require no preparation of the coupler; therefore, the hazard is effectively eliminated.

Step 4--Secure Safe Footing Adjacent to the Car to be Coupled

In this step, the man performing the coupling operation takes a position adjacent to the car to be coupled. From this position, he can observe the coupling operation and perform any needed tasks. Because he is in the immediate vicinity of the end of the car, he is susceptible to injury. The automatic coupler with self-centering does not require that the man be positioned close to the car. Rather, he can take a position back from the car in a safe location, thus effectively eliminating the hazard.

Step 5--Using the Coupler Hook, Align the Coupler

In this step, the man performing the coupling operation using the coupler hook (link aligner) positions the link so that it is centered and at the right level to align the pin. This exposes the man to injury since it is possible for him to have his hand or foot in an unsafe position. The car-mounted link aligner allows him to position and hold the link from outside the car, reducing the inherent hazard. The automatic coupler without self-centering requires the man to use a coupler hook to move the coupler to the proper position. Again, the man's hand and foot are exposed to injury. The addition of self-centering on automatic couplers effectively eliminates this step and its inherent hazards.

Step 6--Visually Signal Motorman to Close with Cars

In this step, there are no apparent hazards which can be attributed to the coupler.

Step 7--Using a Coupler Hook, Insert Coupler as Cars Close

In this step, the man performing the coupling operation must guide the couplers together using a coupler hook while maintaining a safe position. This is a very hazardous step, since the man does not have good leverage and is in a poor position to view the operation. Consequently, he may be tempted to lean over or reach out with his hand between the cars. The modified link-and-pin coupler with the car-mounted link aligner substantially reduces the hazard; however, the man must still be at the end of the car activating the lever in order to perform the step. The automatic couplers effectively eliminate the hazards, since this step is no longer required.

Step 8--Visually Signal Motorman to Stop and Hold Brakes

In this step, there are no apparent hazards that can be attributed to the coupler.

Step 9--Using the Coupler Hook, Couple Cars

In this step, the man performing the coupling operation must insert the pin using the coupler hook. This is a very hazardous operation since the man does not have good leverage, is in a poor position to view the operation, and may have difficulty in positioning the pin. Consequently, he may be tempted to go between the cars, either with his arm or with his body. The modified link-and-pin couplers with the pin inserters substantially reduce the hazards; however, the man must still be at the end of the car to activate the lever. The automatic coupler effectively eliminates the hazards since the step is no longer required.

Step 10--Visually Inspect the Coupler

In this step, the couplers are inspected to ensure that they are coupled. There are no apparent hazards that can be attributed to the coupler.

Step 11--Remove Skid

In this step, the man performing the coupling operation must remove the skid from under the wheel of the car. This is required for all types of couplers. There is a slight element of risk for this step due to the proximity to a dangerous area.

Step 12--Visually Signal Motorman to Pull Cars

There are no apparent hazards that can be attributed to the coupler for this step.

A summary of this analysis is presented in Table 8. From this table, it can be seen that the automatic coupler equipped with self-centering effectively eliminates the hazards associated with the coupling operation. Without self-centering, however, significant hazards still exist. In some respects, these hazards are even greater than those attributable to modified link-and-pin with the car-mounted link aligner. The latter-mentioned coupler mechanism is a definite improvement over link-and-pin with or without a pin inserter. The use of hand-held link aligner is extremely hazardous under the best of conditions and is the least desirable of all.

HAZARD ANALYSIS OF UNCOUPLING OPERATIONS

Although accident frequencies are much lower in the uncoupling operations, sufficient opportunity exists for injuries when improper procedures are followed. A review of each step of the uncoupling operation and the inherent hazards for the various coupler types are presented below.

Step 1--Select Cars to be Uncoupled

In this step, there are no apparent hazards which can be attributed to the coupler.

Step 2--Place Skid Under Wheel of Non-moving Car

In this step, the man performing the uncoupling operation must

Table 8. Hazard Analysis--Coupling Operations (Summary)

Operation	Susceptibility to Injury					
	Link and Pin	Mod. Link and Pin (pin inserter)	Mod. Link and pin (pin inserter, link aligner)	Automatic (no self-centering)	Automatic (self-centering)	Automatic (self-centering, lockset)
1. Select cars to be coupled (CTBC)	--	--	--	--	--	--
2. Place skid under wheel of non-moving car	Low	Low	Low	Low	Low	Low
3. Prepare coupler	Medium[1]	Low[5]	Low[5]	--	--	--
4. Secure safe footing adjacent to CTBC	Low	Low	Low	Low	--	--
5. Using coupler hook, align coupler	Medium[2]	Medium[2]	Low[7]	Medium[8]	--	--
6. Visually signal motorman to close with CTBC	--	--	--	--	--	--
7. Using coupler hook, insert coupler as cars close	High[3]	High[3]	Low[7]	--	--	--
8. Visually signal motorman to stop and hold brakes	--	--	--	--	--	--
9. Using coupler hook, couple cars	High[4]	Low[6]	Low[6]	--	--	--
10. Visually inspect coupling	--	--	--	--	--	--
11. Remove skid	Low	Low	Low	Low	Low	Low
12. Visually signal motorman to pull cars	--	--	--	--	--	--

1. Using coupler hook, remove pin
2. Using coupler hook, align and hold link
3. Using coupler hook, insert link
4. Using coupler hook, insert pin
5. Using lever, remove pin
6. Using lever, insert pin
7. Using lever, align and hold link
8. Using coupler hook, center coupler

set skids under the wheels of the car to be dropped. This is required for all types of couplers, since uncoupling a car leaves it without brakes and the process of buffing up the cars (to release pressure on the coupler in order to activate the release lever) could cause a runaway car. There is an element of hazard when inserting a skid. Although long handles are provided, the man must bend over to insert the skid.

Step 3--Secure Safe Footing

In this step, the man performing the uncoupling operation must take a position adjacent to the car to be uncoupled. From this position, he can observe the coupler and perform any needed tasks. Because he is in the vicinity of the car, he is susceptible to injury; however, the risk is low. The automatic coupler equipped for one-man operation effectively eliminates any risk since the motor cannot be operated during this step and the chance of unexpected car movement is eliminated.

Step 4--Signal Motorman to Release Pressure

In this step, the motorman is signaled to release any pressure that might be on the couplers impeding the uncoupling operation. The motorman backs up against the spragged cars, allowing pressure to be released. The hazards exist because of the coordination required between the men during this operation. On the coupler equipped for one-man operation, this step can be eliminated.

Step 5--Uncouple Cars

In this step, the cars are physically uncoupled. For the link-and-pin couplers, a coupling hook is used to catch the loop on the top of the pin and lift out the pin. This is a hazardous operation, since the man does not have good leverage and is in a poor position to view the operation. Consequently, he may be tempted to go between the cars, whether with his arm or his body. The modified link-and-pin couplers with pin inserters substantially reduce the hazards; however, the man must be at the end of the car to utilize the lever. This is true for automatic couplers also. In either case, sudden movement of the cars could inadvertently cause the worker to fall. The automatic coupler equipped with a device for one-man operation reduces this hazard. Here, the coupler is set in an uncoupled position either with a coupler hook or with the lever. Since this is performed by the motorman, there is no chance of the cars being moved while this is performed.

Step 6--Signal the Motorman to Move the Cars Apart

While the coupler is held in the unlocked position, the man must signal to the motorman to pull the cars apart. While using the coupler hook, the pin is removed entirely and the workman can stand back while the cars separate. With the modified link-and-pin and the automatic coupler, the lever must be held open until the cars separate. This can be somewhat hazardous because of unexpected movement of the cars, particularly if the lever is on the moving car. The automatic coupler equipped for one-man operation effectively eliminates this step.

Step 7--Set Coupler Pin Back in Link and Set Hook Aside

This task is performed for the link-and-pin coupler only. The other types of couplers eliminate the need for this task. The man performing the task is in a somewhat hazardous position, particularly if the pin is on the moving car. It is very likely that he will stand behind the car between the tracks rather than off to the side. This makes him susceptible to injury from unexpected car movement.

A summary of this analysis is presented in Table 9. From this chart, it can be seen that the modified link-and-pin couplers and the automatic couplers are very effective in eliminating the hazards associated with uncoupling operations. However, the automatic coupler equipped for one-man operation eliminates virtually all hazards by removing the man from the hazardous area. The link-and-pin coupler, of course, has elements of extreme hazards and should not be allowed under any condition.

Table 9. Hazard Analysis--Uncoupling Operations (Summary)

Operation	SUSCEPTIBILITY TO INJURY					
	Link & Pin	Modified Link & Pin with Inserter (PI)	Modified Link & Pin (PI Link Aligner)	Automatic No Self-Centering	Automatic Self-Centering	Automatic Self-Centering Lock-Set
1. Select cars to uncouple	-	-	-	-	-	-
2. Place skid under wheel of non-moving car.	Low	Low	Low	Low	Low	Low
3. Secure safe footing.	Low	Low	Low	Low	Low	-
4. Signal motorman to release pressure.	Moderate	Low	Low	Low	Low	-
5. Uncouple cars.	High[1]	Low[3]	Low[3]	Low	Low	-
6. Signal motorman to move cars apart.	-	-	-	-	-	-
7. Set coupler pin back in hole and set hook aside.	Low[2]	-[4]	-[4]	-	-	-

[1]Using coupler hook, remove pin.

[2]Using coupler hook, reinsert pin.

[3]Using lever, remove pin.

[4]Using lever, insert pin.

APPENDIX C

CALCULATION OF HORIZONTAL AND VERTICAL GATHERING RANGES

The extreme requirement on horizontal or vertical gathering range is imposed when coupling from a curve into a tangent track (Figures 17 and 18).

For right-angled triangle, OAE,

$$(R + X)^2 = (R - Y)^2 + C^2$$

where R = horizontal radius of curve

W = 1/2 of effective length between axles (i.e., between truck centers for eight-wheel cars and between axles for four-wheel cars)

C = distance between center of car to coupler face

Y = chord offset (from center line of car to center line of track)

X = horizontal gathering range

and for right-angled triangle, OAB,

$$R^2 = (R - Y)^2 + W^2$$

Combining the above two equations and simplifying, the expression for horizontal gathering range from the center line is given by

$$X = \sqrt{R^2 + C^2 - W^2} - R \qquad (1)$$

From Figure 18, it can be seen that the angular and geometric relationships for vertical gathering range is the same as for the horizontal situation and the expression for vertical gathering range (V) is the same as given by equation (1).

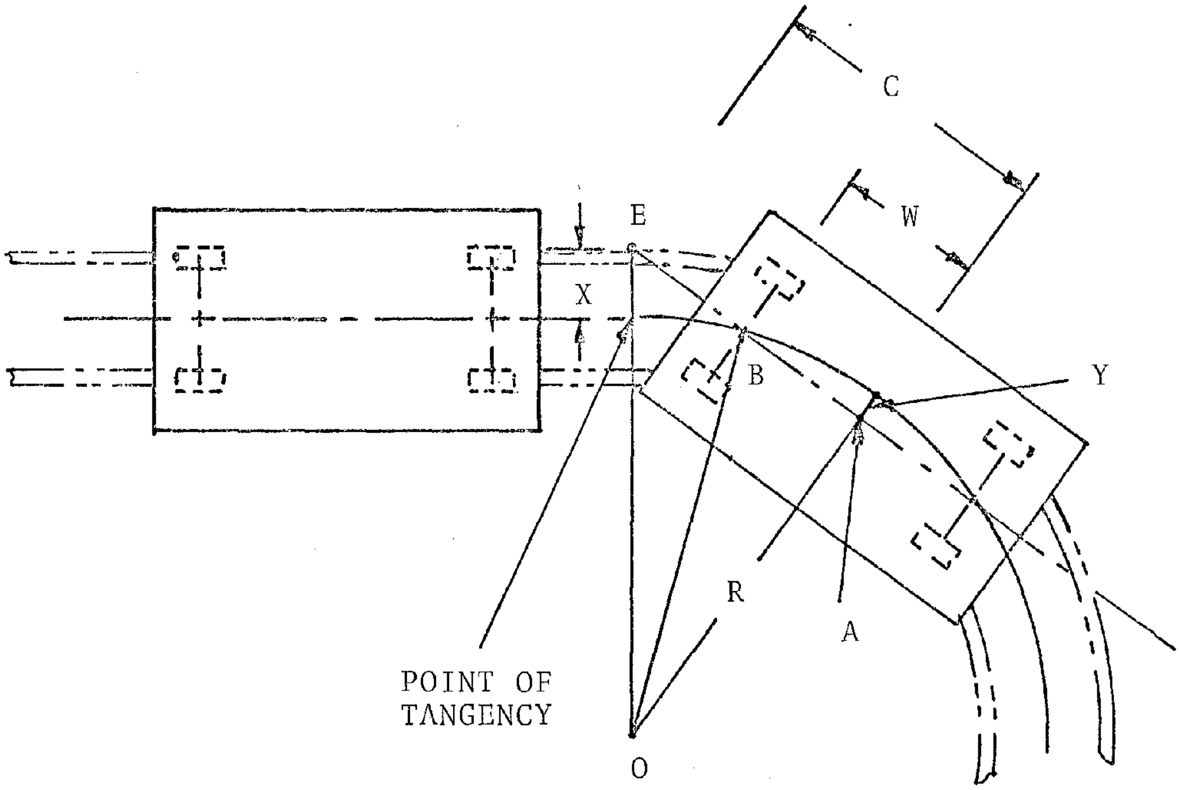

Figure 17. Extreme Requirement for Horizontal Gathering Range

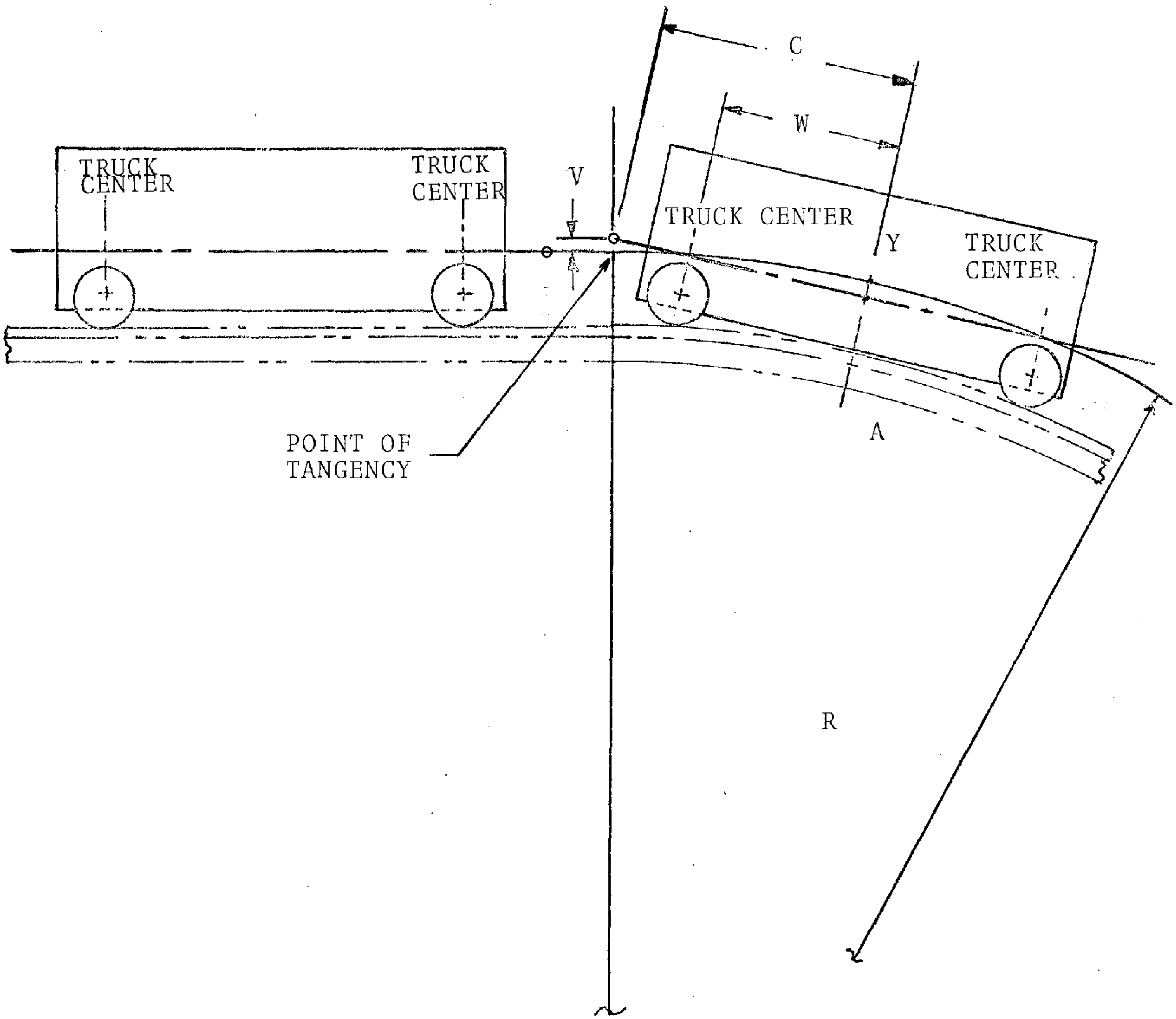

Figure 18. Extreme Requirement for Vertical Gathering Range

APPENDIX D

CALCULATION OF MINIMUM DISTANCE BETWEEN CARS FOR NEGOTIATING CURVES

NEGOTIATION OF HORIZONTAL CURVES

The minimum distance required between two cars for negotiating horizontal curves can be determined by considering the two cars to be on that curve, with their ends just touching as shown in Figure 19.

From triangle CAO, $AO = \sqrt{(\frac{L}{2} + S)^2 + (R - M)^2}$, taking $AY \simeq S$,*

From similar triangles CAO and XYZ,

$$\frac{S}{\frac{D}{2}} = \frac{\frac{L}{2} + S}{\sqrt{(\frac{L}{2} + S)^2 + (R - M)^2}} \qquad (1)$$

where S = half of distance between two cars or coupler protrusion distance

L = length of car

D = width of car

R = curve radius

M = mid-ordinate, $\overline{EC}$ (Figure 19)

As S and M are small in comparison to the curve radius, $\sqrt{(\frac{L}{2} + S)^2 + (R - M)^2}$ can be approximated as $\sqrt{(\frac{L}{2})^2 + R^2}$. This simplificiation leads to

$$S = \frac{DL}{4\,[\sqrt{(\frac{L}{2})^2 + R^2} - D/2]} \qquad (2)$$

*For the practical ranges of curve radii (down to 25 feet), S is greater than .85 AY. Any error incurred by this assumption is particularly small in view of the relative sizes of AY and L/2.

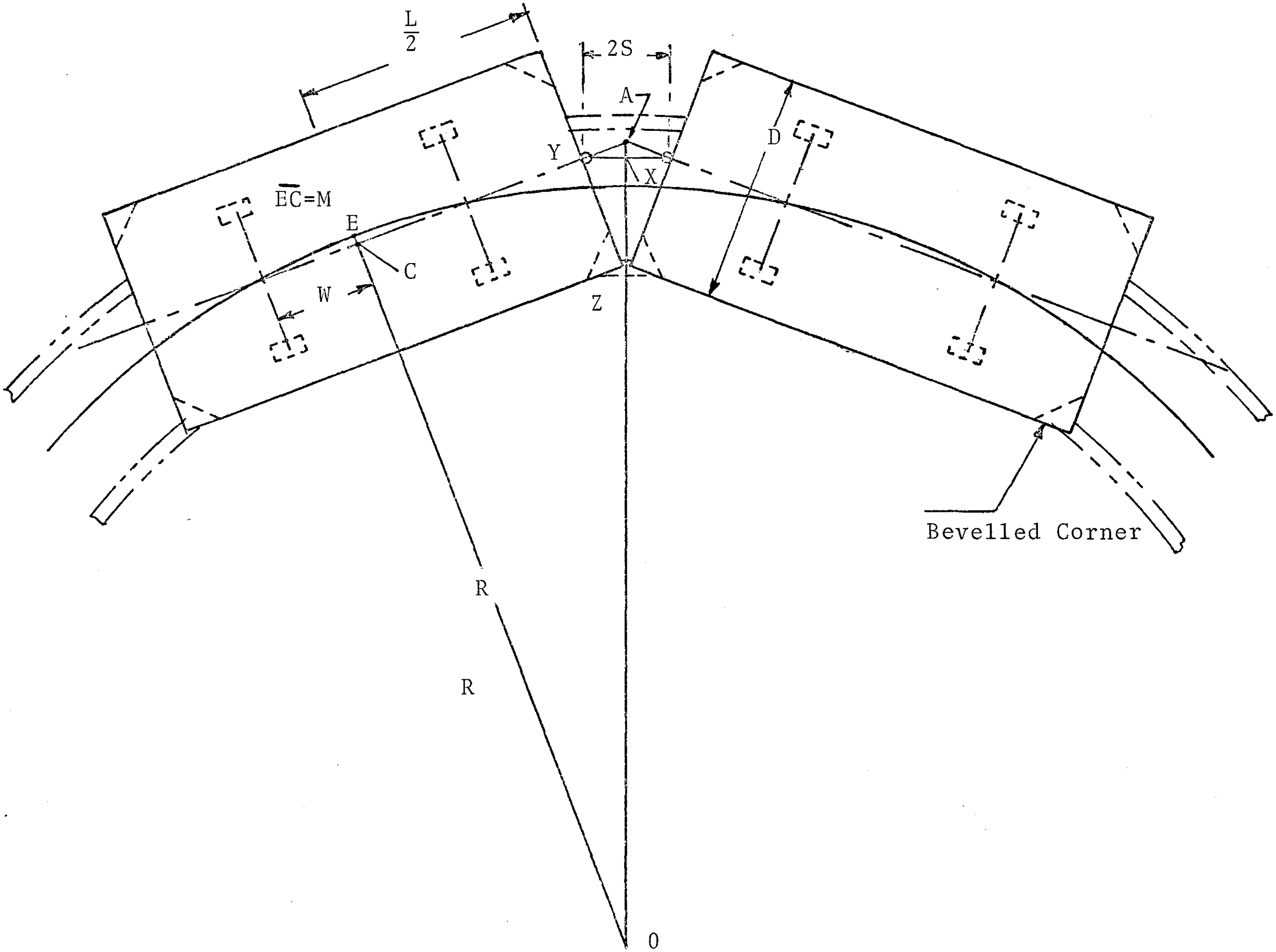

Figure 19. Extreme Case for Horizontal Curve Negotiation

NEGOTIATION OF VERTICAL CURVES

The minimum distance required between two cars for negotiating vertical curves can be determined by considering the two cars on that curve, with their ends just touching as shown in Figure 20.

In triangle ODA,

$$OA = \sqrt{OD^2 + DA^2}$$

$$OD = R - M - H$$

where R = radius of curve

H = coupler mounting position from the axle axis

M = EC

Now, $DA = DY + YA$

$$YA \simeq YX = S$$

$$DA = \frac{L}{2} + S$$

and

$$OA = \sqrt{(R - M - H)^2 + (\frac{L}{2} + S)^2}$$

As M and S are small in comparison to curve radius, OA can be approximated as

$$OA = \sqrt{(R - H)^2 + (\frac{L}{2})^2}$$

From similar triangles DAO and XYZ,

$$\frac{S}{h} = \frac{\frac{L}{2} + S}{\sqrt{(R - H)^2 + (\frac{L}{2})^2}}$$

where h = coupler mounting position from the top of the car.

Simplifying, the minimum coupler protrusion distance (S) is given by:

$$S = \frac{Lh}{2\left[\sqrt{(R - H)^2 + (L/2)^2} - h\right]} \qquad (3)$$

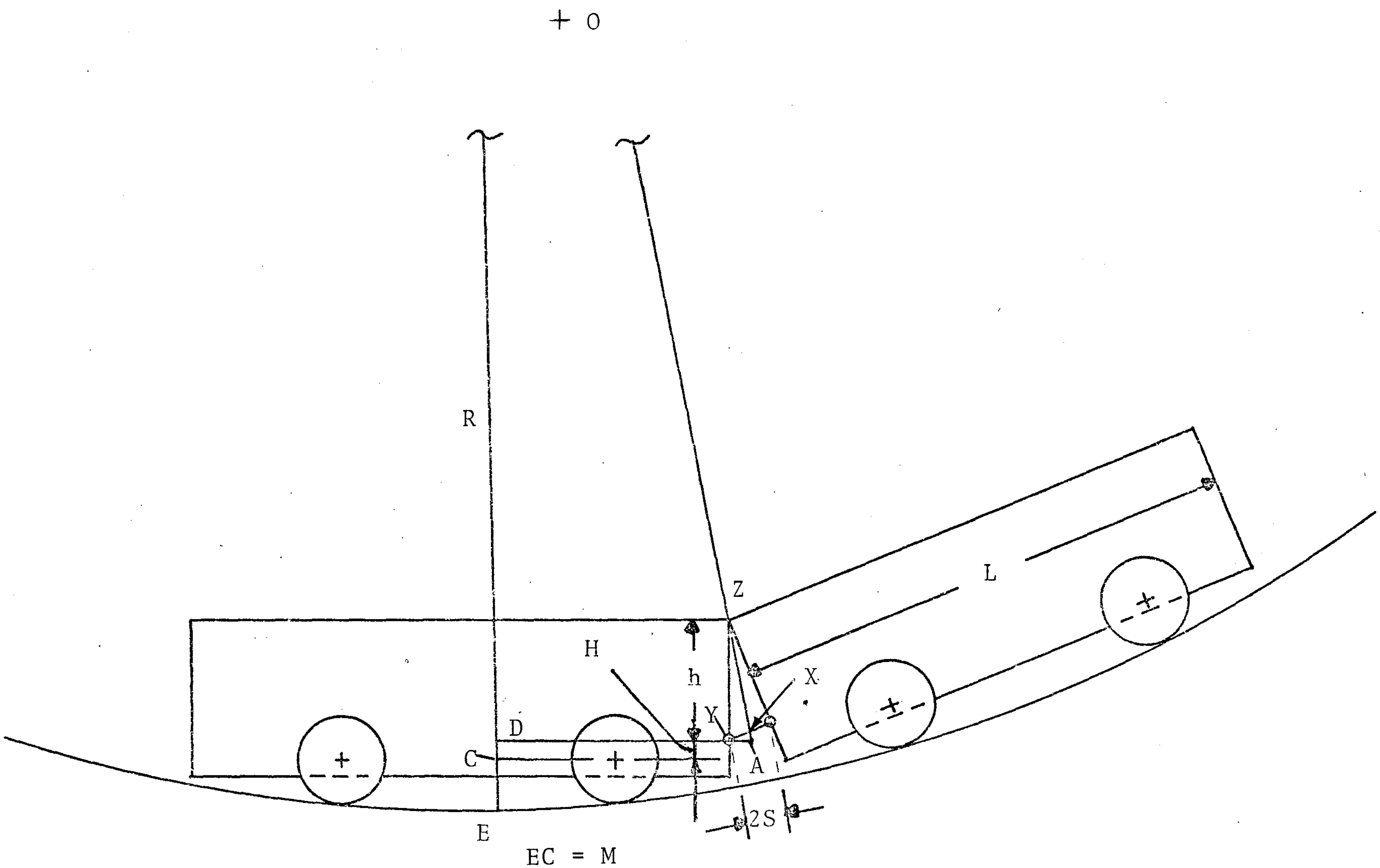

Figure 20. Extreme Case for Vertical Curve Negotiation

APPENDIX E

CALCULATION OF COUPLER HORIZONTAL AND VERTICAL SWING ANGLES

HORIZONTAL SWING ANGLE

The extreme requirement on coupler horizontal swing angle is imposed while traversing a tangent-curve track configuration as shown in Figure 20. For this configuration, coupler swing angle, θ, is given by

$$\theta = 180° - \phi - (90° - \alpha)$$

$$= 90° + \alpha - \phi$$

where α = angle AOD and ϕ = angle BAO

$$OD = OE - DE = R - M$$

As M is small compared to R, neglecting M

$$OD \simeq R$$

And,

$$\cos\alpha = \frac{R}{R + AC}$$

$$\therefore AC = \frac{R}{\cos\alpha} - R$$

$$\tan\alpha = \frac{L}{2R}$$

$$\alpha = \arctan\frac{L}{2R}$$

$$\cos\phi = \frac{AC}{2S}$$

$$\phi = \arccos\frac{AC}{2S}$$

where R = radius of curve

L = length of car between coupler pins

S = length of each coupler from pivot pin to coupler face

$$\therefore \theta = 90° + \arctan\frac{L}{2R} - \arccos\frac{AC}{2S}$$

$$= 90° + \arctan\frac{L}{2R} - \arccos\left[\frac{R}{2S\cos\alpha} - \frac{R}{2S}\right]$$

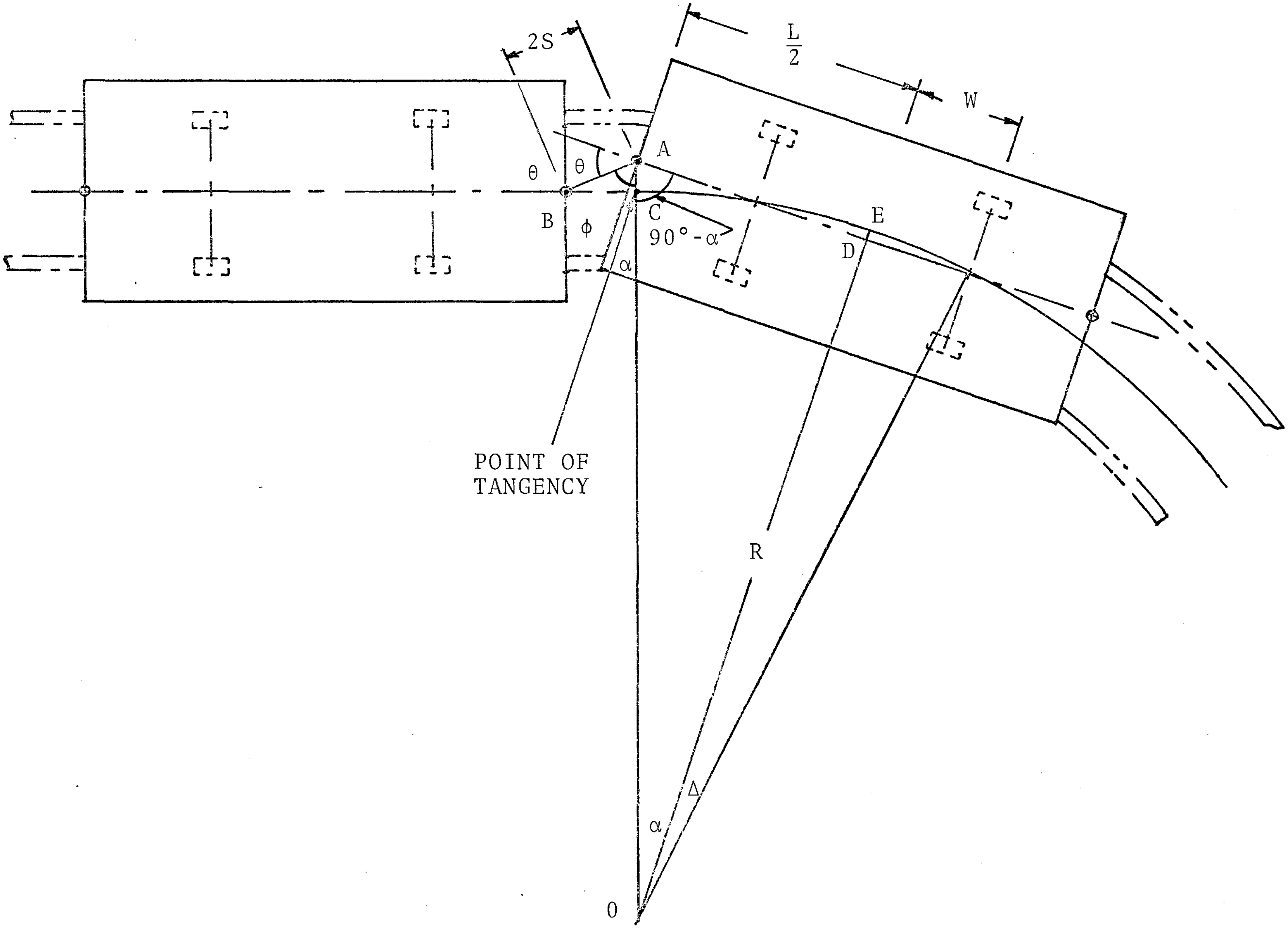

Figure 21. Extreme Requirement for Coupler Horizontal Swing Angle

$$= 90° + \arctan \frac{L}{2R} - \arccos \left[\frac{R}{2S\cos\{\arctan \frac{L}{2R}\}} - \frac{R}{2S}\right] \quad (4)$$

If the mid-ordinate M is not neglected,

$$\alpha = \arctan \frac{L}{2(R - M)}$$

$$R - M = R \cos \Delta = R \cos (\arcsin \frac{W}{R})$$

where Δ = angle subtended by chord W

W = 1/2 of length between truck centers (for eight-wheel car) or between axles (for four-wheel car)

α becomes $\alpha = \arctan \frac{L}{2R\cos (\arcsin \frac{W}{R})}$

and θ is given by

$$\theta = 90° + \arctan \frac{L}{2R\cos (\arcsin \frac{W}{2R})}$$

$$- \arccos \left[\frac{R}{2S\cos \{\arctan \frac{L}{2R\cos (\arcsin \frac{W}{R})}\}} - \frac{R}{2S}\right] \quad (5)$$

Now, for typical R = 100', L = 16' and S = 1.5',

θ = 10.68734° -- using formula (4)

θ = 10.68991° -- using formula (5)

The difference in values of θ obtained using equation (4) and (5) is negligible. As equation (5) is more complicated than (4), the coupler horizontal swing angle, θ, should be calculated using equation (4):

$$\theta = 90° + \arctan \frac{L}{2R} - \arccos \left[\frac{R}{2S\cos \{\arctan \frac{L}{2R}\}} - \frac{R}{2S}\right] \quad (4)$$

VERTICAL SWING ANGLE

The extreme requirement on coupler vertical swing angle is imposed while traversing a tangent-curve configuration as shown in Figure 22. As will be seen from this diagram, the angular and geometric relationships for this vertical configuration are the same as for the horizontal situation, discussed earlier, and the coupler vertical swing angle (θ) is given by the above equation (4).

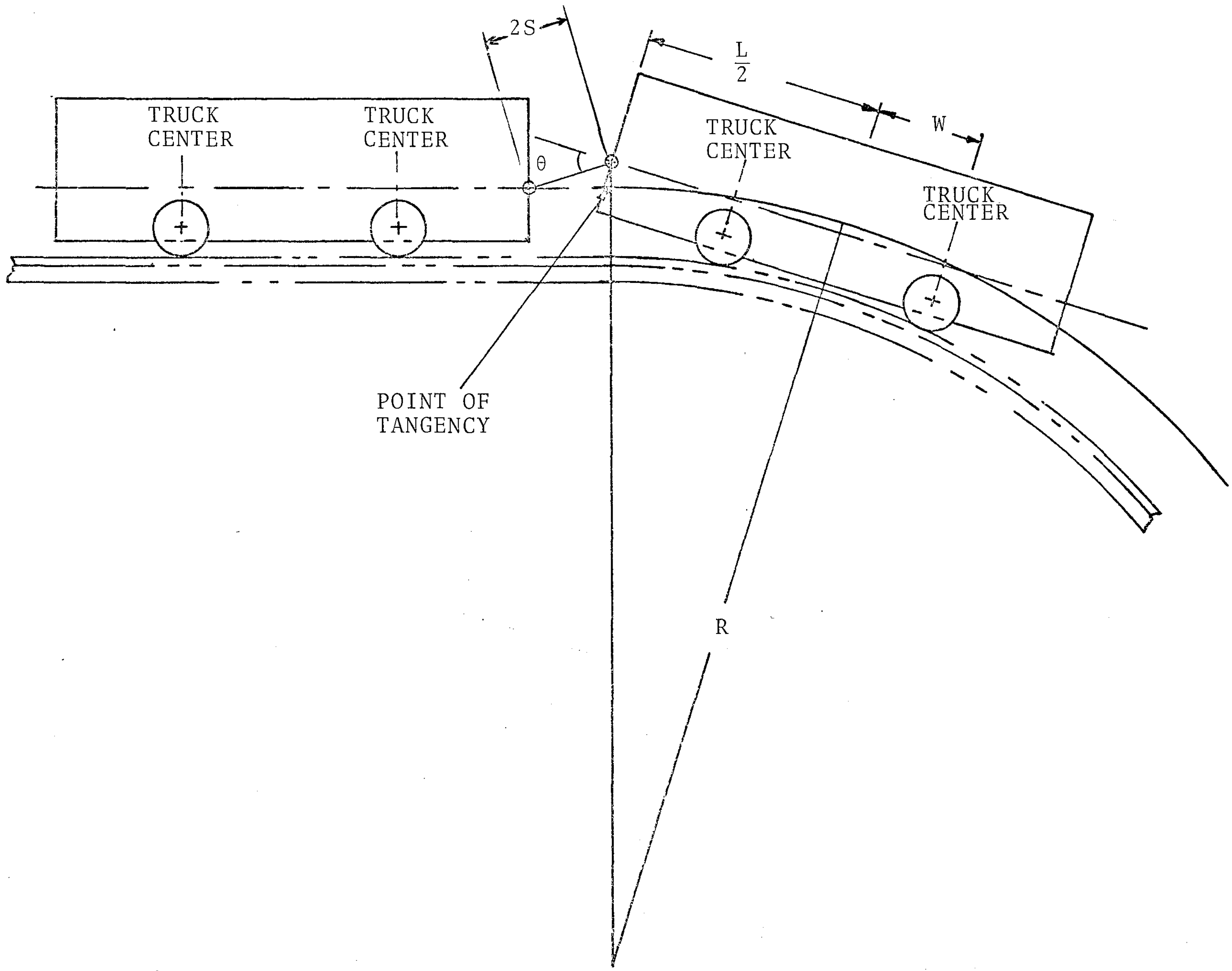

Figure 22. Extreme Requirement for Coupler Vertical Swing Angle